Lesson 8: Why do we see patterns of hot and cold spots in the microwave oven?

Previous Lesson *We used simulations to model how various particles (water molecules, plastic molecules, free electrons) interact with changing electric fields of different frequencies. We connected this particle-scale evidence to macroscopic evidence about the behavior of various materials (water, plastic, aluminum) inside the microwave oven, then modeled our understanding. We read articles to consider whether metal in the microwave oven is safe, and considered the validity and reliability of the authors' claims.*

This Lesson

Investigation, Putting Pieces Together

3 days

We observe a pattern when light bulbs are heated in the microwave oven. We wonder if the pattern can be explained by wave properties and wave reflection in the oven. We use simulations to make sense of wave interference. We make models to explain wave interference from an energy perspective, which provides evidence for the existence of hot and cold spots, and to make sense of the turntable's function. We revise our initial consensus model from the anchor phenomenon and our Driving Question Board.

Next Lesson *We will examine the remaining categories of questions on the Driving Question Board and construct the EM spectrum using the wavelength and frequency of various types of EM radiation. We will write an argument about the relationship between the frequency and wavelength of EM radiation and its interactions with matter, and how this relationship helps explain some of the uses of EM radiation. We will add new questions to the DQB.*

BUILDING TOWARD NGSS	What students will do
HS-PS2-5, HS-PS4-1, HS-PS4-2, HS-PS4-3, HS-PS4-4, HS-PS4-5, HS-ESS2-4	**8.A** Develop, revise, and use a model of wave interactions using an energy, matter, and forces lens to explain how reflection and interference cause patterns of energy transfer into materials in the microwave oven without creating or destroying energy. (SEP: 2.3; CCC: 2.2, 5.3; DCI: PS4.A.3, PS4.B.1)
	8.B Collaboratively revise a model of a microwave oven to explain how the components of the system function to heat food, and how and why these structures could affect a Bluetooth signal. (SEP: 2.3; CCC: 5.2, 6.2; DCI: PS4.A.3, PS4.B.1, PS4.B.2, PS4.C.1)

8.C Ask questions about the structure and function of technologies and phenomena that rely on electromagnetic radiation (including energy transfer). (SEP: 1.4; CCC: 5.2, 6.2; DCI: PS4.B.2, PS4.C.1)

What students will figure out

- When two waves meet in space, they interact through interference to produce a new wave, but the total combined energy of the original waves is conserved.
- The new wave produced by an interference interaction can have a higher wave height (constructive interference) or lower wave height (destructive interference) at a particular point than the original waves did.
- The microwave oven produces hot and cold spots due to constructive and destructive wave interference between the waves emitted from the magnetron and those reflected off of the oven's interior walls.
- The turntable in the microwave oven is designed to move food between hot and cold spots to provide more even heating.

Lesson 8 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	7 min		**NAVIGATE: CONNECT TO THE ANCHOR PHENOMENON** Revisit the patterns in the nachos in the anchor phenomenon. Discuss these as evidence of energy transfer patterns in the microwave oven. Predict how small light bulbs will behave in the oven.	A-D	
2	5 min		**OBSERVE SMALL LIGHT BULBS IN THE MICROWAVE OVEN** Discuss safety precautions for investigating small light bulbs in the microwave oven. Run the demonstration experiment and record observations.	E-F	Microwave Oven Energy Transfer Map
3	10 min		**DEVELOP A MODEL TO EXPLAIN PATTERNS OF HOT AND COLD SPOTS** Construct initial group model posters to explain the patterns in the cheese and the light bulbs.	G	chart paper, markers
4	8 min		**CONDUCT A GALLERY WALK OF INITIAL MODELS FOR HOT AND COLD SPOTS** Give peer feedback on the group models in a gallery walk.	H	3" x 3" sticky notes, markers, initial group model posters
5	10 min		**OBSERVE AND DESCRIBE PATTERNS OF WAVE INTERFERENCE** Use demonstrations of pulses in the Waves on a String simulation for sensemaking about wave interference. Record thinking about matter, energy, and forces on the handout.	I-J	*Wave Interactions*, https://www.openscied.org/general/waveonastring/
6	5 min		**NAVIGATE: MAKE PREDICTIONS ABOUT EQUAL WAVES** Make predictions about other wave interactions on the handout as an assessment.	K	*Wave Interactions*
					End of day 1
7	3 min		**NAVIGATE: REVIEW PREDICTIONS** Turn and talk about predictions on the handout from day 1, and optionally check them in the simulation.	L	*Wave Interactions*, https://www.openscied.org/general/waveonastring/
8	12 min		**CONSTRUCT AN EXPLANATION FOR WAVE INTERFERENCE** Discuss how interference could create hot and cold spots in the microwave oven. Add entries to Personal Glossaries.	M-O	*Wave Interactions*

9	8 min		**CONNECT TO CONTINUOUS ELECTROMAGNETIC WAVES** Discuss slide GIFs to move from thinking about pulses to continuous waves. Turn and talk about moving electromagnetic waves passing through the same point in time and space.	P-R	https://www.openscied.org/general/waveonastring/
10	8 min		**EXPLORE CONTINUOUS WAVE INTERACTIONS IN THE MICROWAVE OVEN** Explore the Interference Animation slides in groups for initial sensemaking.	S-T	computer with access to https://docs.google.com/presentation/d/1S7BaEyymgycR-KBlRaA3UJ9S1gaF2G_S1UMuRhEaIME/edit?usp=sharing
11	10 min		**REVISE MODELS TO EXPLAIN PATTERNS OF HOT AND COLD SPOTS** Revise models of the cheese and the light bulbs in the microwave oven in groups, with a few groups sharing key pieces of their models.	U	computer with access to https://docs.google.com/presentation/d/1S7BaEyymgycR-KBlRaA3UJ9S1gaF2G_S1UMuRhEaIME/edit?usp=sharing, initial group model posters, markers
12	4 min		**SYNTHESIZE IDEAS ABOUT WAVE INTERFERENCE** Individually update the *Progress Tracker*.	V	
					End of day 2
13	3 min		**NAVIGATE: MODEL THE FUNCTION OF THE TURNTABLE** Turn and talk to predict how the light bulbs will behave on the turntable in the microwave oven.	W	
14	4 min		**INVESTIGATE THE FUNCTION OF THE TURNTABLE WITH SMALL LIGHT BULBS** Discuss safety precautions for adding the turntable to the light bulb experiment. Run the demonstration experiment and record observations.	X-Y	Inferring Turntable Function
15	15 min		**REVISE THE CONSENSUS MODEL FROM THE ANCHOR PHENOMENON** Collaboratively revise the initial consensus model from the anchor phenomenon in a student-led Scientists Circle, using talk moves to support discussion flow.	Z	Initial Consensus Model poster from Lesson 1, chart paper, markers

16	15 min		**REVISIT THE DRIVING QUESTION BOARD** Revisit the Driving Question Board. Discuss progress so far in a Scientists Circle, and add new questions to the DQB.	AA-DD	sticky dots (green, yellow, and red), 3” x 3” sticky notes, marker, Class Consensus Model poster, Driving Question Board
17	8 min		**NAVIGATE: COMPLETE AN ELECTRONIC EXIT TICKET** Individually complete an Electronic Exit Ticket.	EE	computer with access to https://docs.google.com/forms/d/1mELxWc9sPbhlNn6Fob7wwDkUiJsLm_n6AjEe-lMW2vY/copy

