Lesson 10: Does all electromagnetic radiation cause damage?

Previous Lesson	*We examined the remaining categories of questions on the Driving Question Board. We constructed the EM spectrum using the wavelength and frequency of various types of EM radiation. We wrote 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 added new questions to the DQB, including why certain EM radiation types harm living organisms and others do not.*
This Lesson Investigation 2 days	Tho-Ge, Pixabay We sort cards to identify the wave properties that characterize harmful EM radiation. We use various data sources to identify the pattern of increased frequency and increased cancer risk. We use a water wave analogy to explain this pattern but find the wave model insufficient. We analyze a photon model, develop our own analogies of the model, and compare the model with our evidence. We determine that the photon model better explains this behavior of EM radiation.
Next Lesson	*We will wonder how EM radiation can be used to create and store digital images. We will read about how the interactions of X-rays with matter can be harnessed to create images of the internal structure of our body, and the advantages and disadvantages of digital and conventional radiography. We will wonder about how EM radiation is used in wireless communication to transmit information.*

BUILDING TOWARD NGSS

HS-PS2-5, HS-PS4-1, HS-PS4-2, HS-PS4-3, HS-PS4-4, HS-PS4-5, HS-ESS2-4

What students will do

10.A Use data about the effect of EM radiation on human beings and solar cells to look for patterns at a macroscopic scale to revise our working explanation of the types of EM radiation that can cause damage to living cells. (SEP: 4.5; CCC: 1.1; DCI: PS4.B.2)

10.B Evaluate the merits of the wave and photon models of EM radiation to determine which reasoning better explains how high-frequency EM radiation can cause ionization of atoms and emission of electrons from a solar cell. (SEP: 7.2; CCC: 2.2; DCI: PS4.B.1, PS4.B.2, PS4.B.3)

What students will figure out

- Some radiation is ionizing and some radiation is not.

- The photons of high-frequency EM radiation have enough energy to knock out electrons of atoms and molecules, turning them into ions with different chemical properties.
- The photons of visible EM radiation or higher frequency have enough energy to cause emission of electrons from photovoltaic materials in solar cells.
- Ionizing radiation can cause changes in the structure of the DNA molecule, potentially altering its function.
- More high-frequency ionizing radiation puts you at greater risk of cancer, but how much the risk increases depends on the type of radiation and the total exposure time.
- The photon model of EM radiation can better explain the interactions of high-frequency EM radiation and matter.

Lesson 10 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	10 min		**NAVIGATE** Turn and talk about the relationship between high frequency of EM radiation and its ability to cause damage. Sort the *Unknown material with identifier: pr.l9.ref* in small groups. Share ideas about how wave properties might affect energy transfer through a wave.	A-C	*Unknown material with identifier: pr.l9.ref*
2	6 min		**USE A SLINKY TO COMPARE INCREASES IN FREQUENCY AND AMPLITUDE** Use a slinky to determine whether increasing frequency and/or amplitude increases the energy of a wave.	D-E	slinky station from Lesson 3, painters tape
3	4 min		**DETERMINE WHAT INCREASES IN ENERGY LOOK LIKE IN A LIGHT WAVE** Compare light and sound waves to determine that an increase in amplitude is an increase in brightness of a light wave and loudness in a sound wave, and an increase in frequency is a change in wavelength for both waves.	F-G	
4	10 min		**GATHER DATA ABOUT FREQUENCY, AMPLITUDE, AND SKIN CANCER RISK** Read articles about benefits and risks of IR, visible light, UV, and X-rays. Categorize information based upon frequency and amplitude to determine which type of radiation increases skin cancer risk.	H	*Amplitude/Frequency Evidence*
5	5 min		**COLLECT DATA ON SOLAR CELL OUTPUT** Look for patterns in a video about solar cell output at different frequencies and amplitudes of EM radiation.	I-J	*Amplitude/Frequency Evidence*, https://youtu.be/XFbCcjvIZhs
6	5 min		**LOOK FOR PATTERNS IN FREQUENCY AND AMPLITUDE DATA** Discuss patterns in the charts. Share out any new questions.	K	*Amplitude/Frequency Evidence*, sticky notes, markers, Driving Question Board
7	5 min		**NAVIGATE: COMPLETE AN EXIT TICKET** Complete an exit ticket about what wave property changes cause more damage to humans, and what details are needed to figure out what makes that type of light more damaging.	L	8.5” x 11” paper
					End of day 1
8	3 min		**NAVIGATE**	M-N	

