Electromagnetic Radiation

DEVELOPER: OpenSciEd

GRADE: High School **|** **DATE OF REVIEW:** June 2023

Educators Evaluating Quality Instructional Products

NextGen Science WestEd

Electromagnetic Radiation

EQuIP RUBRIC FOR SCIENCE EVALUATION

OVERALL RATING: E

TOTAL SCORE: 8

CATEGORY I: NGSS 3D Design Score	CATEGORY II: NGSS Instructional Supports Score	CATEGORY III: Monitoring NGSS Student Progress Score
2	3	3

Click here to see the scoring guidelines.

This review was conducted by the Science Peer Review Panel using the EQuIP Rubric for Science.

CATEGORY I CRITERIA RATINGS			CATEGORY II CRITERIA RATINGS			CATEGORY III CRITERIA RATINGS		
A.	Explaining Phenomena/ Designing Solutions	Extensive	**A.**	Relevance and Authenticity	Extensive	**A.**	Monitoring 3D Student Performances	Extensive
B.	Three Dimensions	Adequate	**B.**	Student Ideas	Extensive	**B.**	Formative	Extensive
C.	Integrating the Three Dimensions	Extensive	**C.**	Building Progressions	Adequate	**C.**	Scoring Guidance	Extensive
D.	Unit Coherence	Extensive	**D.**	Scientific Accuracy	Extensive	**D.**	Unbiased Tasks/Items	Extensive
E.	Multiple Science Domains	Adequate	**E.**	Differentiated Instruction	Extensive	**E.**	Coherent Assessment System	Extensive
F.	Math and ELA	Extensive	**F.**	Teacher Support for Unit Coherence	Extensive	**F.**	Opportunity to Learn	Adequate
			G.	Scaffolded Differentiation Over Time	Adequate			

Electromagnetic Radiation

EQuIP RUBRIC FOR SCIENCE EVALUATION

Summary Comments

Thank you for your commitment to students and their science education. NextGenScience is glad to partner with you in this continuous improvement process. The unit is strong in several areas, including the phenomena used to ground students' learning; scoring guidance for teachers that is clear, relevant, and targeted to each assessment; unit activities that unfold in a logical progression; the central role of safety considerations; and a strong system of assessments that would provide clear evidence of student learning over time.

During revisions, the reviewers recommend paying close attention to the following areas:

- **Claimed Elements of the Three Dimensions.** Consider adjusting either the claims or student activities to ensure closer alignment between claimed elements and student activities throughout the unit. Some Disciplinary Core Idea (DCI) elements claimed in the unit are not fully met by unit activities. Some claimed elements are used only once in the unit. For the Science and Engineering Practices (SEP) category of **Planning and Carrying Out Investigations**, much of this SEP is heavily scaffolded by the teacher. Students may therefore not have opportunities to develop this SEP and take more independence and ownership of it within the scope of the unit.
- **Fading scaffolds.** For the SEP categories of **Planning and Carrying Out Investigations** and **Developing and Using Models**, consider providing more clear and explicit reduction in scaffolding over the course of the unit, allowing students to use the SEPs more independently over time.
- **Connecting Crosscutting Concepts (CCC) across domains**. Consider providing explicit guidance for teachers to help students realize that CCCs are essential for sense-making and building on their work with CCCs from other units.
- **Supports for diverse learners**. While the reviewers found evidence of differentiation and scaffolding across lessons, more explicit and frequent strategies for learners with disabilities would strengthen the unit overall.

Note that in the feedback below, black text is used for either neutral comments or evidence the criterion was met, and purple text is used as evidence that doesn't support a claim that the criterion was met. The purple text in these review reports is written directly related to criteria and is meant to point out details that could be possible areas where there is room for improvement. Not all purple text lowers a score; much of it is too minor to affect the score. For example, even criteria rated as Extensive could have purple text that is meant to be helpful for continuous improvement processes. In these cases, the criterion definitely WAS met. The purple text is simply not part of the argument for that Extensive rating.

CATEGORY I

NGSS 3D DESIGN

I.A. EXPLAINING PHENOMENA/DESIGNING SOLUTIONS

I.B. THREE DIMENSIONS

I.C. INTEGRATING THE THREE DIMENSIONS

I.D. UNIT COHERENCE

I.E. MULTIPLE SCIENCE DOMAINS

I.F. MATH AND ELA

I.A. EXPLAINING PHENOMENA/DESIGNING SOLUTIONS

Making sense of phenomena and/or designing solutions to a problem drive student learning.

i. Student questions and prior experiences related to the phenomenon or problem motivate sense-making and/or problem solving.

ii. The focus of the lesson is to support students in making sense of phenomena and/or designing solutions to problems.

iii. When engineering is a learning focus, it is integrated with developing disciplinary core ideas from physical, life, and/or earth and space sciences.

Rating for Criterion I.A. Explaining Phenomena/Designing Solutions	Extensive

The reviewers found extensive evidence that learning is driven by students making sense of phenomena or designing solutions to a problem because materials are organized so that students are figuring out central phenomena: A microwave oven heated up liquid and food and affected music when a wireless device was inside the microwave oven. In the latter part of the unit, students apply their understanding of the structure and function of EMR used in microwave ovens to explain parallel technologies: medical devices and cell phones. However, Lessons 9–12 are not well-connected to either phenomena or problems.

Materials are organized so that students notice patterns when heating up food in a microwave oven and develop models for how the structure of a microwave oven affects energy transfer to the food inside of it and how it can affect wireless signals. Student questions about these phenomena drive learning and supports for teachers to draw out student questions are provided. There is also guidance on how to make student questions appear more authentic in generation as well as driving the learning. Students regularly return the microwave oven phenomenon to add layers of explanation, or regularly build on what they have learned from smaller phenomena or problems. Related evidence includes:

- Lesson 1: “Develop questions for the DQB. Present slide S. Distribute sticky notes, markers, and pencils to each student. Ask students to develop questions for the DQB on their own, using the resources listed on the slide…Once everyone has contributed to the DQB, ask, Can we articulate a main question that we will answer by investigating all of these questions? Listen for ideas like ‘How does technology that uses radiation work?’ or ‘Why does the structure of a microwave oven block wireless signals?’ When a potential driving question arises, repeat it aloud, and ask, Do you think that by answering this question, we will have answers to most of the questions on our Driving Question Board? Look for agreement using a show of hands, and then write the chosen question at the top of the DQB” (Teacher Edition, page 38).
- Lesson 1: The creation of a class consensus model (Teacher Edition, page 36) and Driving Question Board (Teacher Edition, page 38) serves as a public record of students’ prior

knowledge and their questions about the phenomenon, both of which are revisited during the unit. The class consensus model serves to draw out students' ideas and understanding and serves as a point for agreeing on what the students know related to matter, energy, and forces: "Elicit ideas about components" and "Elicit ideas about energy transfer and forces" (Teacher Edition, page 36).

- Lesson 5: Students use their Exit Tickets from Lesson 4 to predict how microwaves can heat food. "Explain that students will now have a chance to add, remove, or change new components and interactions in our class model for the control to explain our results with the solid or the hole-punched aluminum foil. Give students 4 minutes to revise the class model to explain the results from our tests" (Teacher Edition, page 123). "Develop investigation questions. Present slide I. Say, 'Now that we know what interactions we are uncertain about, let's see if we can frame some questions to guide the investigations, we want to design next period.' Give students a minute to consider what question best captures what we are trying to figure out about the microwave window and walls. Give students 2 minutes to record an investigation question in their notebooks. Ask for volunteers to share their questions and allow students to modify any questions they have in their notebooks. Tell students that we will have to test our microwaves and figure out the answers to these questions next class period" (Teacher Edition, page 112).
- Lesson 5: In the *Microwave Oven Investigation* it is asked, "What question are you trying to answer in the investigation you are planning?" There is guidance for the teacher to help with student questions aligning to the investigation. "At this point, the class will have questions about the door and walls/floor reflecting and/or transmitting microwave radiation. Determine how you would like to make groups to create these investigation plans that align with the student generated questions from the beginning of this class period and assign questions accordingly" (Teacher Edition, page 116).
- Lesson 6: After the microwave investigations of Lesson 5, students are prompted to ask new questions. "Distribute 2 sticky notes and a marker to each student and read the text on the slide: What new questions did you have at the end of last lesson? Get out your questions from the last lesson. Feel free to write any new questions you now have. Give students a couple of minutes to write questions on the sticky notes and to read/revise their prior questions, if they wish" (Teacher Edition, page 131). This leads to the next lesson where students investigate how microwave radiation heats up food.
- Lesson 6: "Say, We figured out a lot, but it seems at the end of the last lesson we were still curious about some of the interactions between the microwave radiation, the microwave oven, and the items inside the microwave oven. Let's share the questions we might have that can help us move our thinking forward. Distribute 2 sticky notes and a marker to each student and read the text on the slide: What new questions did you have at the end of last lesson? Get out your questions from the last lesson. Feel free to write any new questions you now have. Give students a couple of minutes to write questions on the sticky notes and to read/revise their prior questions if they wish. Share questions at the Driving Question Board. Present slide C. Invite students to add new questions to the DQB and categorize them. Read the instructions on the slide outloud[sic] to guide this task: Add any new questions to the corresponding category on the DQB. Quickly read them off and share as you post them. Consider what types or

categories of questions we still have left. What do they have in common?" (Teacher Edition, page 131)