End of day 3

Lesson 8 • Materials List

	per student	per group	per class
Microwave Oven Energy Transfer Map materials	• science notebook • indirectly vented chemical splash goggles		• rectangular light bulb array • microwave oven • microwave-safe plastic cutting board • microwave-safe plastic bowls (1" tall) • microwave-safe glass bowls (100-250 mL) of cool water • oven mitts • IR thermometer • 3-4 neon light bulbs with wires • 3-4 neon light bulbs without wires.
Inferring Turntable Function materials	• science notebook • indirectly vented chemical splash goggles		• circular light bulb array • microwave oven • turntable from microwave oven • microwave-safe glass bowl (100-250 mL) of cool water • oven mitts • IR thermometer
Lesson materials	• 3" x 3" sticky notes • markers • *Wave Interactions* • science notebook • sticky dots (green • yellow • and red) • marker • computer with access to	• chart paper • markers • computer with access to https://docs.google.com/presentation/d/1S7BaEyymgycR-KBlRaA3UJ9S1gaF2G_S1UMuRhEaIME/edit?usp=sharing • initial group model posters	• initial group model posters • https://www.openscied.org/general/waveonastring/ • Initial Consensus Model poster from Lesson 1 • chart paper • markers • Class Consensus Model poster • Driving Question Board

	https://docs.google.com/forms/d/1mELxWc9sPbhlNn6Fob7wwDkUiJsLm_n6AjEe-lMW2vY/copy		

Materials preparation (50 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.

For day 1:
Test the following link for the Waves on a String simulation: https://www.openscied.org/general/waveonastring/

Prepare 3 additional neon light bulbs with the cathode and anode wires, and 3 neon light bulbs without wires. You will use them during the Microwave Oven Energy Transfer Map activity.

For day 2:
Test the GIFs on **slide P**, **slide Q**, and **slide S**.

Have computers available for each student to access the Interference Animation slides. Test the following link: https://docs.google.com/presentation/d/1S7BaEyymgycR-KBlRaA3UJ9S1gaF2G_S1UMuRhEaIME/edit?usp=sharing

For day 3:
Hang the Initial Consensus Model poster from Lesson 1 in the classroom where students can see it.

Have computers available for each student to access the Electronic Exit Ticket. Test the following link: https://docs.google.com/forms/d/1mELxWc9sPbhlNn6Fob7wwDkUiJsLm_n6AjEe-lMW2vY/copy

Day 1: Microwave Oven Energy Transfer Map

- **Group size:** Whole group.
- **Setup:** See *Light Bulb Array Assembly* for setup information for the rectangular light bulb array. Have a microwave-safe glass bowl of cool water available.

- **Notes for during the lab:** Reposition the cardboard with the light bulbs if there is not a clear pattern. Use less water in the microwave-safe glass bowl if you don't see a significant number of light bulbs turning on.
- **Safety:**
    - Remove the metal from the outside of the neon light bulbs to avoid arcing.
    - Run the microwave oven for only 10 seconds at a time. A microwave-safe glass bowl of water must be placed in the oven while running it with the light bulbs. Always check that the water is cool before running the oven again, to prevent overheating it. Wear hot mitts when removing the water from the oven.
    - Follow all the safety protocols outlined in *Light Bulb Array Assembly*.
    - Follow all the safety precautions outlined in the *Microwave Oven Manual*.
    - Keep a fire extinguisher handy.
    - The teacher and all students should wear indirectly vented chemical splash goggles during this investigation.
    - The teacher should place the setup into the oven, remove it, and handle the containers. Use hot mitts to do this.
    - Observers must be at a safe distance of at least 15 feet from the oven door during the activity.
    - Use caution when working with glassware or plasticware--it can break and cut/puncture skin.
    - Use caution when working with sharps--these can cut or puncture skin.
    - Immediately wipe up any spilled liquids--these are a slip/fall hazard.
    - Wash hands with soap and water or use hand sanitizer wipes immediately after completing this activity.
    - Any electrical power cords used near water must be plugged into a GFCI-protected circuit. If a GFCI electrical receptacle is unavailable, provide a GFCI temporary power cord or power strip.
- **Storage:** Place the cardboard and the neon light bulbs in a box so you can reuse them on day 3.

Day 3: Inferring Turntable Function

- **Group size:** Whole group.
- **Setup:** See *Light Bulb Array Assembly* for setup information for the circular light bulb array. Place the turntable back inside the microwave oven. Have a microwave-safe glass bowl of cool water available.
- **Safety:** Run the microwave oven for only 10 seconds at a time. A microwave-safe glass bowl of water must be placed in the oven while running it with the light bulbs. Always check that the water is cool before running the oven again, to prevent overheating it. Wear hot mitts when removing the water from the oven.
- The teacher and all students should wear indirectly vented chemical splash goggles when running this investigation.
- **Storage:** Place the cardboard and the neon light bulbs in a box so you can reuse them.

Lesson 8 • 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 (DCIs):

- **PS4.A.3.** Waves can add or cancel each other as they cross, depending on their relative phase (i.e., relative position of peaks and troughs of the waves), but they emerge unaffected by each other. (HS-PS4-3)
- **PS4.B.1.** Electromagnetic radiation (e.g., radio, microwaves, light) can be modeled as a wave of changing electric and magnetic fields~~ or as particles called photons. The wave model is useful for explaining many features of electromagnetic radiation, and the particle model explains other features~~. (HS-PS4-3)
- **PS4.B.2.** When light or longer wavelength electromagnetic radiation is absorbed in matter, it is generally converted into thermal energy (heat)~~. Shorter wavelength electromagnetic radiation (ultraviolet, X-rays, gamma rays) can ionize atoms and cause damage to living cells~~. (HS-PS4-4)
- **PS4.C.1.** Multiple technologies based on the understanding of waves and their interactions with matter are part of everyday experiences in the modern world (e.g., medical imaging~~, communications, scanners) and in scientific research. They are essential tools for producing, transmitting, and capturing signals and for storing and interpreting the information contained in them~~. (HS-PS4-5)

The coverage of PS4.B.2 and PS4.C.1 builds off their first use in this unit in Lesson 1, when students constructed an initial consensus model of how the microwave oven heats food and why the music from the Bluetooth speaker was affected when one of the wireless devices was in the oven. These DCIs will continue to be developed in Lesson Set 2, in the portions about ionization and information transfer. PS4.B.2 was also previously developed in Lessons 5 and 7.

The first part of PS4.B.1 was established in Lesson 4 and used throughout Lesson Set 1. The wave model part of this DCI will be covered in Lesson 10.

In this lesson, students explore the relationship between the two types of wave interference to explain the uneven distribution of heat inside a microwave oven. Although they use force interactions to make sense of constructive and destructive patterns of wave interference, they ultimately use an energy lens to explain how these wave interactions can result in the observable patterns of heat transfer.

This lesson coherently builds on the prior use of multiple crosscutting concepts (CCCs) in the unit:

- CCC 2.2 is used across this unit to explain energy transfer between electromagnetic waves and matter. This was initially covered with the movement of electrons on a receiving antenna in Lesson 4, and then with water molecules in Lesson 7. In this lesson, students use this cause-effect relationship to consider wave interactions to further their modeling of the anchor phenomenon. In Lessons 10 and 13, this CCC will be expanded to consider other types of EM radiation.
- CCC 6.2 was used in Lesson 6 as a lens to ask questions about the relationship between the structure/shape of the microwave oven and its interactions with different types of matter. Lesson 7 looked at the particle-level structure of materials to infer their interactions with microwave radiation. In this lesson, students look at the macroscopic-level structure to make inferences about the role of the turntable in the oven. Structure and function concepts are further developed for other EM radiation systems in Lesson Set 2.
- This lesson focuses on energy conservation (CCC 5.3) within wave interference as well as energy transfer (CCC 5.2) by electromagnetic waves. This works coherently with the story of energy developed throughout Lesson Set 1 to explain energy transfer within the microwave oven. In Lesson Set 2, the energy story will be expanded to consider other uses of EM radiation and additional interactions with matter.