			Review exit tickets and determine what we need to know about waves to explain why a higher frequency causes more damage.		
9	10 min		**READ ABOUT AND DISCUSS A WATER WAVE ANALOGY** Read about a water wave analogy. Answer questions to determine that this analogy does not match our evidence about amplitude and frequency.	O-P	*Radiation Wave Analogy*
10	12 min		**INTRODUCE THE PHOTON MODEL** Consider a new model of EM radiation as particles called photons.	Q-S	*Photon Model*
11	8 min		**SHARE WITH PEERS AND PROVIDE FEEDBACK** Share ideas about which model better explains which evidence, and get feedback from others on these ideas.	T	*Photon Model*, chart paper, markers
12	10 min		**COME TO CONSENSUS ON MERITS OF THE TWO MODELS** Share ideas about which model better explains which evidence, and record consensus ideas on a poster. Add definitions to Personal Glossaries.	U-V	*Photon Model*, chart paper, markers
13	2 min		**NAVIGATE** Revisit the Driving Question Board to reveal remaining questions about how other devices that use EM radiation work, such as the Bluetooth speaker.	V	Driving Question Board

End of day 2

Lesson 10 • Materials List

	per student	per group	per class
Lesson materials	• science notebook • *Amplitude/Frequency Evidence* • 8.5” x 11” paper • *Radiation Wave Analogy* • *Photon Model*	• *Unknown material with identifier: pr.l9.ref* • slinky station from Lesson 3 • painters tape	• https://youtu.be/XFbCcjvIZhs • sticky notes • markers • Driving Question Board • chart paper

Materials preparation (20 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.

Prior to day 1, make sure you have enough copies of *Unknown material with identifier: pr.l9.ref* from Lesson 9 for groups to sort the cards.

Prior to day 1, re-create enough slinky stations from Lesson 3 so each group of 5 students can use one.

Prior to day 1, open windows/tabs for https://youtu.be/XFbCcjvIZhs. You will use this video on day 1.

Prior to day 2, have a piece of chart paper ready to create a poster that will have the wave model on the left side and the photon model on the right side.

Lesson 10 • Where We Are Going and NOT Going

Where We Are Going

In previous lessons, students figured out that frequency and amplitude influence the energy a wave can transfer. In this lesson, they build on this idea to investigate why high-frequency EM radiation can cause damage to the matter it interacts with.

This lesson provides an opportunity for students to use disciplinary core idea (DCI) PS4.B.1 to explain PS4.B.2:

- 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.
- PS4.B.3: Photovoltaic materials emit electrons when they absorb light of a high-enough frequency.

Students encounter evidence that higher frequency (shorter wavelength) radiation is linked to increases in skin cancer due to the ionization of atoms. They compare this to their past experiences regarding the energy of a wave--that energy increases when frequency and/or amplitude increases. At first, they cannot explain why higher frequency matters. They look to a water wave analogy to try to explain the process of ionization, but realize that this analogy does not explain the increases in energy associated with frequency.

Students then read about the photon model and consider other analogies that can be used along with the photon analogy. Although both models are currently accepted and have merit, there are limitations to using the wave model to explain how EM radiation ionizes atoms and causes damage to cells. Students evaluate the advantages and disadvantages of using a photon model and a wave model to explain why time of exposure and frequency influence the probability of developing cancer, and determine that a photon model can better explain this behavior of EM radiation.

Students encounter or co-develop definitions for *ionizing radiation, photon,* and *photovoltaic material.* **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 do reach the conclusion that light must come in particles or “packets”, but they do not use the term *quantum* to describe this phenomenon. Although this conclusion is consistent with the “quantum hypothesis” that set off the quantum revolution in 1900, further ideas from quantum mechanics are not key concepts that students need in order to explain why high-frequency EM radiation can knock out electrons from atoms and molecules.

LEARNING PLAN for LESSON 10

1 · NAVIGATE

10 min

MATERIALS: science notebook, *Unknown material with identifier: pr.l9.ref*

Connect wave frequency and damage. Say, *I looked through your exit tickets, and you had a lot of ideas about where to go next. Many of you wrote about investigating how radiation can hurt us, and whether technology using radiation might be dangerous. This is something we wondered about last time. Now that we have figured out a lot about EM radiation, let's take a minute to hypothesize based on what we know.*

Present **slide A**. Have students use the prompt to turn and talk about the relationship between high frequency and EM radiation's ability to cause damage. After a minute, elicit ideas using the table below.

Suggested prompt	Sample student response	Follow-up question
Why do we think some forms of EM radiation (UV, X-rays, and gamma rays) would cause more damage than others?	Because a higher frequency means more energy is transferred from the wave.	*And how can more energy cause more damage?*

Accept all ideas about mechanisms without attaching your evaluation of those ideas.

Consider wave properties that might affect energy. Present **slide B**. Organize students into groups of 4. Distribute the *Unknown material with identifier: pr.l9.ref* to each group. Say, *We've figured out that the properties of a wave can help us explain how much energy it can transfer. Let's look back at these cards to find information about wave properties that could be related to how much energy they can transfer or the type of damage they can cause to the matter they interact with.*

Give groups about 5 minutes to go through the cards. As they work, walk around the room and assist as needed. Have students record their ideas in their science notebook.