- Lesson 8: "Now that we have revisited and revised our initial model, let's revisit our Driving Question Board as well. Mark patterns in questions answered using the sticky dots. Display slide BB. Continue with the Scientists Circle. Focus the discussion on identifying (1) questions we agree that we can answer, (2) questions that we have at least a partial answer to, and (3) questions we cannot answer at all. Choose one color of sticky dots to mark each of these categories. Distribute one set of the sticky dots to each student and allow them to come up to the DQB and add their stickies to DQB questions. Give students about 4 minutes to complete this task…Display slide DD. Guide students to shift their conversation to adding new questions to the DQB" (Teacher Edition, pages 173–174).
- Lesson 9: "Determine which group of questions on the DQB to answer next. Present slide A. Bring students in a Scientists Circle around the DQB. Have students spend a minute studying the questions on the slide: What category(ies) of DQB questions do we still have left to answer? How could we answer some of the questions for each of these categories? Ask for a few volunteers to share their ideas for the first prompt. Look for students to identify questions about other forms of electromagnetic radiation. Summarize student's ideas, and transition to the next slide by foregrounding one of these two categories, either say, It sounds like many of you think we have not answered questions about the existence and properties of other types of electromagnetic radiation, other than microwaves and light. OR It sounds like many of you think we have not answered questions about other uses of EM radiation, besides warming food (and sight)" (Teacher Edition, page 180).
- Lesson 10: "Drawing connections between frequency and damage. Present slide A. 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 this radiation might be dangerous. This is something we were wondering about last time. Now that you have figured out a lot about EM radiation, let's take a minute to hypothesize based on what we know" (Teacher Edition, page 194).

The focus of the unit is to support students in making sense of why a microwave oven blocks wireless signals and how it is able to heat up food. These phenomena drive the learning of the unit and in almost every lesson, students return to one or both of these phenomena to use their learning to make sense of them. Related evidence includes:

- Lesson 1: "Ask students to briefly look back in their notebooks at their observations, noticings, and wonderings. Elicit one or two ideas of observations that we are puzzled by. Then say, Let's see if we can make a model that will explain our observations and help us understand what we still need to know. Create initial models. Present slide J. Read the directions aloud: Make a model of the parts and interactions in the system that will explain: how the microwave oven heats up liquid and food why the music was affected when the device was inside the microwave oven, especially when the speaker was farther away Give students 10 minutes to work on their models individually in their notebooks" (Teacher Edition, page 35).

- Lesson 2: “Administer the exit ticket. Distribute a piece of paper to each student. Say, ‘On your exit ticket, use words or pictures to jot down your thoughts about the question on the slide: What do you think is happening between the magnetron antenna and the light bulb to transfer energy all the way across the microwave oven? We’ll use your ideas to figure out where we should investigate further’. Have students turn in their exit tickets as they leave class” (Teacher Edition, page 51).
- Lesson 5: Students use the microwave oven to consider different ways waves interact with materials. They use these ideas to plan an investigation considering the door and walls of the microwave oven using the microwave oven. After the investigations, they develop an energy transfer model utilizing that data. “Now that we have completed all of our investigations, let’s consider the data we have collected. Some of it may be surprising to us. Let’s try to explain what happened using modeling. Let’s model the control results together, then maybe we can use the control results to try and explain what happened with the bowls covered in solid and hole-punched foil” (Teacher Edition, page 122).
- Lesson 6: Substances heating up in the microwave oven is used to help develop a consensus model. “Brainstorm key components we would need in a consensus model that clearly explain: Why does water heat up in the microwave oven? Why doesn’t the microwave-safe plastic heat up in the microwave oven?...Apply our model to explain the behavior of aluminum foil in the microwave oven. Present slide O. Say, Let’s test the usefulness of our model by using it to explain another observation we have made about microwave ovens. Ask students to consider and respond to the prompts on the slide: Can our model help explain why aluminum foil is safer to use in the microwave oven under certain conditions but dangerous in others? Where could we look to find additional information about this?” (Teacher Edition, page 145).
- Lesson 8: Students see a demonstration of small light bulbs in the microwave oven to explore the pattern of hot and cold spots. “Organize students in groups of 3. Distribute posters, and read the prompt out loud: Develop a model, using words and drawings, to explain the patterns in the cheese and the little light bulbs. Give students 8 minutes to develop their models. Students will 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 their initial models to be fully correct” (Teacher Edition, page 161). This then drives the exploration of interference using the wave on a string simulation.
- Lesson 10: As students are introduced to the photon model and which model better explains different evidence, there is reference and connection back to the microwave oven. “Consider which model better explains the evidence. As students work through Question 3 in The Photon Model, glance at which model students circle for each example. 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…Water heats up in the microwave oven while 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)” (Teacher Edition, pages 203–204).
- Lesson 13: As the class is revisiting the DQB, there is prompting to consider the microwave oven as the driving phenomena and the investigations that came from it. “Remind students

here that their work throughout this unit has been a reflection of the nature of science: Scientists work to answer questions they have about natural phenomena, like the way microwaves work. These questions motivate the need to use different methods, like investigations, simulations, or discussions to gather and evaluate data that could help them make sense of different phenomena" (Teacher Edition, page 237).

- The wireless speaker demonstration with the microwave helps connect the anchoring phenomena to Lessons 9–12. However, it may not be explicit to students that the connection is being made between the speaker demonstration and the learning in those lessons. The teacher is prompted to ask, "Can we explain how EM radiation can be used for heating up food and sending information?" (Connection to the anchoring phenomenon)" and "Can we explain whether all EM radiation is safe for us?" (Teacher Edition, page 180) Some teachers may not use explicit verbiage to connect these prompts to the phenomena.

Suggestions for Improvement

- Consider adding guidance to connect the wireless speaker demo and questions that stem from it to the work done in Lessons 9–12. It might be helpful to put a note with suggested specific verbiage to connect the speaker demonstration after the questions asked in Step 1 of Lesson 9 on page 180.
- Consider adding a connection between the safety of EM radiation explored in Lessons 10–11 and the utilization of the safety manual of the microwave in Lesson 1 to better connect the lessons to the anchoring phenomena.

I.B. THREE DIMENSIONS

Builds understanding of multiple grade-appropriate elements of the science and engineering practices (SEPs), disciplinary core ideas (DCIs), and crosscutting concepts (CCCs) that are deliberately selected to aid student sense-making of phenomena and/or designing of solutions.

i. Provides opportunities to *develop and use* specific elements of the SEP(s).

ii. Provides opportunities to *develop and use* specific elements of the DCI(s).

iii. Provides opportunities to *develop and use* specific elements of the CCC(s).

Rating for Criterion I.B. Three Dimensions	Adequate

The reviewers found adequate evidence that the materials give students opportunities to build understanding of grade-appropriate elements of the three dimensions because students develop and use high school elements of all three dimensions in their sense-making of the unit phenomena. There is a reasonable match between the elements claimed in the "Elements of NGSS Dimensions" document and the student activities and prompts found in the unit, although some elements claimed are not used or developed.

Science and Engineering Practices (SEPs) | **Rating: Adequate**

The reviewers found adequate evidence that students have the opportunity to use or develop the SEPs in this unit. There are three SEPs with elements that are considered focal. They are described in the materials as "intentionally develops students' engagement in these practice elements" (Teacher Edition, page 15). However, the SEP of **Planning and Carrying out Investigations** is not explicitly used or developed from the perspective of the student. There are also a few elements that are not claimed as focal but are part of the claimed performance expectations that are developed in this unit (and not stated as across multiple units/courses).