This lesson coherently builds on the unit's prior use of multiple science and engineering practices (SEPs):

- SEP 1.1 was used in Lessons 1 and 7, when students developed models that served as tools to identify questions that could help us investigate the interactions between matter and EM radiation.
- SEP 2.3 is used in this lesson individually and as a class. Similarly to previous model development in this unit, students create and revise models to explain observed patterns and to identify gaps in small-scale mechanisms that can help explain energy transfer.

Students encounter or co-develop definitions for the following words in this lesson: *interference*, *constructive interference,* and *destructive interference.* **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

This lesson does not cover the ionizing or data transfer parts of DCIs PS4.B.2 and PS4.C.1; these will be covered in Lesson Set 2.

This lesson does not cover the photon parts of DCIs PS4.B.1; these will be covered in Lesson 10.

This lesson does not explicitly cover the behavior or formation of standing waves. Although we use the properties to make sense of wave interference, and we see standing waves in the microwave oven animation slides, we don't spend time defining them. Similarly, we do not discuss harmonics or define nodes or antinodes.

LEARNING PLAN for LESSON 8

1 · NAVIGATE: CONNECT TO THE ANCHOR PHENOMENON

7 min

MATERIALS: None

Consider the patterns in the anchor phenomenon. Present **slide A**. Say, *At the end of the last class, we thought about how we might explain the patterns we observed in the nachos when we started this unit.* Extend student thinking to energy transfer with the slide's prompt:

- *What do the patterns we observed with the nachos suggest about how energy transfers inside the microwave oven?*

Elicit ideas from 1-2 students. Display **slide B**. Read the question aloud:

- *What did we think was happening in the microwave oven then?*
    A. *Cheese contains more water than chips.*
    B. *More energy ends up in some places than in others.*
    C. *Every place inside of the oven ends up with the same amount of energy.*

Tell the class to think about this for a moment. Then invite them to raise their hands for the answer they feel reflects their ideas. Ask a couple of students for each answer (A, B, C) to explain their reasoning.

Consider limitations of our data and other ways to observe energy transfer. Display **slide C**. Say, *To figure out what is causing the patterns in the cheese, we should consider what data we have and its limitations.* Use the slide's prompts to elicit student ideas, as shown in the table below.

Before moving on from the first prompt, if students have not mentioned the use of the light bulb (from Lesson 2), remind them of this method. For the second prompt, if they do not mention the different water content in cheese and chips, highlight this limitation and ask why that could make it harder to explain the patterns. Suggest using a single type of material, such as light bulbs, to run the same test to eliminate that matter composition variable.

Suggested prompt	Sample student response
How have we collected data about energy transfer in the microwave oven so far?	We used a light bulb. We measured the temperature at different places.

	We put things with aluminum foil in the oven. We put water inside.
What are the limitations of the current data from the nachos?	The nachos don't show a clear pattern. The nachos don't show what is happening while the microwave oven is running. We don't know why the cheese heats up but the chips don't. We put a light bulb inside, but it doesn't help us see clear patterns of energy transfer. The cheese and chips are different types of food, so maybe the pattern is because they have different water content.
How could we adapt some of these methods to address these limitations?	We could put lots of light bulbs in the oven. We could make a layer of cheese that's the same all over to show the pattern more clearly. We could put several cups of water in the microwave oven and measure the temperatures.

Predict how small light bulbs will behave in the microwave oven. Present **slide D**. Say, *Previously we used a single, large light bulb to observe energy transfer in the microwave oven.* Have students turn and talk about the following prompts:

- *If we put many light bulbs across the microwave oven, what do you think we will see the light bulbs do?*
- *What safety precautions should be followed for this test?*

Ask a few pairs to share out. Accept all answers. If students are stuck, use guiding questions such as:

- *Would all the bulbs light up?*
- *What would that say about energy transfer?*

2 · OBSERVE SMALL LIGHT BULBS IN THE MICROWAVE OVEN

5 min

MATERIALS: Microwave Oven Energy Transfer Map

Check safety precautions. Present **slide E**. Distribute the neon light bulbs with and without metal wires on them for students to pass around until everyone has seen them. Elicit ideas about safety precautions with the slide's prompts:

How can we ensure that...

- *...we heat food or liquids that we know will absorb some of the microwave radiation?*
- *...metal objects aren't within 1 inch of the walls, floor, or ceiling of the oven?*
- *...objects inside do not reach dangerous temperatures?*

Listen for the following ideas:

- Remove the metal from the outside of the bulbs.
- Include a container of water.
- Make sure the water does not overheat.
- Run the oven for only 15 seconds at a time.

If any of these precautions are not mentioned, use guiding questions to remind students of places where the *Microwave Oven Manual* or other safety instructions gave us these guidelines.

ALTERNATE ACTIVITY	If students proposed other intriguing investigation options from the prompt on **slide C**, you can take some time to conduct one or more of them. However, be extra attentive to safety precautions. **Do not** conduct any experiments that do not comply with all the safety guidelines discussed throughout the unit.

Observe an array of small light bulbs in the microwave oven. Present **slide F**. Ask students to bring their science notebook and a pen to the demonstration area around the microwave oven. Describe the light bulb array on the cardboard and place it in the oven on the microwave-safe platform, along with a bowl of water. Read the slide's instructions aloud:

We will develop models for explaining the patterns in the cheese and the light bulbs.

- *Observe the small light bulbs while the microwave oven is running.*
- *Record your observations of any patterns in your science notebook.*

Make sure everyone stands at least 15 feet away from the oven. Run the oven for 15 seconds (or 10 seconds for repeated demonstrations--see the Safety callout). Instruct students to write their observations in their notebooks. If necessary, rotate the group so all students can see the demonstration clearly.

SAFETY PRECAUTIONS

- Only the teacher should operate the microwave oven.
- This experiment should **not** be conducted or replicated at home.
- These are not LEDs. Make sure to only use the provided/specified bulbs. Make sure the metal is removed from the outside of the bulbs.
- Make sure to also place a container of water in the oven.
- Make sure all parts of the bulbs are at least 1.5 inches from the oven's walls and floor.
- Have students stand at least 15 feet away from the oven.
- Students and the teacher should wear indirectly vented chemical splash goggles when running this experiment.
- Do not heat the bulbs for more than 15 seconds--longer than that could cause them to overheat and shatter.
- If you conduct the experiment multiple times, do not run the oven for more than 10 seconds per demonstration. Be sure to test the water's temperature with a thermometer, and replace the heated water with cool water before it approaches boiling.
- Use mitts to remove materials from the oven.

Ask a few volunteers to share their observations. Take a few moments to guide the class to a consensus about what we saw.

ALTERNATE ACTIVITY

If it is not possible to use the light bulb array in the classroom, use https://youtu.be/3Z7ay5TcPYs. It will allow students to observe the energy transfer pattern inside the microwave oven when the turntable is removed.