Then elicit student ideas in response to the questions on the slide, as shown in the table below. Record these ideas, which should include frequency, wavelength, and amplitude, on the board. The goal of this navigation is to elicit student ideas about wave frequency and energy to consider how a higher level of energy transferred through a wave can affect matter.

Suggested prompt	Sample student response	Follow-up question
What type of damage do you think some of these types of EM radiation cause to the matter they interact with (e.g., microorganisms, cells)?	They destroy matter, microorganisms, and tumor cells.	*Have we explored how EM waves can damage or change matter?*
Which wave properties might influence how EM radiation interacts with matter?	EM radiation that causes damage has higher frequency and shorter wavelength. There is no information about amplitude. Speed is equal for all EM radiation, so it might not influence how much energy a wave transfers.	*How does this help us understand how some forms of EM radiation can cause more damage than others?*

After this discussion, say something like, *It seems that we have proposed some relationship between frequency and energy transfer and between amplitude and energy transfer. Because we can't see some types of EM radiation, let's think about waves that we can more easily study, like sound, string, or light waves. Do we think those waves also change in energy when their frequency or amplitude increases?*

Move on to **slide C**. Give students 3 minutes to discuss the questions in their groups and then ask them to share out, as shown in the table below.

Suggested prompt	Sample student response
Would changing the amplitude of any wave (sound, light, string) cause a change in the amount of energy that wave can transfer? Why?	Yes, because higher amplitude means larger forces are being transferred through the wave. If I increase the amplitude of a sound wave, it hurts my ears. There's definitely more energy because it's moving over a larger space.

Would changing the frequency of any wave cause a change in the amount of energy that wave can transfer? Why?	Yes, because higher frequency means that forces are transferring at a higher rate through the wave. We learned in middle school that increasing the amplitude or frequency of a sound wave increases the amount of energy.

Pose the slide's third question:

- *What do you think these changes might mean for an EM wave?*

Listen for students to say that both changes can lead to an increase in energy.

2 · USE A SLINKY TO COMPARE INCREASES IN FREQUENCY AND AMPLITUDE

6 min

MATERIALS: slinky station from Lesson 3, painters tape

Determine the slinky's usefulness to study changes in energy. Project **slide D**. Say, *It seems like we think increasing the frequency or increasing the amplitude will increase the wave's energy. I have our slinkies from the wave investigation in Lesson 3. How could we use these to figure out whether increasing the frequency or amplitude actually increases the energy of the wave?*

Listen for students to suggest that we can increase the frequency and the amplitude of the slinky wave to determine whether the wave is increasing or decreasing in energy.

Use the slinky to compare the energy of waves. Project **slide E**. Go over the instructions:
Stretch out your slinky. Make a low-amplitude, low-frequency wave. Consider the energy it takes to...

- *...increase the frequency of the slinky wave.*
- *...increase the amplitude of the slinky wave.*
- *...increase both amplitude and frequency together.*

Divide students into groups of 5. Explain that they will have 3 minutes to complete the investigations on the slide, and then 2 minutes to discuss the final question in their groups before sharing their observations and thoughts with the class.

Discuss results. After 5 minutes, have students share out. They should say that increasing the amplitude or frequency of the wave increased how much energy they had to use, and that increasing both at the same time led to a greater energy increase than increasing one alone. Ask them to consider which led to a greater increase--frequency or amplitude--and whether they believe light would behave in the same manner.

Then focus their attention on the slide's question:

- *Would we see the same patterns in light waves?*

Ask students to talk in their groups, but do not have them share out at this point.

3 · DETERMINE WHAT INCREASES IN ENERGY LOOK LIKE IN A LIGHT WAVE

4 min

MATERIALS: None

Motivate identifying what it looks like to increase energy in a light wave. Say, *Light and sound are waves, and we've talked about increasing their frequency and amplitude. But what would it look like to increase or decrease the frequency or amplitude of a visible light wave?*

Compare increasing the energy of light and the energy of sound. Project **slide F**. Give students 1 minute to talk to a partner about the prompt:

- *How might increasing the amplitude and frequency of light be like increasing the amplitude and frequency of sound?*

Bring the class back together and discuss what increasing the frequency and amplitude of light would look like. Example prompts and responses are in the table below.

Suggested prompt	Sample student response	Follow-up question
What does it sound like to increase the amplitude of a sound wave?	The sound gets louder.	*Does that make sense with what we just saw with our slinkies?*
How might increasing the amplitude of a light wave be like increasing the amplitude of a sound wave? What might increasing the volume of light look like?	It might be light getting brighter, like adjusting the brightness on the flashlight.	*Would decreasing the amplitude make it dimmer?* *If we make a light dimmer, does that mean that the waves have more or less energy?*

So what can we say it means to increase the amplitude of light?	It means the light gets brighter.	*Does that mean that the wave has more or less energy?*
What does it sound like when we increase the frequency of a sound wave? How might that be like increasing the frequency of a light wave?	The pitch gets higher. It might be like the light getting higher, like changing colors or something. Increasing frequency changed the type of wave in our cards. Increasing frequency changes the type of wave.	*What does increasing the frequency do to the wavelength of the light?*