Asking Questions and Defining Problems

- *Ask questions that arise from examining models or a theory, to clarify and/or seek additional information and relationships.*
    - Lesson 6: "Review what we learned about EM radiation and matter interactions. Present slide A. Start off the lesson with the prompts on the slide: What did we figure out in the last lesson about the ways that microwave radiation can interact with matter? How does this help us explain what happens to the microwave radiation when it reaches the metal walls, door, and water inside of the oven? Say, 'We figured out a lot, but it seems at the end of the last lesson we were still curious about some of the interactions between the microwave radiation, the microwave oven, and the items inside the microwave oven. Let's share the questions we might have that can help us move our thinking forward. Ask new questions. Present slide B. Distribute 2 sticky notes and a marker to each student and read the text on the slide: What new questions did you have at the end of last lesson? Get out your questions from the last lesson. Feel free to write any new questions you now have. Give students a couple of minutes to write questions on the sticky notes and to read/revise their prior questions, if they wish" (Teacher Edition, page 131).
    - Lesson 9: "Record new questions about EM radiation. Present slide P. Distribute one set of the sticky dots to each student and give them a minute to record any new questions they have about the different types of EM radiation. Add questions on the DQB. Present slide Q. Meet at the DQB in a Scientists Circle. Invite students to come up to the DQB and add their stickies to DQB questions. Similar to Lesson 3 and Lesson 8, encourage students volunteers to take over in facilitation of this DQB build" (Teacher Edition, page 187).
- *Ask questions to clarify and refine a model, an explanation, or an engineering problem.*
    - Lesson 1: "How well does your partner's model explain how the microwave oven functions to heat liquid and food? How well does your partner's model explain why the music was affected when the device was inside the microwave oven, especially when the speaker was farther away? Use sticky notes to indicate the areas where you have questions, and write your specific questions on the sticky notes" (Teacher Edition, page

13). Students use sticky notes to ask clarifying questions about their partners' models and explanations.
    - Lesson 4: "What questions did the simulation raise for you and your jigsaw group about how energy transfers from the antenna to distant electrons?" (Lesson 4, Visualization Handouts, Teacher Edition, page 93)
    - Lesson 8: "Now that we have revisited and revised our initial model, let's revisit our Driving Question Board as well. Mark patterns in questions answered using the sticky dots. Display slide BB. Continue with the Scientists Circle. Focus the discussion on identifying (1) questions we agree that we can answer, (2) questions that we have at least a partial answer to, and (3) questions we cannot answer at all. Choose one color of sticky dots to mark each of these categories. Distribute one set of the sticky dots to each student and allow them to come up to the DQB and add their stickies to DQB questions. Give students about 4 minutes to complete this task…Display slide DD. Guide students to shift their conversation to adding new questions to the DQB" (Teacher Edition, pages 173–174).

Developing and Using Models

- *Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationship between systems or between components of a system.*
    - Lesson 1: Students develop an initial model based on their prior knowledge and previous experiences to illustrate how energy transfers from components of the microwave oven to the food inside it. "Create initial models. Present slide J. Read the directions aloud: Make a model of the parts and interactions in the system that will explain: how the microwave oven heats up liquid and food, why the music was affected when the device was inside the microwave oven, especially when the speaker was farther away" (Teacher Edition, page 35). They revise the model after receiving peer feedback. "Use the handout to evaluate a partner's models. Distribute a copy of the Initial Modeling Peer Feedback handout, colored pens, and sticky notes to each student. Direct them to switch models with a partner to provide peer feedback. Point out the M-E-F poster as a reference" (Teacher Edition, page 35).
    - Lesson 3: Students use the M-E-F triangle to develop a model to explain how energy is transferred across the slinky particles when the wave moves through it (Teacher Edition, page 64) and how energy is stored in the slinky system (Teacher Edition, page 65).
    - Lesson 5: Students use the class model to make predictions about matter in the microwave oven. "What did you predict the EM radiation does when it encounters different types of matter that we might put in the microwave oven?" (Teacher Edition, page 108). There is guidance to help students connect their model to predictions Explaining What Happened. This connects to predicting the relationship between components of a system, "(1) Ask students to use their model to predict how different the data would be if we add a container of water partially wrapped with aluminum foil" (Teacher Edition, page 124).

- Lesson 7: Students use a model on a slide to predict components of the system (charges in a molecule). How do you predict the charge will be distributed in each of these molecules?" (Teacher Edition, page 140). Students use molecule representations (paper cutouts) and a simulation to illustrate relationships between components of a system. "Pass out one molecule cutout per student while they are working through the Turn and Talk. Encourage students to use the cutouts to consider how different charges would respond in the presence of an electric field. Say briefly, Try using these to help visualize what different parts of each molecule would feel in an electric field" (Teacher Edition page 141). "For each matter type, use the questions to connect the conclusions we reached about energy transfer at a macroscopic scale to the observations you made in the simulation. If you notice any limitations of your model or explanation, write a '?' to show this. What happens on a macroscopic scale to matter of each type when we expose them to EM radiation in the microwave oven? What particle-scale observations from the simulation help us to explain this observation?" (Lesson 7, Handout – Field Particle Interactions).
- Lesson 8: "Organize students in groups of 3. Distribute posters, and read the prompt out loud: Develop a model, using words and drawings, to explain the patterns in the cheese and the little light bulbs. Give students 8 minutes to develop their models. Students will 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 their initial models to be fully correct. As students are developing their models, use this opportunity as a pre-assessment moment of ideas that have been built throughout the unit and students should be including. Look for these key model ideas: Include the components of the microwave oven that influence energy transfer, such as the magnetron, the walls, or the objects inside. Cause and effect relationships that connect different parts of the model. Connections between the structure of the microwave 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 reflect off the walls of the microwave oven back into the cooking cavity. For a better understanding of the expectations of the revised models after learning about interference, look at the assessment guidance moment 8.A.2 at the end of day 2" (Teacher Edition, page 161). "Present slide U. Read the instructions for this task out loud: Revise your model, using words and drawings, to explain the patterns in the cheese and the little light bulbs. Be sure to include details about matter, energy, and forces in your model" (Teacher Edition, page 169). Students develop an initial model of how the components of the microwave oven system causes the pattern in heating they observed with the lightbulbs. Later, after learning about interference and receiving feedback from peers, the students revise their models and incorporate their new learning.
- Lesson 8: "Have students gather in a Scientists Circle. Make sure you have the 'Microwave Investigation' poster from Lesson 1 visible for all students. Make a blank poster available with markers to the students. Ask students to work together to revise

the models 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. Encourage multiple students to weigh in on collectively developing the visual representations and written explanations. Have students write or draw the new model on the poster, as you use talk moves to facilitate whether we have consensus" (Teacher Edition, page 172). The class revises its consensus model explaining how the components of the microwave oven work together to heat food and why the wireless signal was blocked from the microwave.

- *Develop and/or use multiple types of models to provide mechanistic accounts and/or predict phenomena and move flexibly between model types based upon merits and limitations.*
    - Lesson 4: Students use multiple models of EM radiation to explain how electric and magnetic waves propagate through space. They first use the PhET antenna simulation to visualize electric fields and how this is caused by and results in the movement of electrons. They use this simulation to begin to explain energy transfer, in this case from one antenna to another, and connect this to the antenna and magnetron in the microwave. "Suggest we use the different visualizations provided by the simulation to identify the changes in the system in these different locations that can help us explain how energy transfers from the transmitting antenna. Say, The simulation has a few different visualizations for electric field, or the force an electron would feel from electron 1. Within your group, try splitting up to record observations for different visualizations, then join together to make sense of what you saw separately. This will feel like a jigsaw, but each person is looking at different settings on the simulation" (Teacher Edition, page 89). However, because students use the models they are told to use, they do not show evidence of using the last part of the SEP element (…*and move flexibly between model types based upon merits and limitations*).
- *Develop and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems.*
    - Lesson 12: Students use a simulation to develop and test a coding system for transferring information using EM waves they work as a class to develop a consensus model of the system representing how information flow is mediated by changes in the motion of electrons in antennas and energy transfers through EM radiation. They use this model to organize their response to the lesson question. "Draw a diagrammatic representation of the parts of the system. An example is shown to the right. By the end of the period this will be referred to as the Wireless Communication Model in the rest of the lesson. Save one copy of it that you built with your last period class for reference and keep it posted in the room for the rest of the unit. Discuss the second question on slide J, 'What needs to happen in our system to communicate information?' Cue students to consider the interactions/steps happening between each part, working left to right in the model. Add annotated arrows between each part similar that capture the ideas shown below, as well a title for the model, in the form of this question, 'What needed to happen in our system to communicate information?' Ask students how the

speed of the waves traveling in the simulation compares to the speed that all EM waves travel" (Teacher Edition, pages 225–227). However, this model does not generate data.