3 · DEVELOP A MODEL TO EXPLAIN PATTERNS OF HOT AND COLD SPOTS

10 min

MATERIALS: chart paper, markers

Develop initial group models for the observed patterns. Organize students in groups of 3 and distribute a sheet of chart paper and markers to each group. Present **slide G**. Read the instruction aloud:

- *Develop a model, using words and drawings, to explain the patterns in the cheese and the small light bulbs.*

Give groups the remaining 8 minutes to develop their models.

Students do not yet have the concept of interference to explain the patterns. They may come up with other mechanisms of waves interacting. It is not important for these initial models to be fully correct. As the groups develop them, use this opportunity as a pre-assessment of ideas that we have built throughout the unit that should be included.

Look for these key model ideas:

- components of the microwave oven that influence energy transfer, such as the magnetron, the walls, and/or the objects inside
- cause-and-effect relationships that connect different parts of the model
- connections between the structure of the oven and how it functions
- matter and energy relationships that connect visible changes (cold and hot spots, light) and non-visible mechanisms (e.g., charged particles vibrating)
- waves reflecting off of the walls of the oven and back into the cooking cavity

To better understand what will be expected of students' revised models later in this lesson, after they learn about interference, see the Assessment callout at the end of day 2.

4 · CONDUCT A GALLERY WALK OF INITIAL MODELS FOR HOT AND COLD SPOTS

8 min

MATERIALS: 3" x 3" sticky notes, markers, initial group model posters

Compare and give feedback on models in a gallery walk. Distribute sticky notes and markers. Present **slide H**. Describe the activity using the prompts:

- *Add check marks in places of the model that agree with our understanding.*
- *Add questions on sticky notes to places where the model does not yet explain the patterns we observed.*

Give students a few minutes to walk around the classroom to leave feedback on the initial group models. ✱ If they have trouble identifying limitations of the models, ask them whether the model they are evaluating explains the patterns of light bulbs being on/off in the microwave oven.

Briefly review the feedback. Have students return to their own group's poster and take a minute to review the feedback they received. Tell them they will have a chance to revise their model after we investigate more causal mechanisms.

Keep the initial group model posters to use on day 2.

✱ **ATTENDING TO EQUITY**

Building classroom culture and agreements: Strong Community Agreements are essential for productive gallery walks. This is a good opportunity to revisit and/or revise those agreements. As this is the fifth unit in the course sequence, it is assumed that working on refining and revisiting Community Agreements has become an established routine, with fading scaffolding. However, if you are doing this unit out of sequence, a more intentional revisiting of those agreements before starting this discussion may be helpful.

5 · OBSERVE AND DESCRIBE PATTERNS OF WAVE INTERFERENCE

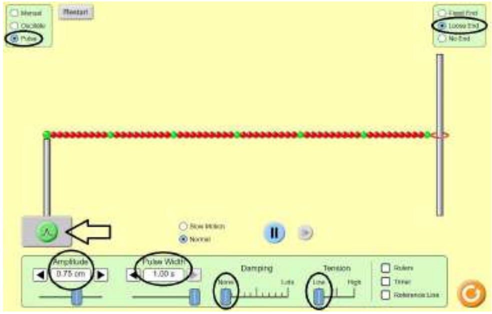
10 min

MATERIALS: *Wave Interactions*, https://www.openscied.org/general/waveonastring/

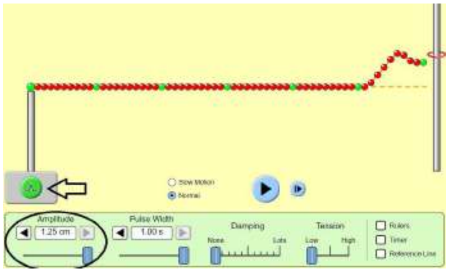
Transition to considering wave interactions. Say, *Our models seem to do a great job of explaining how energy transfers in the microwave oven, but they don't yet explain why this varies by location. I saw some models that showed waves reflecting in the oven and overlapping with other waves. Let's use the Waves on a String simulation to look at what happens when waves reflect and overlap like that.*

Remind students that this simulation is an oversimplification of the microwave oven system. Say, *It's really tough to study the reflection of electromagnetic waves, because they have magnetic and electric fields that radiate in all directions, which we can't see directly with our eyes. That makes things complicated. The simulation allows us to focus on a single dimension--just back and forth.*

Demonstrate overlapping waves with the simulation. Display the simulation at https://www.openscied.org/general/waveonastring/ using the following settings:

<table>
<tr>
<td>Waves on a String simulation action:</td>
<td>Open the simulation and select the "Pulse" and "Loose End" settings at the top.
At the bottom, select the following settings:
"Amplitude" to 0.75 cm
"Pulse Width" to 1 second
"Damping" to none
"Tension" to low
When you are ready to show students the wave interactions, click the green pulse button at the bottom of the piston to create the first wave pulse.</td>
<td></td>
</tr>
</table>

Orient students to what they are looking at, which is a string attached on one end and loose on the other, similar to the slinkies in Lesson 3. Say, *We were just looking at a pulse, but we know that inside the microwave oven, there is more than a single pulse being transmitted. I'm going to send another pulse.*

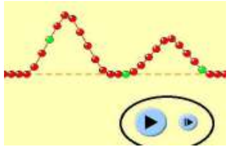
Waves on a String simulation action:	Change the **"Amplitude"** to **1.25 cm**, and when the first wave is on top and gets to the loose end, click the **green pulse button** again to create the larger pulse. 

Project **slide I**. Use the prompts to elicit noticings and wonderings about the behavior of the pulses. After a few moments, invite students to share. Listen for the following ideas:

- When the pulse hits an end, it changes the way it's going and moves in the opposite direction.
- When two pulses overlap, the amplitude changes but the pulses keep moving.
- What would happen if we add more pulses?
- This does not look like the microwave oven!

Explain that scientists use the term *interference* to talk about situations when waves overlap in space.

Describe wave interactions using words and drawings. Present **slide J**. Distribute the *Wave Interactions* handout to each student. Suggest that we use the simulation's slow-motion function to observe the interactions between two overlapping waves more clearly. Switch to slow motion and let the pulses move back and forth as students draw what they see happening for Interactions A and B.

Waves on a String simulation action:	To allow students to better see what is happening while the waves interact: ● Let the wave pulses get close together but not yet touching. ● Use the **step forward button** (to the right of the play/pause button) to step through the interaction frame by frame. ● Press **play** again until the waves are close again (this will be the other interaction of A/B), and repeat the step-through process. 

Run through interactions A and B in slow motion a few times, and make sure all students have drawn what is happening with the matter during and after the wave interactions. Then give them 5 minutes to complete the energy and forces prompts on their handout for Interactions A and B.

6 · NAVIGATE: MAKE PREDICTIONS ABOUT EQUAL WAVES

5 min

MATERIALS: *Wave Interactions*

Make predictions about other wave interactions. Present **slide K**. Instruct students to complete the prompts on their handout for Interactions C and D.

Collect *Wave Interactions* as an assessment before students leave. ✱

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment: Look for student work on the handouts to:

- Identify that the total energy is the same at all points in time for the wave interaction. (CCC: 2.2, 5.3; DCI: PS4.A.3)
- Show that the waves add up to a larger wave shape when they are both up (Interaction A) and cancel when one is up and the other is down (Interaction B). (DCI: PS4.A.3)
- Show that the wave shapes and directions return to their original state after the waves have passed through each other, showing the energy is unchanged. (CCC: 5.3; DCI: PS4.A.3)
- Use logic about how forces act on the particles of the string in a way that pulls the particles up or down, and how these forces add or cancel based on their relative directions (cause) to result in a new wave shape while the waves meet in space (effect). (CCC: 2.2; DCI: PS4.A.3)

See the *Wave Interactions Key* for example answers.