Recap our conclusions about increasing light's frequency and amplitude. Say, *OK, if we're referring to increasing the amplitude of light, we're talking about making it brighter. If we're talking about increasing the frequency, we're making the wavelength smaller and moving to the right on the electromagnetic spectrum.*

Say, *Now that we know a bit more about what it means to increase the frequency and amplitude of light, let's consider our original concerns.*

Make predictions about increases in energy and the harm a wave can cause. Project **slide G**. Ask the class to silently consider the questions on the slide:

- *Do you think increasing the energy of a wave increases the risk of harm?*
- *If so, then what do you think causes more harm: an increase in amplitude or an increase in frequency?*

Have students share out their predictions. Accept all answers.

4 · GATHER DATA ABOUT FREQUENCY, AMPLITUDE, AND SKIN CANCER RISK

10 min

MATERIALS: *Amplitude/Frequency Evidence*

Introduce the articles. Say, *It seems like some of us think that if we increase the energy of a wave in one of these ways, or both ways, it might increase the risk of harm.* Tell students you have health and wellness articles that discuss the frequencies and amplitudes of various EM radiation technologies, their uses, and how they are or aren't correlated to increased risk of skin cancer.

✱ **ATTENDING TO EQUITY**

Universal Design for Learning: A focus question and subquestions are included in the *Amplitude/Frequency Evidence*. Focus questions help students *engage* in the task

Motivate tracking frequency and amplitude information. Ask, *How can we use these articles to make sense of whether increases in frequency or amplitude, or both, increase the risk of harm?* Guide students to determine that they can review the articles and keep track of the harm associated with the increased frequency and amplitude of various technologies.

Distribute the reading and review the table. Project **slide H**. Distribute the *Amplitude/Frequency Evidence* to each student and direct their attention to the instructions on the slide. Preview the reading and point out the table for recording the information they find. ✱ Give students 10 minutes to complete this table in pairs. Use the *Radiation Chart Key* as a guide for what information they should add over the course of this class period.

If students have trouble keeping track of the different frequency ranges of EM radiation types, direct them to the images to the right of each section in the reading. The curved line on the graph shows the approximate emission spectrum of our Sun, but this detail isn't crucial to student understanding.

ADDITIONAL GUIDANCE	While students read, direct attention to the facts that (a) the Sun emits a wide variety of frequencies and (b) specific technologies tend to emit a specific range of frequency, such as IR, visible light, UV, or X-rays. The graph of the Sun's emission spectrum is most commonly labeled with "intensity" versus frequency. But instead of introducing a new term to make sense of, we label the axes as amplitude versus frequency; as intensity is proportional to the square of the amplitude, this iteration of the graph is still useful for students.

and remember the goals they have established for use of the handout. Further periodic questions help them create short-term comprehension objectives that guide them toward the overall goal of the handout.

5 · COLLECT DATA ON SOLAR CELL OUTPUT

5 min

MATERIALS: *Amplitude/Frequency Evidence*, https://youtu.be/XFbCcjvIZhs

Consider collecting more data. Display **slide I**. Say, *The reading mentioned that radiation can ionize particles, which can cause damage.* Pose the questions on the slide:

- *What other measurements might show us more evidence about how different amplitudes and frequencies of EM radiation interact with matter?*
- *What might we see by testing different frequencies and amplitudes?*

Listen to multiple students' suggestions, and acknowledge them as valid and interesting. If students don't mention solar cells specifically, transition to sharing your own idea alongside theirs, and say, *I do have a video of measurements using a solar cell. It's not exactly the same as the ideas that you all mentioned, but do you think it will be relevant anyway?*

If they do mention solar cells, acknowledge this idea alongside the others. Press students for details about what they would expect to see in the experiments they suggested. Then say, *I do have a video of measurements using a solar cell. Let's check it out.*

Show the solar cell video. Project **slide J**. Give the class a moment to record each data source on the slide in their tables. Show the Solar Cell Demonstration at https://youtu.be/XFbCcjvIZhs. While showing the video, pause after each light is used with the solar cell, and ask students what they noticed about the electric current. Give them time to record their data.

6 · LOOK FOR PATTERNS IN FREQUENCY AND AMPLITUDE DATA

5 min

MATERIALS: *Amplitude/Frequency Evidence*, sticky notes, markers, Driving Question Board

Discuss patterns in the data. Display **slide K**. Lead a Consensus Discussion using the prompts:

- *What patterns do we notice about how EM radiation of high/low frequency and high/low amplitude impacts matter?*
- *Which causes greater skin cancer risk in humans?*
- *Which causes greater electron flow from a solar cell?*
- *Can we explain these patterns?*

KEY IDEAS

Purpose of this discussion: Determine patterns that exist between increases in frequency and amplitude and (a) skin cancer risk and (b) electron flow from a solar cell.