Planning and Carrying Out Investigations.

- *Plan an investigation or test a design individually and collaboratively to produce data to serve as the basis for evidence as part of building and revising models, supporting explanations for phenomena, or testing solutions to problems. Consider possible confounding variables or effects and evaluate the investigation's design to ensure variables are controlled.*
    - Lesson 1: This element is claimed for Lesson 1 in the "Elements of NGSS Dimensions" document. The teacher is told to, "Have students brainstorm ideas for investigations and data individually, and write them in their notebook as shown on the slide. After 3–4 minutes, make a poster of students' ideas. Title a piece of chart paper 'Ideas for Investigations and Data We Need.' Elicit ideas and write them on the poster. Listen for ideas such as: We could try putting the phone in a different metal box. We could take apart the microwave oven. We could research other technologies. We could try heating various kinds of foods in the microwave oven…" (Teacher Edition, page 18). In an Exit Ticket at the end of the lesson, *s*tudents brainstorm possible investigations to answer their questions about microwave ovens and related technology and justify how those investigations would address the questions (Teacher Edition, page 40). Although students brainstorm general ideas for future investigations, they do not plan the investigations in this lesson or consider confounding variables or effects.
    - Lesson 3: Students conduct an informal investigation using the handout, "Introduce Wave Simulation Observations as a place to organize and document their thinking about variables they can control and/or observe/measure in this simulation. Encourage them to label parts of the image in whatever way helps them think, and to use the back of the handout for any additional drawings they want to record" (Teacher Edition, page 68). Later, students carry out investigations using the variables they've identified on their student sheets, "Instruct students to carry out their investigations of amplitude in partners using Wave Property Relationships. Share the simulation link: https://phet.colorado.edu/sims/html/wave-on-a-string/latest/wave-on-a-string_en.html. Remind students to keep the settings on 'Oscillate' and 'No End'. Encourage them to collect no fewer than three and no more than five data points for each investigation. Give partners 5 minutes to carry out the investigation and record their results In column D of the table on Wave Property Relationships" (Teacher edition, page 71). Because students conduct rather than plan an investigation, there is no evidence that they use this element in the lesson.
    - Lesson 5: Students plan an investigation to produce evidence as part of developing and revising models and for supporting explanations of the microwave oven phenomenon. They consider possible confounding variables and evaluate their investigations' designs to ensure variables are controlled when they conduct it. "Say, Now that we have completed all of our investigations, let's consider the data we have collected. Some of

it may be surprising to us. Let's try to explain what happened using modeling. Let's model the control results together, then maybe we can use the control results to try and explain what happened with the bowls covered in solid and hole-punched foil. Develop an energy flow diagram to explain the results of the control" (Teacher Edition, page 122).

- *Plan and conduct an investigation to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of data and refine the design accordingly.*
    - Lesson 3: Students plan and conduct an investigation on how the controlled variables — amplitude, frequency, dampening, and tension — in the waves on a string simulation affect other variables. They use their findings as evidence to consider how this connects to energy transfer through waves. "Introduce Wave Simulation Observations as a place to organize and document their thinking about variables they can control and/or observe/measure in this simulation. Encourage them to label parts of the image in whatever way helps them think, and to use the back of the handout for any additional drawings they want to record" (Teacher Edition, page 68). Students decide on how much data to measure and which variables to test and in what order. However, students do not plan related to the accuracy of data needed or consider limitations on the precision of the data as they are using a simulation and not real-life data.
    - Lesson 5: There are questions students work through as they plan and conduct their investigation. "We identified the metal walls and floor–I have some aluminum foil here, which is also metal. We could use the foil to think about how microwave radiation interacts with the walls. Do you think microwave radiation interacts with metals like this the same way light does?... What material interactions do we disagree on? Where do we need more evidence to explain what is occurring when the waves interact with these materials?" (Teacher Edition, pages 111–112). There is not specific verbiage to connect these ideas to limitations on the data collection from the perspective of the student.
- *Plan and conduct an investigation or test a design solution in a safe and ethical manner including considerations of environmental, social, and personal impacts.*
    - Lesson 1: Safety considerations about the microwave oven are established. "Elicit 1–2 ideas in response to the prompts: What experiences or ideas do you have that suggest microwave technology might pose a risk? Where could we find more information about how to use this microwave oven safely? Encourage students to add any questions to their Notice and Wonder chart. This will ensure that questions about the potential risks of using a microwave oven end up on the DQB. Then say, 'We take safety very seriously. Any time we are working with something electronic, the best way to find out how to use it safely is to read the manual'" (Teacher Edition, page 32).
    - Lesson 5: The teacher is prompted to go over safety and ethical concerns. "Say, We are considering ways to investigate our microwave system to collect evidence for reflection

or transmission using water in our system. Before we start testing different materials, like foil with holes in it, in our microwave, let's consider how we can safely use our microwave with something like metal in it. What safety concerns do we have, and how could we address them? Validate any and all safety concerns that students have raised so far. Emphasize this line of thinking as an important aspect of work that scientists and engineers need to be considering. Say, raising trying to anticipate safety concerns ahead of time is an important responsibility for scientists and engineers to always be considering – including the possible personal, societal, and environmental impacts of any scientific investigation or engineering design solution. Refer to any versions of this principle in the classroom that you have posted from the start of the year. If an explicit statement about this isn't already posted from prior work in OpenSciEd Unit P.1: How can we design more reliable systems to meet our communities' energy needs? (Electricity Unit) add this now: Each of us individually and our entire class have a personal and ethical responsibility to consider the possible personal, societal, and environmental impacts of any scientific investigation we plan and carry out or engineering design solution we design" (Teacher Edition, page 114–115).

- Lesson 5: Students plan a revised investigation to meet the safety considerations when completing the investigation planning handout. "9. What are some safety concerns we should consider before testing these kinds of materials in the microwave?... 12. Discuss and document your group's proposed investigation plan that meets our safety guidelines AND that the whole class could use to produce the data needed to answer our question on Microwave Oven Investigation" (Lesson 5, Handout – Student Procedure).

Analyzing and Interpreting Data.

- *Evaluate the impact of new data on a working explanation and or model of a proposed process or system.*
    - Lesson 10: Using what they learned about wave amplitude and frequency from Lesson 3 and the relationship of these variables on the amount of energy in electromagnetic radiation, students read excerpts to collect new data about how energy and high amplitude and high frequency EM radiation affects humans. They learn that increases in frequency of radiation cause more damage than increases in amplitude. These new data do not make sense to students, so they must revise their models to explain the process of ionization caused by higher frequencies of EM radiation. Students use this new information about the photon model of light to explain their evidence more accurately (Teacher Edition, pages 195–198).

Using Mathematical and Computational Thinking

- *Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and or support claims or explanations.*
    - Lesson 3: Students combine algebraic representations of frequency and wave speed to derive the mathematical model that relates them to wavelength. "Use variable

expressions to build a mathematical relationship. Ask students to take a few minutes to consider these equation definitions and which of these variables they found to cause changes in others. Then ask for some ideas. Listen for students to identify that both frequency and wave speed (through tension) affected the wavelength, and that these definitions all include the same parts..." (Teacher Edition, page 76)

- *Apply algebra techniques and functions to represent and solve scientific and engineering problems.*
    - Lesson 3: Students apply algebraic techniques to their data from their investigations to test their mathematical model of frequency, wave speed, and wavelength. "Read the top of the slide: Scientists sometimes create mathematical models to quantitatively describe the relationships between variables. Then pose the first question, Can we use our results plus our definitions of the variables to create any equations to relate our variables? Refer students to the Relationships Between Physical Wave Properties poster. Listen for students to suggest considering the variables that we defined with fraction or equation forms on the poster. If they do not, guide them to these variables (frequency, period, wavelength, and wave speed) by rewriting their definitions as equations on the board. Use variable expressions to build a mathematical relationship. Ask students to take a few minutes to consider these equation definitions and which of these variables they found to cause changes in others. Then ask for some ideas. Listen for students to identify that both frequency and wave speed (through tension) affected the wavelength, and that these definitions all include the same parts. Ask for suggestions on how to combine frequency and wave speed in a way that would cancel out time, as it is the part that wavelength doesn't have. If students suggest using period, guide them to use only the controllable variables to derive the wavelength. Listen for the suggestion to divide wave speed by frequency. Using student ideas, show on the board that this results in wavelength (see the example image below). Evaluate whether the data supports the equation we developed. Pose the slide's follow-up question: Is this equation supported by our data and conclusions? Ask students to explain how this equation is or is not supported. Listen for them to say that increasing wave speed caused an increase in wavelength, and increasing frequency caused a decrease in wavelength, so their locations in the equation make sense and are supported by the data" (Teacher Edition, page 76). Students investigate and represent mathematical relationships between wave properties but do not apply techniques of algebra to solve scientific and engineering problems.