What to do: Before the next class, look over students' work. Provide written feedback on their matter, energy, and forces reasoning for Interactions A and B, and scan their responses for Interactions C and D. If many students are struggling, take time at the beginning of the next class to review those parts and give students a chance to update their predictions before sharing with a partner.

Building toward: 8.A.1 Develop, revise, and use a model of wave interactions using an energy, matter, and forces lens to explain how reflection and interference cause patterns of energy transfer into materials in the microwave oven without creating or destroying energy. (SEP: 2.3; CCC: 2.2, 5.3; DCI: PS4.A.3, PS4.B.1)

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING CAUSE AND EFFECT

Similarly to Lesson 5, drawing cause-and-effect relationships in this context requires students to draw connections between the structure and function of the microwave oven and changes in energy transfer. The use of this CCC also requires them to consider how the net force from constructive and destructive interference is the result of how EM radiation is reflected to different parts of the oven.

End of day 1

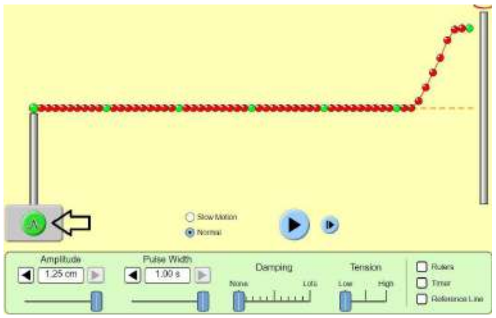
7 · NAVIGATE: REVIEW PREDICTIONS

3 min

MATERIALS: *Wave Interactions*, https://www.openscied.org/general/waveonastring/

Compare predictions for waves of equal height interacting. Present **slide L**. Remind students where we left off last time, and return *Wave Interactions*. Have them turn and talk to compare their predictions about matter for Interactions C and D with a partner.

After a few minutes, say, *Let's check our predictions.* Show the simulation at https://www.openscied.org/general/waveonastring/ with the wave pair interacting with the setup below.

Waves on a String simulation action:	Open the simulation and select the **"Pulse"** and **"Loose End"** settings at the top. At the bottom, select the following settings: ● **"Amplitude"** to **1.25 cm** ● **"Pulse Width"** to **1 second** ● **"Damping"** to **none** ● **"Tension"** to **low**  Click the **green pulse button** to send the first wave. When the first wave is on top and gets to the loose end, click the **green pulse button** again to create the other wave. Let the simulation cycle through the interactions for students. Use the **pause** and **step forward buttons** for more detailed analysis, if needed.

Say, *Let's see if we can make sense of what is happening.*

8 · CONSTRUCT AN EXPLANATION FOR WAVE INTERFERENCE

12 min

MATERIALS: *Wave Interactions*, science notebook

Explain interference using matter, energy, and forces. Present **slide M**. Give students a few minutes to work in pairs to answer the prompts, using their work on the *Wave Interactions* handout. Then ask a couple of partner pairs to share for each prompt, as shown in the table below.

Suggested prompt	Sample student response

✱ **ATTENDING TO EQUITY**

Supporting emergent multilinguals: Students who are learning English benefit from redundancy of content and vocabulary.

What pattern do we see with how the matter of the waves behaves?	When both wave pulses are on the same side and overlap, the height of the wave increases for a moment. When both waves are on the opposite side and overlap, the height of the wave decreases. Both waves keep moving after they combine. The different wave shapes combine into one shape because the string can't do two things at once.
What happens to the total energy in the system?	The total energy stays the same before and after. While they are interacting, the energy adds or cancels based on the direction of the wave. Energy is not created or destroyed.
How do the forces acting on the string particles help explain the outcome when they meet?	Maybe the forces add up, then the combining waves are on the same side. The forces cancel each other out when the waves are on opposite sides. The bonds stretch and pull the string up or down, and those forces add or cancel.

Build a consensus explanation for hot and cold spots. Present **slide N**. Build on the pattern share-out by eliciting student ideas with the prompt: ✱ ✱

- *Can our reasoning about matter, forces, and energy here help to explain the hot and cold spots we observed in the microwave oven?*

Accept all answers, but listen for these ideas:

- Waves must be adding in hot spots and canceling in cold ones.
- The hot spots could be places where waves are combining and getting taller.

One way to provide an opportunity to hear ideas again is to revoice them. For example, after a few students have shared their thinking, check to clarify what students agree upon by saying, "So I'm hearing ______ and ______. Do I have that right?" For all science students, but particularly those learning English, the opportunity to hear scientific language in varied contexts is fundamental to the development of disciplinary literacy.

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING ENERGY AND MATTER

Similarly to Lesson 5, students explore how interactions between matter and EM radiation cause changes in how energy is reflected and absorbed in various parts of the microwave oven. Encourage them to use ideas about reflection, transmission, and absorption to make sense of energy flow in the oven.

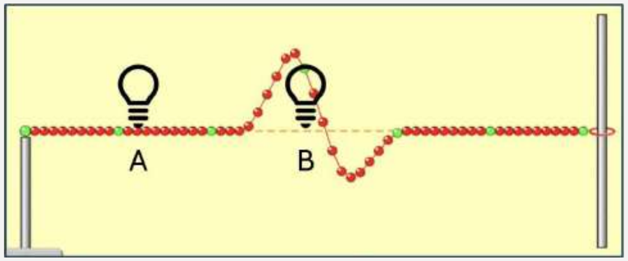
Add entries to Personal Glossaries. Present **slide O**. As a class, add the terms *interference*, *constructive interference*, and *destructive interference* to students' Personal Glossaries. Use student ideas to develop definitions for these concepts. They may look something like this: "*Interference* happens when two waves pass through each other. *Constructive interference* is when the amplitudes of both waves add up, creating a wave with a larger amplitude. *Destructive interference* occurs when the forces from both waves are pointing in opposite directions, canceling each other out."

9 · CONNECT TO CONTINUOUS ELECTROMAGNETIC WAVES

8 min

MATERIALS: https://www.openscied.org/general/waveonastring/

Consider limitations of the simulation and our understanding so far. Present **slide P**. Use the slide's prompts and GIF to facilitate discussion between students about limitations so far, as shown in the table below.

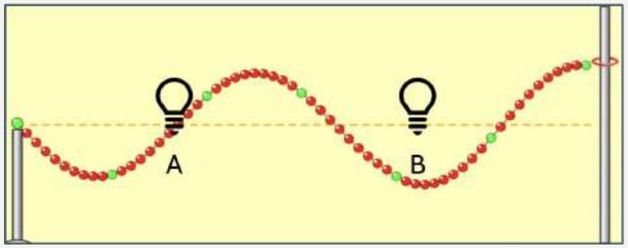


Suggested prompt	Sample student response
How would light bulbs behave if these waves were transferring energy to them?	The bulbs would light up when the wave was big near the bulb--lots of energy to transfer. The bulbs would not light up most of the time and would only occasionally turn on.
Does this match what we saw in the microwave oven?	The brightness of the bulbs changed with the pulses, but in the oven, it didn't change. In the microwave oven, multiple bulbs were on at the same time, but wouldn't be for this.

Ask what we know is different in the microwave oven from our model with the wave pulses. Listen for students to suggest that the waves in the oven are continuous, not pulses.