Listen for these ideas:

- The table shows a pattern of increases in frequency and increases in the possibility of skin cancer. Higher frequency ionizing radiation, such as UV and X-rays, contributes to cancer risk.
- The table shows that the solar cell only emits electrons when the EM radiation is visible light frequency or higher.
- There isn't a clear pattern that shows high amplitude alone contributes to an increased skin cancer risk or increased solar cell output.
- High frequency and high amplitude together seem to have a greater effect on matter than increases in frequency alone.
- We cannot explain why an increase in the frequency of EM radiation would increase the radiation's energy more than an increase in amplitude.

During the discussion, prompt students to identify where in the text they found their information. Remind them that the discussion is meant to pull out key information from the article and determine any patterns that have emerged about the frequency and amplitude of light in relation to (a) increased cancer risk and (b) electron output from a solar cell. See the *Radiation Chart Key* for an example of what data to use to lead this discussion.

Share any new questions. To close the conversation, ask whether students have any new questions. If they do, prompt them to share the question with the class, record it on a sticky note, and quickly add it to the Driving Question Board.

ADDITIONAL GUIDANCE	In *OpenSciEd Unit B.3: Who gets cancer and why? What can we do about it? (Cancer Unit)*, students explored various factors that impact the chances of developing cancer in humans. Use ideas about the cellular-level mechanisms students bring to establish connections between the interactions of ionizing radiation and genetic material. For example, you can ask: • *Could exposure to ionizing radiation throughout life help explain the increased risk of skin cancer with age?* • *Can lifestyle choices and environmental factors influence the impact of ionizing radiation on cancer development across different age groups?*

7 · NAVIGATE: COMPLETE AN EXIT TICKET

5 min

MATERIALS: 8.5" x 11" paper

Say, *We've learned a lot today about the role of increasing frequency and amplitude of EM radiation and the chances of damage. Let's take a moment to capture some of our thinking, and consider what data we still need to explain our findings.*

Assign the exit ticket. Project **slide L**. Distribute a piece of paper to each student. Direct them to complete the exit ticket by answering the questions on the slide:

- *Which causes greater changes in matter (humans and/or solar cells): high amplitude or high frequency?*
- *What evidence do we have from class to support your answer?*
- *What other details would we need to figure out why we see this pattern?*

Have students turn in their exit ticket at the end of class. Explain that next time, we will look into what data we think we need to figure out why some changes to a wave's energy increase the risk of skin cancer and some do not.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment:

- The risk of damage increases when both amplitude and frequency are increased, but the pattern for frequency and damage is more consistent than the pattern for amplitude and damage. (CCC: 1.1)
- The slinky activity provided evidence for increased energy due to increases in amplitude and increases in frequency. (SEP: 4.5; DCI: PS4.B.2)
- The information in the *Amplitude/Frequency Evidence*, solar cell data, and subsequent organization of data to identify patterns in the chart provide evidence that increases in frequency can increase damage. (SEP: 4.5; CCC: 1.1; DCI: PS4.B.2)
- Although there is evidence that increased energy through frequency increases can cause more damage through the emission of electrons, students cannot explain--based upon the evidence and their slinky activity--why an increase in frequency causes more damage than an increase in amplitude. (SEP: 4.5; DCI: PS4.B.2)

What to do:

If students do not make connections between the patterns of frequency and the changes in matter (cancer in humans and electron output in solar cells):

- Direct them to mark the boxes that have increases in frequency and damage in one color and the boxes that have increases in amplitude and damage in another color.
- Prompt them to compare the markings and determine which change in energy seems to have the larger effect.

If students do not cite their evidence:

- Direct them to go back and highlight sections that helped them answer their questions.
- Prompt them to think about the solar cell demonstration and consider any patterns from that as well.

If students do not consider what they cannot explain:

- Prompt them at the beginning of day 2 to consider how much energy they felt they needed to put into the slinkies to increase frequency, then to increase amplitude, then both.
- Ask them to compare what they felt moving the slinky to the information in the chart, and to try to explain the frequency increase patterns in the chart.

Building toward: 10.A.1 Consider qualitative data about the effect of EM radiation on human beings and solar cells, to look for patterns in evidence at a macroscopic scale to evaluate our current explanation of energy in different frequencies and amplitudes. (SEP: 4.5; CCC: 1.1; DCI: PS4.B.2)

End of day 1

8 · NAVIGATE

3 min

MATERIALS: None

Revisit exit ticket responses. Display **slide M**. Say, *Last time, we completed an exit ticket about what kinds of data we would need to figure out why a higher frequency wave could cause skin cancer but a lower frequency wave didn't seem to cause that damage.* Pose the question on the slide:

- *What other details would we need in order to figure out why a higher frequency results in more damage?*

Listen for students to say:

- We would need to know what is special about a higher frequency versus a higher amplitude.
- We would need to know what happens when the damage occurs, and how a wave can cause damage.