Constructing Explanations and Designing Solutions

- *Make a quantitative and/or qualitative claim regarding the relationship between dependent and independent variables.*
    - Lesson 3: Students make claims about how changing various wave properties affects the energy transferred by a wave. The questions are posed by the teacher during consensus building to help students derive their explanations. "Return to the Relationships Between Physical Wave Properties poster. Present slide W. Use the

prompts to facilitate consensus building: How does changing frequency affect the other variables? How can we visually represent this? Does changing frequency affect how much energy is transferred by the wave? If so, does increasing frequency increase or decrease the energy transferred?" (Teacher Edition, page 74). "Take one of these independent variable cards and make a prediction about what would happen if you increased or decreased it: Identify all the other variable cards that would be affected by this change and add them to column B. Record the remaining variables that would not be affected by this change in column C. Put an up or down arrow next to the independent variable in column A to indicate if you are making a prediction for an increase or for a decrease in it. Put an up or down arrow next to each of the dependent variables in column B to indicate the predicted effect on it" (Student Handout – Wave Property Relationships).

- *Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.*
    - Lesson 4: As a whole class, students develop an explanatory model of energy transfer from an antenna via EM radiation after engaging in the jigsaw discussion of different views of the simulation (Teacher Edition, page 93). "Ask students to use evidence and their new ideas to discuss how we would need to change the model in the Energy Transfer from an Antenna poster in order to show: How do changes at one place cause changes at other places in the system? How does the vibrating electron at A cause energy to transfer? What do we call this system of changing electric and magnetic fields? Give students a few minutes to discuss these changes before inviting them to share. Listen for the following ideas: We should add changing magnetic and electric fields as the mechanism behind energy transfer. The vibrating electron changes electric fields, which changes magnetic fields, and so on. Electromagnetic radiation is what we call this system of changing fields… Once you have a useful model of changing fields the consensus poster, say, We identified 'electromagnetic radiation' as important as soon as we read the microwave manual. Are we ready to describe what that is now?" (Teacher Edition, page 98). Students do not discuss the assumption that theories and laws operate today as in the past and the future.

Engaging in Argument from Evidence

- *Evaluate claims, evidence, and/or reasoning behind currently accepted explanations or solutions to determine the merits of arguments.*
    - Lesson 10: Students consider an analog model for light as a wave to conclude that the model does not match the evidence for amplitude and frequency. Then they read about the particle model and evaluate which evidence is better explained by the particle model or the wave model. Students determine that both models have merits and can explain different aspects of the behavior of waves. In this lesson, the photon model better fits the evidence since the wave model is limited by its ability to explain

the connections between high frequency and ionization (Teacher Edition, pages 201–203). "Consider which model better explains the evidence. As students work through Question 3 in The Photon Model, glance at which model students circle for each example. 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 infrared from a heater absorbed by a solar cell is best explained by a particle model because IR photons don't have enough energy to eject electrons, so the solar cell just heats up" (Teacher Edition, page 203).

- *Construct, use, and or present an oral and written argument or counter argument based on data and evidence.*
  - Lesson 9: Students construct a written argument based on evidence about the relationship between frequency, and wavelength of EM radiation and its interactions with matter. They also include how this relationship helps explain the uses of EM radiation and they present this written argument to a peer (Teacher Edition, pages 185–186). "Later in this lesson, you will need to present an oral argument to other students about why you think these EM radiation types can be used for that particular purpose. Your argument should answer the following question: How could the properties of EM radiation help explain why some types of EM radiation are used for this purpose? Here are some guiding questions to help you write a stronger argument: Are there any relationships between the frequencies and wavelengths of electromagnetic radiation and their interactions with matter? How do the interactions of EM radiation with matter help explain its use in some applications. Why are some EM radiation types used for some applications but not others? Write your argument in the space below" (Lesson 9, Handout – EM Radiation Applications).

Obtaining, Evaluating, and Communicating Information

- *Critically read scientific literature adapted for classroom use to determine the central ideas or conclusions and or to obtain scientific and or technical information to summarize complex evidence, concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.*
  - Lesson 11: Students read scientific literature about X-ray technology to determine how it works, its benefits and risks, and how to minimize those risks (Lesson 11, page 5, Handout – Radiography Conventional vs. Digital). "Read the prompts out loud to describe the task: Use the reading to gather information to help us explain: What happens at the X-ray detector? How is the computer (digital) image created and stored?... To support students in identifying the main ideas from a scientific text, encourage them to paraphrase the text in simplified terms. Consider using prompts such as, 'What is the main idea?' or, 'How could you say that in your own words?' as you walk around the room and monitor progress" (Teacher Edition, page 214). "Make sure you mention to students that the information presented in this reading is based on the following scientific article: Bansal, G. J. (2006). Digital radiography. A

comparison with modern conventional imaging. Postgraduate medical journal, 82(969), 425–428. In addition to adapting the information in the original text for classroom use, we added additional text about digital information" (Teacher Edition, page 214).

- *Compare, integrate and evaluate sources of information presented in different media or formats as well as in words in order to address scientific questions or solve a problem.*
    - Lesson 2: Students read about magnetrons and integrate this information with other sources including a video and a diagram from a microwave oven manual to answer questions about changing electric fields. "Lead a Building Understandings Discussion of the questions from Part III. Use the prompts from the reading and the strategies in the Building Understanding callout at right to get students talking about their ideas: IIIa: How do moving charged particles affect electric fields? IIIb: Where might electric fields cause energy to transfer, either inside or outside the magnetron? IIIc: How might the magnetron design affect the electric field inside the oven's cooking area?" (Teacher Edition, page 47).
    - Lesson 6: Students compare a variety of sources to explain how radiation interacting with greenhouse gases contributes to global climate change (Lesson 6, Assessment – Explaining Temperature Rise).
    - Lesson 7: "To scaffold the engagement with this practice, students will be introduced to the Evaluating Information Checklist, a tool that will help them quickly assess the validity and reliability of claims from sources they evaluate. This tool, together with examples for how to use it, are intended to help students engage in this practice as needed. Throughout the rest of this unit, these supports will be adjusted and gradually removed so that students become increasingly responsible for evaluating the validity and reliability of the information they explore. In OpenSciEd Unit P.6: Earth's History and the Big Bang (Cosmology Unit), students will continue using different elements of this SEP" (Teacher Edition page 138). This tool is modeled through the reading of the first paragraph together (Teacher Edition, page 146).
    - Lesson 12: Students integrate sources of information to provide an answer to the question: how do wireless electronic devices use EM waves to reliably communicate different types of information? (Teacher Edition, page 231). "Summarize how our wireless electronic devices are designed to use electromagnetic waves to reliably communicate different types of information to each other. Your summary should include: Key ideas gathered from across the stations and our class model. How the system is designed to do the things related to sub-questions on the next page. How electromagnetic wave behavior and matter interactions are used to do this. It can also include annotated diagrams if helpful" (Lesson 12, Handout – Communicate Information). In the stations activity, students read several articles that also contain data tables, charts, graphs, and diagrams. Students then summarize the information they learned in their written response.
    - Lesson 13: "Identify the mechanism that the first poster claims will cause the effect you identified in question 3 and record them in the second column of the table below. Is this mechanism consistent with science ideas we have figured out in class? Why or why

not? Record your ideas in the third column of the table below." "2b. Valid claims are supported by evidence and consistent with scientific ideas. Reliable claims use evidence that comes from credible sources, and can be verified either against data sets, or additional experiments. Is the first post valid and/or reliable? Why or why not?" (Evaluating 5G Safety).