Observe continuous wave interference. Present **slide Q**. Use the prompts and GIF to facilitate student-to-student discussion:

- *What patterns do we observe?*
- *How does this help explain the hot and cold spots in the microwave oven?*



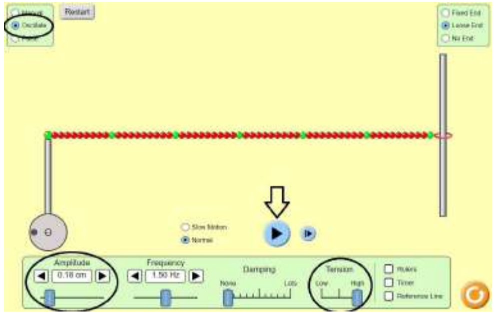
Listen for students to say that bulb A would stay off while bulb B would be on, and that this matches what we saw in the microwave oven.

ADDITIONAL GUIDANCE	Some students may say that bulb B would turn on and off. This is a great opportunity to come back to frequency. Remind students that light bulbs are almost always turning on and off but are doing it very quickly. The frequency of the waves in a microwave oven is 2.4 KHz, which means 2,400 cycles per second. This is much faster than the human eye can detect.

To show students how this GIF wave was created, show them the simulation with the setup below.

<table>
<tr>
<td>Waves on a String simulation action:</td>
<td>Open/reset the simulation and select the following settings:

“Oscillate” and “Loose End”
“Amplitude” to 0.18 cm
“Frequency” to 1.5 Hz
“Damping” to none
“Tension” to high

Once all settings have been changed, display the simulation and click the “Restart” button in the upper left.</td>
<td></td>
</tr>
</table>

Ask, *How does the input amplitude compare to the wave height of the combined wave from interference?* Listen for students to notice that the input amplitude is tiny but the resulting combined wave height is much larger. If they have a hard time seeing this, use a reference line to show the input amplitude.

Compare string and electromagnetic waves. Present **slide R**. Say, *Let’s look at how we have modeled electromagnetic waves.* Ask students to turn and talk with the prompts:

- *How do electromagnetic waves compare to those in the string?*
- *What do the arrows represent?*
- *What would happen when two electromagnetic waves pass through the same place in space?*

Listen for these ideas:

- The electromagnetic waves move in all directions.

- The string waves depend on matter, but the electromagnetic waves don't.
- The arrows represent the forces generated by the moving fields.
- When two electromagnetic waves meet, their forces add up or subtract.

10 · EXPLORE CONTINUOUS WAVE INTERACTIONS IN THE MICROWAVE OVEN

8 min

MATERIALS: computer with access to https://docs.google.com/presentation/d/1S7BaEyymgycR-KBlRaA3UJ9S1gaF2G_S1UMuRhEalME/edit?usp=sharing

Model electromagnetic wave interference. Say, *I have a short animation that shows waves generated by the magnetron and waves reflected off of the oven wall*. Project the Interference Animation slides (https://docs.google.com/presentation/d/1S7BaEyymgycR-KBlRaA3UJ9S1gaF2G_S1UMuRhEalME/edit?usp=sharing). Show students how to scroll up and down to see the sequence.

Present **slide S**. Lead a discussion using the prompts:

- *What do the arrows represent?*
- *What do the wave colors represent?*
- *What do the dots represent?*

Listen for the following ideas:

- The arrows represent forces arrows.
- The arrows represent electromagnetic fields.
- The orange arrows are the waves generated by the magnetron.
- The blue arrows are the waves reflected off of the wall.
- The dots represent the wave that results from the two waves interfering.

Use the wave sequence to make sense of hot and cold spots. Present **slide T**. Have students gather in their groups from the initial modeling task on day 1. Distribute a computer with access to https://docs.google.com/presentation/d/1S7BaEyymgycR-KBlRaA3UJ9S1gaF2G_S1UMuRhEalME/edit?usp=sharing to each group. Give them 4 minutes to step through the wave sequence to find evidence to help answer the slide's prompts:

- *Where would the cold spots be located?*
- *Where would the hot spots be located?*

While students work with the Interference Animation slides, return the initial group model posters created on day 1 to the respective groups.

11 · REVISE MODELS TO EXPLAIN PATTERNS OF HOT AND COLD SPOTS

10 min

MATERIALS: computer with access to https://docs.google.com/presentation/d/1S7BaEyymgycR-KBlRaA3UJ9S1gaF2G_S1UMuRhEaIME/edit?usp=sharing, initial group model posters, markers

Revise group models for the observed patterns. Keep students in groups with access to the Interference Animation slides, https://docs.google.com/presentation/d/1S7BaEyymgycR-KBlRaA3UJ9S1gaF2G_S1UMuRhEaIME/edit?usp=sharing. Present **slide U**. Read the instructions aloud:

- *Revise your model, using words and drawings, to explain the patterns in the cheese and the small light bulbs.*
- *Be sure to include details about matter, energy, and forces in your model.*

Give students about 8 minutes for this task. While they work, walk around the classroom and use guiding questions to support their modeling. An example model and guiding prompts are provided in the *Example Interference Model*. Look for models with strong examples of the elements in the Assessment callout box below, and tell those groups you would like them to share with the class. ✱

ADDITIONAL GUIDANCE

This modeling task covers crucial pieces of the story that students will need on day 3 to revise the initial consensus model from the anchor phenomenon. If students struggle, it is important to use this time to troubleshoot and build understanding.

When all groups have finished, have the groups you identified share out the key elements of their models. Keep the revised group models to review after class.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment: Look for students' revised models (SEP: 2.3) to:

- Show how the microwave oven's structure serves to create and reflect microwave radiation in order to cause wave interference. (SEP: 2.3; CCC: 2.2; DCI: PS4.A.3)
- Illustrate how interference causes the wave heights/forces/energy of the microwave radiation to combine, creating new wave shapes with lots of energy in some places and little to none in others. (SEP: 2.3; CCC: 2.2; DCI: PS4.A.3)
- Explain how the bulbs lighting up (or the cheese melting) is caused by energy transfer to them from the microwave radiation through the electric fields of the waves applying forces to the electrons (matter) in the bulbs (or in the water in the cheese), causing them to vibrate. (SEP: 2.3; CCC: 2.2, 5.3; DCI: PS4.B.1)

✱ ATTENDING TO EQUITY

Supporting emergent multilinguals: Priming some groups before a whole-class discussion not only signals to them that they are expected to share their ideas in public, but also gives them an opportunity to prepare ahead of time. This strategy is particularly effective with quiet students and emergent multilingual students, who will gain confidence from having additional time to organize their ideas before sharing them with others.

- Show how in places where the bulbs light up, constructive interference causes the forces/energy of the interfering waves to add together, creating larger forces/energy that light the bulbs. (SEP: 2.3; CCC: 2.2, 5.3; DCI: PS4.A.3)
- Show how in places where the bulbs do not light up, destructive interference causes the forces/energy of the interfering waves to cancel out, creating little to no forces/energy that cannot light the bulbs. (SEP: 2.3; CCC: 2.2, 5.3; DCI: PS4.A.3)

See the *Example Interference Model* for a version of what student models could look like. The models are likely to represent these concepts in many different ways and not match this example, which is fine; it is *not* meant to represent a single way of correctly modeling these processes.

What to do: As groups revise their models, review their progress and provide guiding questions to help them focus on the parts they are still missing. See the *Example Interference Model* for sample prompts.

If students struggle with any of the M-E-F perspectives, point them toward the M-E-F poster from *OpenSciEd Unit P.2: How forces in Earth's interior determine what will happen to its surface? (Earth's Interior Unit)* and the *Wave Interactions* handout. If there is a lot of variation between models, consider reconvening for a whole-class discussion about them before having students update their *Progress Tracker*.