Consider how analogies can be helpful in sensemaking. Display **slide N**. Say, *One way to evaluate a model more deeply is by using an analogy.* Ask students to turn and talk about the prompts on the slide. After a minute, elicit 1-2 ideas as shown in the table below.

Suggested prompt	Sample student response
What sorts of analogies could apply to our wave model of EM radiation?	We could think about damage done by other waves, like water waves or sound waves.
What details would this analogy need to contain?	We would need to think about higher amplitudes and higher frequencies, and which causes more damage.

9 · READ ABOUT AND DISCUSS A WATER WAVE ANALOGY

10 min

MATERIALS: *Radiation Wave Analogy*

Introduce a water wave analogy. Display **slide O**. Distribute the *Radiation Wave Analogy* handout to each student and ask them to read Part A with a partner. Explain that they will answer Questions 1-4 in Part B to consider what the water wave analogy can and cannot explain about our evidence. ✱

ADDITIONAL GUIDANCE	Students may find the water wave analogy intuitive, but the point of bringing it up here is to "break" our model. To motivate the transition to the *Photon Model*, students must be convinced that the water wave model does not match our evidence about skin cancer and solar cell output. Use the questions on **slide O** to guide them to this conclusion.

ASSESSMENT OPPORTUNITY	**What to look for/listen for in the moment:** ● A water wave analogy is useful because the frequency and amplitude of water waves affect energy just like EM radiation, and both water waves and EM radiation transfer energy. (SEP: 4.5) ● The water wave analogy doesn't match the patterns in our qualitative evidence because larger amplitude waves would destroy the sandcastle more quickly than higher frequency waves. (SEP: 4.5; CCC: 1.1) ● The patterns in the data about EM radiation suggest that UV frequencies or higher are needed to cause skin cancer in humans and visible light frequencies or higher are needed to cause electrons to emit from a solar cell. For both, the patterns show that amplitude only matters if frequency is high enough. (SEP: 4.5; CCC: 1.1; DCI: PS4.B.2) ● See the *Wave Analogy Key*. **What to do:** If students do not see the conflict between the water wave analogy and the qualitative evidence in Questions 1-4, ask questions such as the following: ● *What types of water waves would we expect to destroy the sandcastle: high amplitude or high frequency?* ● *What type of EM radiation increases skin cancer risk: high amplitude or high frequency?* ● *What does this say about our wave model of EM radiation?* If they do not bring up the solar cell evidence, plan to point out this connection explicitly in Part 2 of the *Photon Model*.

✱ SUPPORTING STUDENTS IN ENGAGING IN DEVELOPING AND USING MODELS

A central aspect of modeling is the idea that models have merits and limitations. In discussion of the water wave analogy, encourage students to wrestle with this idea directly. Say, *The wave model of EM radiation is clearly valuable--it's helped us figure out so much. But this new data about skin cancer and solar cells suggests that it's not always useful for explaining all things about the radiation's behavior.*

✱ SUPPORTING STUDENTS IN ENGAGING IN DEVELOPING AND USING MODELS

Remind students here about the Nature of Science: Scientific Knowledge Is Open to Revision in Light of New Evidence. You can mention that historically, scientists believed light was purely a wave phenomenon, but as with our experience, this model did not match their observations, which led them to revise their ideas about the behavior of light.

Building toward: 10.A.2 Consider qualitative data about the effect of EM radiation on human beings and solar cells, to look for patterns in evidence at a macroscopic scale to evaluate our current explanation of energy in different frequencies and amplitudes. (SEP: 4.5; CCC: 1.1; DCI: PS4.B.2)

Lead a Building Understandings Discussion of the wave model's limitations. Display **slide P**. Conduct a discussion using the table below. ✱

Suggested prompt	Sample student response
Do the patterns we noticed match your prediction for the water wave analogy with skin cancer risk?	No--the water wave does more damage with higher amplitude, but the evidence shows more skin cancer risk from higher frequencies, like UV and X-rays.
What about the patterns in solar cell output?	It's the same problem. The solar cell only puts out electrons with visible light or higher. For lower frequencies like IR, the amplitude doesn't matter.
What does this say about our wave model of EM radiation?	It means that it's wrong. It means that it doesn't always work. I don't know--I thought we've been saying EM radiation is a wave this whole time.
How do you think scientists deal with situations where new evidence doesn't quite fit their current model?	Maybe they don't use that model, or they look for a new model. Maybe they revise that model.
If we were to look at a new model, what kind of data would we want to look for?	We would need to look at increases in frequency and amplitude and the energy of the wave. We would need to see if it could explain why frequency increases would lead to ionization.

10 · INTRODUCE THE PHOTON MODEL

12 min

MATERIALS: *Photon Model*

Consider the photon model as a class. Display **slide Q**. Distribute the *Photon Model* handout to each student. Tell them to consider what they notice about the pictures, and briefly ask them to share out. Listen for ideas such as:

- The light comes in particles.
- The particles have wavy lines inside them.
- The higher the frequency, the higher the energy.
- The particles can reflect, absorb, or transmit.