- *Evaluate the validity and reliability of and/or synthesize multiple claims, methods, and/or designs that appear in scientific and technical text or media reports, verifying the data when possible.*
    - Lesson 7: Students evaluate the validity and reliability of multiple claims that appear in the media, suggesting ways that they could verify the data empirically (Teacher Edition, pages 146–147). Students use the Evaluating Information Checklist to evaluate sources. There are specific prompts for both validity and reliability. "Distribute Metal in the Microwave [sic] all students. Instruct half the students to use Metal in the Microwave Part A: Company Website, while the other half uses Metal in the Microwave Part B: Local Newspaper on the other side. Ask them to evaluate the validity and reliability of their assigned reading using Evaluating Information Checklist" (Teacher Edition, page 146).
    - Lesson 13: Students evaluate validity and reliability of sources on the summative assessment. "Valid claims are supported by evidence and consistent with scientific ideas. Reliable claims use evidence that comes from credible sources, and can be verified either against data sets, or additional experiments. Is the second post valid and/or reliable? Why or why not?" (Evaluating 5G Safety).

Disciplinary Core Ideas (DCIs) | Rating: Extensive

The reviewers found extensive evidence that students have the opportunity to use or develop the DCIs in this unit because they must use grade-appropriate elements of these DCIs: **PS2.B Types of Interactions**, **PS3.A Definitions of Energy**, **PS4.A Waves and Wave Properties**, **PS4.B Electromagnetic Radiation, PS4.C Information Technologies and Instrumentation,** and **ESS2.D Weather and Climate**. They must use these DCIs explicitly to make sense of and explain how microwave ovens and EMR-related technologies work.

PS2.B: Types of Interactions

- *Forces at a distance are explained by fields per meeting space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields.*
    - Lesson 2: Students use the magnetron as a way to learn more about how electric fields work. "Discuss how electric fields affect energy transfer inside and outside the magnetron. Present slide F. Lead a Building Understandings Discussion of the questions from Part III. Use the prompts from the reading and the strategies in the Building Understanding callout at right to get students talking about their ideas: IIIa: How do moving charged particles affect electric fields? IIIb: Where might electric fields cause energy to transfer, either inside or outside the magnetron IIIc: How might the

magnetron design affect the electric field inside the oven's cooking area?" (Teacher Edition, page 47). Students learn "... vibrating electrons in the magnetron antenna affect electric fields and somehow enable energy transfer in the microwave oven" (Teacher Edition, page 50).

- Lesson 3: Through the simulation and slinky, students figure out "When the first particle in the wave on a string is moved (as a force is applied to it, which transfers energy to it), it stretches the electric field (bond) between it and the next particle. When a bond is stretched (or compressed), energy is transferred to the fields that produce the bond, and when it is unstretched (or uncompressed), that energy transfers out of the fields and back into the motion of the particles around it. A larger amplitude means that the electric fields (bonds) between particles will be stretched farther in either direction in a given amount of time (period); this increase in vibration speed transfers more energy along the wave" (Teacher Edition, page 55).
- Lesson 4: Students make sense of magnetic fields. The teacher should listen for the following ideas during a turn and talk. "As the electron wiggles, electric and magnetic fields are produced. We saw magnetic fields changing along with electric fields" (Teacher Edition, page 94). They make sense of changes in magnetic fields. The teacher should listen for "Both fields are perpendicular to each other. Both fields travel as waves with the same wavelength. We should add perpendicular magnetic fields traveling alongside the electric fields. At every point, there will be two perpendicular arrows growing larger and smaller, and flipping directions at the same time" (Teacher Edition, page 95). They are introduced to a simulation to identify other patterns between the electric and magnetic fields.
- Lesson 5: Before the investigation, students are reminded of fields. "Point to the class consensus model that we produced, and ask someone to summarize what electromagnetic radiation is. Look for students to say that it consists of changing electric and magnetic fields transferring energy across space" (Teacher Edition, page 108).
- Lesson 7: Students figure out that charged particles in an electric field experience force, the direction of which depends on the direction of the field and the charge of the particles. They also learn that forces from changing electric fields in the microwave will cause polar molecules, like water, to rotate in the direction of the fields. They learn that interaction between microwave radiation and water molecules will transfer energy out of the fields and into thermal or kinetic energy of the water (Teacher Edition, page 135).
- Lesson 8: Students use the wave on a string simulation. "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?" (Teacher Edition, page 168).

    - Lesson 13: Students use their understanding of waves, EM radiation (energy), and its effects on matter to evaluate the validity and reliability of claims in published materials of the relative dangers of 5G technology (Teacher Edition, page 238).
    - Lesson 8: Students use the wave on a string simulation. "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?" (Teacher Edition, page 168).

PS3.A: Definitions of Energy

- *Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved even as within the system energy is continually transferred from one object to another and between its various possible forms.*
    - Lesson 5: Students develop a model of the transfer of energy in a microwave oven to different types of matter inside it. On page 122, the Teacher Edition states, "Present slide Y. Use a piece of chart paper to co-develop a model to explain 'Where did the energy in the system come from to increase the temperature of the matter in our control?'" On page 123, the Teacher Edition states, "Present slide Z. Distribute notebook paper to students. Explain that students will now have a chance to add, remove, or change new components and interactions in our class model for the control to explain our results with the solid or the hole-punched aluminum foil." The quantitative aspect of this DCI is not explicitly addressed by the lesson activities.
- *These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled either as motions of particles or energy stored in fields. This last concept includes radiation, a phenomenon in which energy stored in fields moves across space.*
    - Lesson 3: Students develop a model of physical waves that is used in later lessons, which helps them understand electromagnetic radiation as a wave and the energy transferred by it. "Motivate developing a diagrammatic model of energy transfer. Suggest that we try to apply our M-E-F thinking to this system, to help use the particle-level model to explain how energy is transferred across solid matter when a wave moves through it. Establish and model how energy is transferred into the system. Display slide E. Use the prompts on the slide and in the table below to establish how energy is transferred into the system (by a hand or other contact force)" (Teacher Edition, page 64).
    - Lesson 6: There is a side note to help with the idea of "particle" level being beneficial. "Note that students' focus is on developing a particle scale cause-effect mechanism for a macroscopic observation we made in the previous lesson. Help students to make this connection – even though we can't see this mechanism on a particle scale directly, the connection between the mechanism and the macroscopic evidence helps convince us that it's useful" (Teacher Edition, page 141).

PS3.D: Energy in Chemical Processes and Everyday Life

- *Although energy cannot be destroyed, it can be converted to less useful forms — for example, to thermal energy in the surrounding environment.*
    - Lesson 5: The investigations conducted in this lesson, and the models constructed by students use this DCI as a way to explain how microwaves interact with matter inside it. In this case, water without aluminum foil covering is heated but with aluminum foil is not. "Use the prompts below to co-develop the parts of the model. Add the corresponding part of the model to the poster as you get each response. An example model is shown below. Where did the energy in the system come from to heat up the matter in both of the bowls in our control condition? How did the amount of energy being transferred into the water in each bowl compare to the one bowl that absorbed energy in test 1? How did it compare to test 2?" (Teacher Edition, page 122)

PS4.A: Wave Properties

- *The wavelength and frequency of a wave are related to one another by the speed of travel of the wave, which depends on the type of wave and the medium through which it is passing.*
    - Lesson 3: Students investigate the energy of a physical wave in terms of the motion of particles and the energy stored in fields within the bonds between particles. This builds upon previous learning in OpenSciEd Physics Units 2, 3, and 4. They develop a model and consider the medium through which it is passing. "Say, Let's represent this part of the system together, so we can refer to collections of particles that are changing across it. When scientists refer to the matter that a physical wave is moving through, they call it the medium. Add the middle box (medium/materials) to the transfer diagram and add the annotated arrow going to it…How is energy transferred from the medium to the last particle?" (Teacher Edition, pages 65–66). Students use the simulation to see how properties of waves are connected. "Distribute a deck of Wave Variable Cards to each group and a copy of Wave Property Relationships to each student. Cue students to work with the cards and follow the directions on the handout as they discuss and record predictions for the relationships between the wave properties" (Teacher Edition, page 71).
    - Lesson 13: In the transfer task students need to use the idea that frequency is connected to energy but do not use the relationship between frequency, wavelength, and speed or that the speed depends on the medium it passes through. This element is not claimed in the rubric, but it is claimed in the front matter document "Elements of NGSS Dimensions."
- *Information can be digitized; in this form, it can be stored reliably in computer memory and sent over long distances as a series of wave pulses.*
    - Lesson 11: Students read literature about how EM radiation can cause electric currents that can be used to create digital images. These digital images can be reliably stored on our computers (Lesson 11, Handout – Radiography Conventional vs. Digital). "What

happens at the X-ray detector? How is the computer (digital) image created and stored?" (Teacher Edition, page 214).