Review the models closely before the next class to know what details may need to be further supported before and during the revision of the initial consensus model from the anchoring phenomenon.

Building toward: 8.A.2 Develop, revise, and use a model of wave interactions using an energy, matter, and forces lens to explain how reflection and interference cause patterns of energy transfer into materials in the microwave oven without creating or destroying energy. (SEP: 2.3; CCC: 2.2, 5.3; DCI: PS4.A.3, PS4.B.1)

12 · SYNTHESIZE IDEAS ABOUT WAVE INTERFERENCE

4 min

MATERIALS: science notebook

Add new understandings to the *Progress Tracker*. Present **slide V**. Have students use the slide to guide their work. Give them 3 minutes to add a new diagram to their *Progress Tracker* that explains wave interference through matter, energy, and force perspectives, and explains its role in the heat distribution across the microwave oven.

End of day 2

13 · NAVIGATE: MODEL THE FUNCTION OF THE TURNTABLE

3 min

MATERIALS: None

Make predictions about light bulbs and the turntable. Say, *Last class, we made sense of why there are hot and cold spots in the microwave oven. However, with both the nacho and light bulb experiments, we had removed the oven's turntable. What do you think the function of the turntable is?* ✱ ✱

Present **slide W.** Have students turn and talk with the prompt:

- *If we put the light bulbs on the turntable and run the microwave oven, what do you predict will happen?*

Ask a few pairs to share their predictions. Accept all ideas. Say, *Let's test these predictions!*

✱ SUPPORTING STUDENTS IN ENGAGING IN DEVELOPING AND USING MODELS

This is a good opportunity to remind students about the Nature of Science: Scientific Models, Laws, Mechanisms, and Theories Explain Natural Phenomena. One way to test the power of the model we have developed in this lesson is to use it to make predictions about energy transfer in the microwave oven.

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING STRUCTURE AND FUNCTION

Given the patterns of energy transfer that we have seen in the microwave oven, students should be in a good position to make inferences about the function of the turntable. In this lesson, students are able to connect ideas about energy transfer and matter interactions within the constraints of the oven structure. Encourage them to use ideas about absorption, reflection, and transmission, along with the patterns in the

	light bulbs we saw in the last class, to predict how rotating the matter inside the microwave oven can change those patterns.

14 · INVESTIGATE THE FUNCTION OF THE TURNTABLE WITH SMALL LIGHT BULBS

4 min

MATERIALS: Inferring Turntable Function

Consider safety guidelines. Present **slide X**. Say, *As always, before we do an experiment with the microwave oven, we need to consider the safety guidelines and make sure we follow them. What did we determine we needed to do when we used the light bulbs last class? Do we need to take any additional precautions because we're adding the turntable this time?*

Listen for students to say we should take similar precautions as we did without the turntable.

Observe light bulbs on the turntable. Present **slide Y**. Have students bring their science notebook and a pen and gather in the demonstration area around the microwave oven. Tell them to make observations during the experiment and consider the prompts from the slide:

- *How do your observations compare to your model and your partner's predictions?*
- *What do your observations suggest about the role of the turntable in energy transfer inside the microwave oven?*

Have everyone stand at least 15 feet away from the microwave oven. Run the oven for 15 seconds (or 10 seconds for repeated demonstrations--see the Safety callout), and instruct students to write their observations in their notebooks. If necessary, rotate the group so everyone can clearly see the demonstration.

For each prompt on the slide, ask a few students to share their answers.

SAFETY PRECAUTIONS

- Only the teacher should operate the microwave oven.
- This experiment should **not** be conducted or replicated at home.
- The bulbs are not LEDs. Use only the provided/specified bulbs. Make sure the metal is removed from the outside of the bulbs before placing them in the oven.
- Make sure to also place a microwave-safe glass bowl of water in the oven.
- Make sure all parts of the bulbs are at least 1.5 inches from the oven's walls and floor.
- Have students stand at least 15 feet away from the oven.
- The teacher and all students should wear indirectly vented chemical splash goggles during this investigation.
- Do not heat the bulbs for more than 15 seconds--longer than that could cause them to overheat and shatter.

	• If you conduct the experiment multiple times, do not run the oven for more than 10 seconds per demonstration. Test the temperature of the water with a thermometer, and replace it with cool water before it approaches boiling. • Use hot mitts to remove materials from the oven.

ALTERNATE ACTIVITY	If it is not possible to use the light bulb array in the classroom, use https://youtu.be/Gjwg-Q8fyeI. It will allow students to observe how the turntable influences the energy transfer pattern inside the microwave oven.

15 · REVISE THE CONSENSUS MODEL FROM THE ANCHOR PHENOMENON

15 min

MATERIALS: Initial Consensus Model poster from Lesson 1, chart paper, markers

Revise the consensus model from the anchor phenomenon. Display **slide Z**. Say, *Now that we can explain the structure of the microwave oven, and how that interacts with microwave radiation, let's update our initial class consensus model.*

Gather the class in a Scientists Circle. ✱ Make sure the Initial Consensus Model poster from Lesson 1 is visible. Hang a piece of chart paper titled "Class Consensus Model" and make markers available to students. Explain that they will work together to revise our model from the beginning of the unit, to answer the questions on the slide:

- *how the microwave oven heats food/liquid*
- *why the music was affected when the wireless device was inside the microwave oven, especially when the speaker was farther away*

For this student-led model development, encourage everyone to weigh in on collectively developing the visual representations and written explanations. Have students write and/or draw the new model on the poster as you use talk moves, listed below, to facilitate developing a revised consensus model.

When soliciting ideas to develop or modify the model or explanation:

- *How should we represent it? Are we OK with that?*
- *How could we modify what we have so we account for the evidence that we agree is important to consider?*
- *What modifications might you make to clarify confusion or address the discontent that this group feels?*
- *Is more evidence or clarification needed before we can come to an agreement? What is that?*

When inviting support or critique:

- *Who feels like their idea is not quite represented here?*
- *Would anyone have put this point a different way?*
- *What ideas are we in agreement about?*
- *Are there still places where we disagree? Can we clarify these?*

When soliciting ideas for next questions or investigations to pursue:

- *Where should we go next to help us with areas where we are not sure/not in agreement?*
- *What new questions do we have that might help us move forward?*

✱ ATTENDING TO EQUITY

Building classroom culture and agreements: As this is the fifth unit in the course sequence, it is assumed that working on refining and revisiting Community Agreements has become an established routine, with fading scaffolding. At this point, asking students to take on greater leadership in facilitation and documentation of discussion is a natural progression for their learning community. However, if you are doing this unit out of sequence, a more intentional revisiting of those Community Agreements before starting this discussion may be helpful.