Ask for a volunteer to read the first paragraph of the handout aloud. If you think your students would benefit, continue to have more volunteers read the entire first page aloud.

Identify features that differ from the wave model. Display **slide R**. Explain that we will continue to analyze this photon model to see if it can better explain the increases in frequency linked with the ionization of atoms. Tell students to work with a partner to read the rest of Part 1 and answer Question 1 in the table. Tell them they can go on to Part 2 and 3 when both partners are ready.

Observe students' work on Question 1. As pairs work, circulate around the room and look at responses to Question 1. Try not to "correct" their thinking--instead, check in with a question if it looks like anyone is stuck. If partners aren't writing much, check in to confirm that they understand the assignment. For example, say, *Are you clear on what the table for Question 1 is asking? Look closer at this first diagram--try using this image to describe high amplitude and high frequency for the wave model and the photon model.*

Observe students' work on Question 2. If partners are having difficulties identifying ideas from the text, consider asking a few groups to share parts of the text they highlighted. See *Photon Model Key* for ideas that students might highlight.

Use students' work to gauge when most of the class is ready to move on to Question 3. Question 3 will be the focus of the discussion that concludes this lesson, so for all students to participate, it's worth ensuring that they think through it as partners first.

Transition to Questions 3 and 4. Display **slide S**. Say, *In a few minutes we'll transition to getting peer feedback for our ideas on Questions 3 and 4. If you haven't started Part 3 yet, go there now. If you've already thought through Question 3, move on to Question 4 so you can get feedback on those ideas also.*

✱ ATTENDING TO EQUITY

Universal Design for Learning: The creation of a new analogy in Question 4 on the handout allows students to *engage* with the ideas around frequency, amplitude, and the two models for EM radiation. As they create analogies, they use their imagination and past experiences to make sense of complex ideas in creative ways. This approach also recruits interest from students and helps them make connections to how the information is valuable and relevant to their goals of explaining why high-frequency EM radiation can cause damage.

In many cases, the most productive work students can do with an analogy is to build it themselves, and think about the conditions in which it does and doesn't apply. If they have trouble making the distinction between the two models, give them more time to discuss and share possible analogies.

Consider which model better explains the evidence. As pairs work through Question 3, glance at the model they circle for each example and why. They should answer as follows:

3a. Evidence we have seen about **cold spots from destructive interference in the microwave oven** is best explained by a **wave model** because *waves can interfere and cancel out.*

3b. Evidence we have seen about **high-amplitude IR not emitting electrons from photovoltaic material** is best explained by a **photon model** because *IR photons don't have enough energy to eject electrons, so the solar cell just heats up.*

3c. If students have trouble coming up with other examples of evidence, suggest the following:

- Antenna electrons move in response to a radio wave (wave model preferred).
- Water heats up in the microwave oven, but plastic doesn't heat up (wave model preferred).
- Microwave radiation reflects off of a metal surface (both models work).
- A light bulb lights up in the microwave oven (both models work).
- X-rays and gamma rays can be dangerous, even in small amounts (photon model preferred).
- Sunshine can increase skin cancer risk, but a UV filter can reduce this risk (photon model preferred).

Make sure to provide time for students to develop their analogies in Question 4. ✱

ASSESSMENT OPPORTUNITY	**10.B.1 What to look for/listen for in the moment:** See 10.B.2 and the *Photon Model Key*. **What to do:** If students have trouble distinguishing between the two models in Question 3a and 3b on the handout, consider spending more time with these ideas leading up to the class discussion. Use the peer feedback protocol on **slide T** and encourage students to push each other's thinking. If they struggle to create an analogy, consider presenting a partial analogy or allowing a partner pair to share their analogy, prompting others to think of how other instances might relate to the photon model. **Building toward: 10.B.1** Evaluate the merits of the wave and photon models of EM radiation to determine which reasoning better explains how high-frequency EM radiation can cause ionization of atoms and emission of electrons from a solar cell. (SEP: 7.2; CCC: 2.2; DCI: PS4.B.1, PS4.B.2, PS4.B.3)

11 · SHARE WITH PEERS AND PROVIDE FEEDBACK

8 min

MATERIALS: *Photon Model*, chart paper, markers

Form small groups of 4 and exchange feedback. Display **slide T**. Draw students' attention to the instructions on the slide. Circulate around the room as the groups share. Allow them to ask questions first, but if they are hesitant to contribute, model the question starters in your own questioning:

- *What represents ionization in your analogy?*
- *What objects absorb and emit photons? How is that similar to or different from the water wave analogy?*
- *What represents changes in frequency and amplitude? How is that similar to or different from the water wave analogy?*

Listen for groups who make connections between the evidence and their models. Identify 1-2 of these groups, point out that their explanation will be useful to share with the class, and ask their permission to present their models to the class on the next slide.