- Lesson 12: Students make a consensus model about wireless communication. During this consensus model, "Emphasize that Modern computer chips use a digital code to store, encode, transmit, detect, and decode information. The devices that communicate wirelessly use antennas to send and receive billions of EM pulses per second which allows them to send and receive lots of kinds of information quickly" (Teacher Edition, page 228). "Sampling is the next step of digital encoding of an audio signal that allows for the creation of information packets that can be sent digitally. During sampling, your device will record samples of the electric current in the microphone at regular intervals of time. Then the sequence of sample values are[sic] converted into a sequence of binary 1s and 0s…Once the original audio that you recorded has been converted into a digital signal, it will be sent from your device as a series of pulses that represent either 1s or 0s…." (Lesson 12, Reading – Transmitting Digital Audio).
- Lesson 13: Students investigate 5G. "This is possible, in part, because 5G networks will use a portion of the electromagnetic radiation (EMR) spectrum to transmit digital information that isn't currently being used by other wireless communication devices" (Evaluating 5G Safety).

PS4.B: Electromagnetic Radiation

- *Electromagnetic radiation 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.*
    - Lesson 2: "Discuss how electric fields affect energy transfer inside and outside the magnetron. Present slide F. Lead a Building Understandings Discussion of the questions from Part III. Use the prompts from the reading and the strategies in the Building Understanding callout at right to get students talking about their ideas: IIIa: How do moving charged particles affect electric fields? IIIb: Where might electric fields cause energy to transfer, either inside or outside the magnetron? IIIc: How might the magnetron design affect the electric field inside the oven's cooking area?" (Teacher Edition, page 47). At the end of this lesson students jot in an Exit Ticket words or pictures that explains what they think is happening between the magnetron antenna in a microwave oven and a light bulb. "Say, On your exit ticket, use words or pictures to jot down your thoughts about the question on the slide: What do you think is happening between the magnetron antenna and the light bulb to transfer energy all the way across the microwave oven?" (teacher Edition, page 51).
    - Lesson 4: In this lesson students reinforce their understanding of the wave model of EM radiation, drawing on observations of two simulations to investigate electric and magnetic fields, and how these fields can transfer energy through space to exert non-contact forces (Teacher Edition, pages 87–93).
    - Lesson 8: In this lesson students figure out that when two waves meet in space, they can interact through interference. This can produce either a higher combined wave

height (constructive interference) or lower combined wave height (destructive interference) at a particular point in space and time than that of either individual wave before they met. “Model electromagnetic wave interference. Say, Here I have a short sequence of waves generated by the magnetron and waves reflected by the wall. Project the Wave Interactions Google Slideshow sequence. Show students how to scroll up and down, so they can see the sequence. Lead a discussion using the prompts on slide S: What do the arrows represent? What wave colors 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 by the wall” (Teacher Edition, page 168).

  - Lesson 10: Students gather information from two readings on the wave and photon models of EM radiation, and they use information from both readings to explain which type of EM radiation is most likely to cause skin cancer (Teacher Edition, page 201). Students learn about the differences between the wave model and photon model and consider the benefits of each. “What does this say about our wave model of EM radiation? How do you think scientists deal with situations where new evidence doesn’t quite fit their current model? If we were to look at a new model, what kind of data would we want to look for?” (Teacher Edition, pages 202–203). Students are introduced to the photon model. Later in the lesson, they discuss, “Did everyone agree that the (particle model) was better for explaining (why the high amplitude IR radiation didn’t cause the solar cell to emit any electrons)? Who can give us an explanation of why the particle model works better here, using details from the reading?” (Teacher Edition, page 205). “Both the photon model and the wave model for EM radiation are incomplete. Scientists apply the particle model to understand some phenomena, and the wave model to explain others. All models in science work this way. Every model is incomplete, and scientists must choose the merits and limitations of the model based on the evidence and objectives for that situation. Question 3: Consider a few examples of evidence that we have seen. Which do you think is better explained by a particle model, and which is better explained by a wave model, both, or neither?” (Lesson 10, Handout – The Photon Model, page 4).
  - Lesson 13: “1a. What information would be important in order to determine whether 5G radiation is dangerous or not? Circle all that apply: Frequency/wavelength; Amplitude/intensity; Duration of exposure; Length of antenna” (Lesson 13, Assessment – Evaluating 5G Safety).
- *Once light or longer wavelength electromagnetic radiation is absorbed in matter, it is generally converted into thermal energy. Shorter wavelength electromagnetic radiation can ionize atoms and cause damage to living cells.*
  - Lesson 1: Students observe a demonstration of a teacher heating food in the microwave, which is an implicit use of this DCI. Students are not expected to identify the relationship between wavelength and energy or the transformation of electromagnetic energy into thermal energy (Teacher Edition, page 34).

- Lesson 5: Students plan and conduct an investigation of the interactions of microwaves on water uncovered and covered with foil, with the walls and door of the microwave oven. They gather data on temperature, which is used as a proxy for the conversion of the energy in microwave radiation to thermal energy in the objects inside the microwave oven. "Develop an energy flow diagram to explain the results of the control. Present slide Y. Use a piece of chart paper to co-develop a model to explain 'Where did the27nergyy in the system come from to increase the temperature of the matter in our control?'" (Teacher Edition, pages 121–122).
- Lesson 6: Students answer question 3b on the assessment, which states, "Using the model of matter-energy interactions the Earth's atmosphere, develop an explanation for how interactions between electromagnetic radiation and greenhouse gases could cause an increase in Earth's temperature. Be sure to explain what is causing these interactions to shift over the past few hundred years, and how evidence (from the data included in this assessment, or from our experiments with the microwave oven) supports your explanation. Use any combination of words, diagrams, and symbols" (Lesson 6, Assessment – Explaining Temperature Rise, page 5). The ionization of atoms and damage to cells from shorter wavelength radiation is not discussed.
- Lesson 7: Students learn that interaction between microwave radiation and water molecules will transfer energy out of electric fields and into thermal or kinetic energy of the water (Teacher Edition, page 135). "Brainstorm key components we would need in a consensus model that clearly explain: Why does water heat up in the microwave oven? Why doesn't the microwave-safe plastic heat up in the microwave oven? Write your ideas in the science notebook… Make sure your models include: The difference in charge at the particle level between water (polar) and plastic (nonpolar); The direction of forces acting on different parts of the system; How these particles interact with microwave radiation inside the microwave oven; How the particle motion relates to the observed changes in temperature" (Teacher Edition, page 145). The ionization of atoms and damage to cells from shorter wavelength radiation is not discussed.
- Lesson 8: "Use wave sequence to make sense of hot and cold spots. Present slide T. Have students gather in their groups from the initial modeling task in day 1 and distribute computers with access to <the simulation>. Give students four minutes to step through the wave sequence to find evidence that can help them answer the slide prompts: Where would the cold spots be located? Where would the hot spots be located?" (Teacher Edition, page 169) The ionization of atoms and damage to cells from shorter wavelength radiation is not discussed.
- Lesson 9: "Present slide I. Describe the task by reading the slide prompts: Identify some of the ways EM radiation types are used. Use the information on the cards and the guiding questions on Part 3 of the handout to identify connections between the uses of EM radiation and their properties. Be ready to present an oral argument to other students about why we can use some EM radiation for some applications but not others. Give students the rest of the class to complete this part. Encourage them to use some of the guiding prompts included in EM Radiation Applications: How do different

frequencies and wavelengths of electromagnetic radiation affect their ability to interact with matter? How do interactions of EM radiation with matter affect help explain its use in some applications. Why are some EM radiation types used for some applications but not others?" (Teacher Edition, page 183)

- Lesson 10: "Consider wave properties that might affect energy. Present slide B and organize students into groups of four. Handout Electromagnetic Radiation Cards. Say, 'We have figured out that the properties of a wave can help us explain how much energy it can transfer. Let's look back at the EM radiation cards to look for 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 groups work, roam around the room and assist as needed. Have students record their ideas in their science notebooks. After five minutes, elicit student ideas using the questions on the slide to the class: What type of damage are some of these types of EM radiation causing to the matter they interact with (e.g., microorganisms, our skin)? Which wave properties influence how much energy a wave transfers?" (Teacher Edition, page 194). Students have a discussion regarding the EM spectrum and danger to living cells. "Lead a Key Ideas discussion with students using the prompts on the slide. 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?" (Teacher Edition, page 198).
- Lesson 13: Students consider potential dangers of EM radiation and critique arguments regarding it. "In the assessment students identify potential health effects of long-term exposure to 5G technologies. Students examine two social media posts providing different pieces of evidence arguing for and against safety risks associated with 5G" (Teacher Edition, page 236).