ASSESSMENT OPPORTUNITY	**What to look for/listen for in the moment:** Look for the revised consensus model (SEP: 2.3) to include these elements: ● Electromagnetic waves transfer energy across space via changing electric (and magnetic) fields. (CCC: 5.2; DCI: PS4.B.1) ● The structure of the magnetron creates microwave radiation inside the microwave oven by vibrating electrons that change electric fields. (CCC: 6.2; DCI: PS4.C.1) ● The structure of the metal walls of the microwave oven reflects microwave radiation (including from the magnetron and the cell phone) inside the oven. (CCC: 6.2; DCI: PS4.C.1) ● Reflected waves add to or cancel each other with the waves coming out of the magnetron to cause uneven transfer of energy to matter, creating hot and cold spots in the microwave oven, which is structured with a turntable to minimize the effects of cold spots. (CCC: 5.2, 6.2; DCI: PS4.A.3, PS4.B.2) ● Liquid/food heats up, represented as energy transfer from microwave radiation to polar water molecules in the form of thermal energy (the function of the microwave oven). (CCC: 5.2, 6.2; DCI: PS4.B.2) ● Less microwave radiation gets from the phone to the Bluetooth speaker than when the phone isn't in the microwave oven, because some of the radiation is reflected back into the oven due to the oven's structure. (CCC: 6.2) **What to do:** Use the suggested talk moves above to facilitate this discussion. **Building toward: 8.B** Collaboratively revise a model of a microwave oven to explain how the components of the system function to heat food, and how and why these structures could affect a Bluetooth signal. (SEP: 2.3; CCC: 5.2, 6.2; DCI: PS4.A.3, PS4.B.1, PS4.B.2, PS4.C.1)

16 · REVISIT THE DRIVING QUESTION BOARD

15 min

MATERIALS: sticky dots (green, yellow, and red), 3" x 3" sticky notes, marker, science notebook, Class Consensus Model poster, Driving Question Board

Use our model to identify gaps in our explanation. Keep students in the Scientists Circle. Display **slide AA**. Give students a minute or two to think on their own about the prompts:

- *What are the limitations of our updated class consensus model?*
- *What questions does our model still not answer?*

✱ SUPPORTING STUDENTS IN ENGAGING IN ASKING QUESTIONS AND DEFINING PROBLEMS

Ask a couple of volunteers to share their ideas. Say, *Now that we have revisited and revised our initial model, let's revisit our Driving Question Board as well.*

Mark patterns on the DQB with sticky dots. Display **slide BB**. Continue in the Scientists Circle. Focus the discussion on identifying (1) questions we agree that we can answer, (2) questions we have at least a partial answer to, and (3) questions we cannot answer at all.

Designate one color of sticky dots to mark each category. Distribute a set of sticky dots to each student and have them come up to the DQB and add their dots to the existing questions. Give them about 4 minutes to complete this task.

Discuss progress on the DQB. Display **slide CC**. Continue giving students ownership and encourage them to use the slide's prompts to guide their discussion:

- *What strategies have allowed us to explore the questions we can answer now?* ✱
- *What do the questions we cannot answer have in common?*
- *What new related phenomena can we explain, or have new questions about?* ✱

Add new questions. Display **slide DD**. Point out the prompt:

- *What new questions do we have about microwave radiation or related phenomena?*

Distribute 3" x 3" sticky notes and markers, and guide students to shift their conversation to adding new questions to the DQB. Have them take the lead in the discussion and posting process. If students struggle to take ownership of the DQB discussion, provide support by reminding them about how the routine is typically structured:

- Students take a couple minutes to write down new questions.
- Students gather around the DQB and take turns adding their new questions, quickly reading them aloud as they post them. Everyone should post at least one new question.
- Together, students consider what types or categories of questions are still unanswered. This includes creating new categories, if needed.
- Students use the DQB to suggest what we could look into next.

ASSESSMENT OPPORTUNITY	**What to look for/listen for in the moment:** • questions about related phenomena or technology (e.g., the Sun, a radio, a bad cell phone signal, an X-ray machine, something else that generates radiation) (SEP: 1.4; DCI: PS4.B.2, PS4.C.1) • questions that use energy and matter to seek a mechanistic explanation (e.g., "How does a

Remind students that their work throughout this unit has been a reflection of the Nature of Science: Scientists work to answer questions about natural phenomena, such as the way microwave ovens work. These questions motivate the need to use different methods, such as investigations, simulations, and discussions, to gather and evaluate data that could help us make sense of various phenomena. In this unit, students' questions have motivated a set of explorations to build and refine models that could explain how electromagnetic waves work.

✱ ATTENDING TO EQUITY

Universal Design for Learning: Use this opportunity to revisit or identify new examples of phenomena from students' own contexts. As we move into Lesson Set 2, the focus shifts from the microwave oven to other uses of EM radiation. Use unanswered questions about the Bluetooth speaker from the anchor phenomenon to help this shift in focus. Highlight examples that involve wireless data transfer in students' everyday lives. This can increase student *engagement* by broadening the class mission to explain not only the microwave oven phenomena but also other familiar, everyday phenomena related to EM radiation.

microwave oven transfer energy to food?") (SEP: 1.4; CCC: 5.2)

- questions about how distance affects microwave radiation or wireless signals (SEP: 1.4; DCI: PS4.B.2, PS4.C.1)
- questions about how electromagnetic radiation may be dangerous (SEP: 1.4; DCI: PS4.B.2)
- questions about other types of electromagnetic radiation and their uses, and the structure of devices that use them (SEP: 1.4; DCI: PS4.C.1, CCC: 6.2)

What to do: Remind students about the resources they can look at to help them generate new questions, including their models in their Progress Trackers, the updated Class Consensus Model poster constructed today, and the Related Phenomena and Technology poster from Lesson 1.

Building toward: 8.C Ask questions about the structure and function of technologies and phenomena that rely on electromagnetic radiation (including energy transfer). (SEP: 1.4; CCC: 5.2, 6.2; DCI: PS4.B.2, PS4.C.1)

17 · NAVIGATE: COMPLETE AN ELECTRONIC EXIT TICKET

8 min

MATERIALS: computer with access to https://docs.google.com/forms/d/1mELxWc9sPbhlNn6Fob7wwDkUiJsLm_n6AjEe-lMW2vY/copy

Complete an Electronic Exit Ticket. Present **slide EE**. Direct students to complete the Electronic Exit Ticket at https://docs.google.com/forms/d/1mELxWc9sPbhlNn6Fob7wwDkUiJsLm_n6AjEe-lMW2vY/copy individually on computers.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment: Use *Electronic Exit Ticket Key* to assess student work.

What to do: This assessment is designed to make it easy to gather information about where students are still struggling to put the pieces together. It assesses lesson-level performance expectations from Lessons 7 and 8.

Building toward:
7.A Develop and revise a model to illustrate absorption of microwave radiation as movement of charged particles in response to particle-level forces from changing electric fields. (SEP: 2.3; CCC: 2.2; DCI: PS2.B.2, PS4.B.2)

7.B Evaluate multiple claims from advertisement media to determine the validity and reliability of claims made about the relationship between the structure, shape, and molecular substructure of aluminum foil and its interaction with electromagnetic radiation. (SEP: 8.4; CCC: 6.2; DCI: PS2.B.2)

8.A Develop, revise, and use a model of energy, matter, and forces in wave interactions through space to explain how the structure of the microwave oven is designed to use reflection and constructive/destructive interference of electromagnetic waves that cause patterns of varied amounts of energy being transferred to materials (effect) without creating or destroying energy. (SEP: 2.3; CCC: 2.2, 5.2, 5.3, 6.2; DCI: PS4.A.3, PS4.B.1)

8.B Collaboratively revise a model of a microwave oven to explain how the components of the system function to heat food, and how and why these structures could affect a Bluetooth signal. (SEP: 2.3; CCC: 5.2, 6.2; DCI: PS4.A.3, PS4.B.1, PS4.B.2, PS4.C.1)

8.C Ask questions about the structure and function of technologies and phenomena that rely on electromagnetic radiation (including energy transfer). (SEP: 1.4; CCC: 5.2, 6.2; DCI: PS4.B.2, PS4.C.1)