If no group's members are sharing analogy ideas with each other, don't press this point. If some groups come up with a particularly memorable or insightful analogy, encourage them to share it with the class early in the next consensus discussion.

As students finish giving each other feedback, prepare a piece of chart paper with a line down the middle. Write "Wave Model" on the left side and "Photon Model" on the right, as shown on **slide U**.

12 · COME TO CONSENSUS ON MERITS OF THE TWO MODELS

10 min

MATERIALS: *Photon Model*, chart paper, markers

Work toward consensus on what each model explains. Display **slide U**. Say, *I heard a lot of great discussion about which evidence is best explained by which model. Let's come to consensus on that, so we have a record for these two models going forward.*

Start with the two examples of evidence in Questions 3a and 3b. Ask for a volunteer to read the evidence out loud, and then state which model their group decided worked better for explaining it.

Press for an explanation that references an appropriate model. Ask, for example, *Did everyone agree that the (photon model) was better for explaining (why the high-amplitude IR radiation didn't cause the solar cell to emit electrons)? Who can explain why the (photon model) works better here, using details from the reading?* Continue this process for as much evidence as students are able to share.

ASSESSMENT OPPORTUNITY

10.B.2 What to look for/listen for in the moment:

- See the *Photon Model Key* for detailed responses.
- Some evidence, such as cold spots from destructive interference in the microwave oven, is better explained by a wave model, because waves can interfere and cancel out (Question 3a). (SEP: 7.2; DCI: PS4.B.1)
- Other evidence is better explained by a photon model. (SEP: 7.2; DCI: PS4.B.1)
- A photon model better explains why only visible light or higher frequency radiation can cause electrons to emit from photovoltaic material in a solar cell, because IR photons don't have enough energy to eject electrons (Question 3b). (CCC: 2.2; DCI: PS4.B.1, PS4.B.3)
- A photon model better explains why only UV or higher frequency radiation can cause ionization. (CCC: 2.2; DCI: PS4.B.1, PS4.B.2)
- Some evidence (reflection, water heating up in the microwave oven) can be explained by both models. (SEP: 7.2)

What to do: Press the class to connect evidence about ionization and solar cell electron output to the photon model. Use this discussion to check for understanding about the ionization and solar cell details outlined in the *Photon Model*. Ask students to use the photon model to explain, with details from the reading, why increasing the amplitude of the IR radiation did not cause more electron output from the solar cell.

If students cannot use a photon model to make sense of solar cell data:

- Ask them to describe two ways that the photon model can explain an increase in energy in EM radiation. *(Higher amplitude, higher frequency.)*
- Ask them to describe what happened to the electrons emitted from the solar cell when we increased the IR amplitude but not frequency. *(Zero electrons were emitted from the solar cell.)*

If students do not agree on which model is better for explaining certain pieces of evidence:

- Encourage them to try to convince each other of their position.
- Keep in mind that both a wave model and a photon model can be valid.

If students are stuck reasoning through an example:

- Ask them to share their analogy.
- Contrast the water wave analogy with a student-generated photon model analogy to help them consider the limitations and merits of both models.

Building toward: 10.B.2 Evaluate the merits of the wave and photon models of EM radiation to determine which reasoning better explains how high-frequency EM radiation can cause ionization of atoms and emission of electrons from a solar cell. (SEP: 7.2; CCC: 2.2; DCI: PS4.B.1, PS4.B.2, PS4.B.3)

Review the lesson question. After students have shared several examples of evidence, say, *We started our last class asking, "Does all electromagnetic radiation cause damage?" Can we answer that now?*

Record definitions. Present **slide V**. Ask students to jot down definitions for *ionizing radiation, photon,* and *photovoltaic material* in their Personal Glossaries, such as:

- Ionizing radiation: EM radiation that has enough energy to knock electrons out of the atoms and molecules of the matter it interacts with.
- Photon: a particle of EM radiation. The energy of each particle depends on the frequency of the radiation.
- Photovoltaic material: a material that converts EM radiation of visible light or higher frequency to electrical energy in moving electrons, like a solar cell.

13 · NAVIGATE

2 min

MATERIALS: Driving Question Board

Motivate a closer look at the use of high-frequency EM radiation. Continue projecting **slide V**. Direct the class to look back at the DQB. Point out that we still have questions about how other EM radiation devices work, such as the Bluetooth speaker. Tell students that we will need to dig deeper into how these devices work in our next class period.

Additional Lesson 10 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA	This is the CCSS for ELA/Literacy-related idea that is used to support sensemaking in this lesson: CCSS.ELA-LITERACY.RST.11-12.7 Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem. Students question whether increases in the energy of EM radiation through a higher frequency or higher amplitude contribute to an increased risk of skin cancer. They use evidence from the *Unknown material with identifier: pr.l9.ref*, health and wellness articles, and a solar cell video to find patterns, and determine that higher frequency EM radiation can cause skin cancer.