- *Photovoltaic materials emit electrons when they absorb light of a high enough frequency.*
  - Lesson 10: Students view a video of a solar cell and record data on output from the video (Teacher Edition, page 198). "Some human-made devices use this idea with photovoltaic materials to convert photon energy to electrical energy in moving electrons. Materials like silicon, used in solar cells, emit electrons when they absorb photons of visible light or higher frequency. Each individual photon that hits such a material will eject an electron, as long as that photon contains enough energy. Many photons together can eject enough electrons to charge a battery or light a bulb" (Lesson 10, Handout – The Photon Model, page 3). Students learn about solar cells and how the particle model fits the data for this phenomenon through a YouTube video link. Note that the link provided in the teacher materials does not currently work.

PS4.C: Information Technologies and Instrumentation

- *Multiple technologies based on the understanding of waves and their interactions with matter are part of everyday experiences in the modern world and in scientific research. They are* *essential tools for producing, transmitting, and capturing signals and for storing and interpreting the information contained in them.*

- Lesson 1: Students view the first demonstration by the teacher in which they show how a Bluetooth speaker's signal from a wireless device can be disrupted by a closed microwave oven. Later they engage in home learning to elicit their family's ideas about digital signals and the uses of microwave ovens (Teacher Edition, pages 31 and 37).
- Lesson 8: This DCI element is claimed in the unit overview materials, but the reviewers could not find evidence for this element in Lesson 8. Students make sense of the patterns of heating in the microwave oven but do not learn about producing, transmitting, and capturing signals and storing/interpreting information in those signals.
- Lesson 9: Students use information in a card sort to gather information on different types of EM radiation and how this radiation interacts with matter including heating up, ionizing, or breaking apart molecules. Students learn that the interactions of EM radiation with matter can be harnessed for various applications such as medical imaging, telecommunications, and energy production (Teacher Edition, page 175). "Identify EM radiation properties that could explain their uses. Present slide I. Describe the task by reading the slide prompts: Identify some of the ways EM radiation types are used. Use the information on the cards and the guiding questions on Part 3 of the handout to identify connections between the uses of EM radiation and their properties" (Teacher Edition, page 183).
- Lesson 11: Students read literature about X-ray technology to determine how it works, its benefits and risks, and how to minimize those risks. The reading also provides information about how EM radiation can produce electric currents that can be used to create digital images (Lesson 11, Handout – Radiography Conventional vs. Digital).
- Lesson 12: Students gather information from multiple sources in various formats from four different stations. "Emphasize that at the end of visiting the four stations, and gather information which they will record on Gather Station Information, they will then synthesize all that information independently in the next class to communicate an individual response that explains the entire section of our driving question board related to how do our wireless electronic devices use EM waves to reliably communicate different types of information." (Teacher Edition, page 229).
- Lesson 13: Students use their understanding of waves, EM radiation (energy), and its effects on matters to evaluate the validity and reliability of claims in published materials of the relative dangers of 5G technology (Teacher Edition, page 238).

ESS2.D Weather and Climate

- *The foundation for Earth's global climate systems is the electromagnetic radiation from the sun, as well as its reflection, absorption, storage, and redistribution among the atmosphere, ocean, and land systems, and this energy's re-radiation into space.*
    - Lesson 6: In the transfer task, students use a model and other sources of information to identify the proportion of EM radiation from the sun that is absorbed, reflected, or

transmitted when it enters Earth's atmosphere. After reaching Earth, matter on the surface absorbs this radiation and then emits IR that is more readily absorbed by greenhouse gases. Because of the concentration of carbon in the atmosphere, it has contributed to the increase in global average temperatures (Teacher Edition, page 127). "Almost all of the energy entering Earth's systems comes from the sun. That energy travels through empty space in the form of electromagnetic radiation. Look at the model below for Earth's atmosphere. Much like the door of a microwave oven, the atmosphere allows almost all of the visible light from the Sun to transmit into Earth's systems, but reflects or absorbs some radiation with longer and shorter wavelengths, preventing it from reaching Earth's surface. The electromagnetic radiation that is transmitted through the atmosphere will mostly be absorbed by air, plants, rock, and water. Earth's systems together absorb about 71% of incoming solar radiation." Students answer questions such as, "Use the ***Model of Matter-Energy Interactions in Earth's Atmosphere*** to fill in… the table below to show which types of electromagnetic radiation are radiated by the Sun towards Earth/reflected back into space/transmitted to the surface/ radiated back out by Earth's systems…" and "Using the model of matter-energy interactions the Earth's atmosphere develop an explanation for how interactions between electromagnetic radiation and greenhouse gases could cause an increase in Earth's temperature" (Lesson 6, Assessment – Explaining Temperature Rise).

Crosscutting Concepts (CCCs) | **Rating: Extensive**

The reviewers found extensive evidence that students have the opportunity to use or develop the CCCs in this unit because a majority of the claimed CCC elements are used and developed in the unit.

Patterns

- *Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality and explanations of phenomena.*
    - Lesson 10: Students examine various examples of EM radiation and its effect on skin cancer risk in humans. Then they look for patterns in this data to conclude that higher frequency radiation tends to be more dangerous than higher amplitude radiation. "Introduce 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, that it might increase the risk of harm. Tell students that you have a health and wellness article that discusses different frequencies and amplitudes of various different EM radiation technologies, their uses, and how they are or aren't correlated to increased risk of skin cancer. Motivate tracking frequency and amplitude information. Ask students, How can we use this article to make sense of if increases in frequency or amplitude, or both, increase the risk of harm?" (Teacher Edition, page 197).
- *Mathematical representations are needed to identify some patterns.*
    - Lesson 3: Students use mathematical reasoning and representations to identify the pattern that connects frequency, wave speed, and wavelength. "What to do: Writing

frequency, wavelength, and wave speed as equations or using definitions in fraction form (as seen in the example poster above) will be helpful when developing the equation for wavelength toward the end of the lesson. (This can also be done for period, but that isn't critical for future conversations.) If students don't represent the variables this way, encourage them to do so to make sense of the variables. Give them one example and have them create these representations for the other variables" (Teacher Edition, page 70). "Use variable expressions to build a mathematical relationship. Ask students to take a few minutes to consider these equation definitions and which of these variables they found to cause changes in others. Then ask for some ideas. Listen for students to identify that both frequency and wave speed (through tension) affected the wavelength, and that these definitions all include the same parts" (Teacher Edition, page 76).

    - Lesson 9: Students use patterns in information provided in a card sort to evaluate different types of EM radiation and argue which types are most likely to cause harm to humans. "Then use the second prompt to motivate the need to investigate the mathematical relationship between frequency, wavelength, and speed: Is this in line with the relationship between frequency and wavelength we just found? Accept all answers. Say, How could speed be the same when frequency and wavelength is different for each EM radiation type? Let's revisit the relationships we discovered between these three variables earlier and see if we can make sense of this. Make sense of EM Radiation speed values. Display slide H. Distribute calculators for students to complete Part 2 of the handout. Encourage students to use the cards to explore this relationship further to see if we can explain this mathematical relationship" (Teacher Edition, page 183).
- *Empirical evidence is needed to identify patterns.*
    - Lesson 4: Students identify different patterns of electric fields by collecting data with compasses and an electromagnet to provide evidence for causality and explanations of how EM waves propagate through space. "Ask, could it be useful to use physical equipment to observe whether and how changes in electric fields can cause changes in magnetic fields? Accept 1–2 ideas and then say, I've got some materials that generate electric and magnetic fields. Let's try it out and see if we can fill in some gaps in our understanding…Carry out the demonstration, letting students observe the changes in the magnetic field registered by the compasses. Mention that as you change the direction you are turning the crank of the generator (clockwise versus counterclockwise), the direction of the current will change direction as well. Elicit 1–2 ideas with the prompts: What happened when we used the generator to change the direction of the electric field in the wire? How might this help us understand what is happening inside the cooking area of the microwave oven?" (Teacher Edition, page 97).

Cause and Effect

- *Cause and effect relationships can be suggested and predicted for complex natural and human design systems by examining what is known about smaller scale mechanisms within the system.*

- Lesson 4: Using two different simulations, students examine electric field and magnetic field propagation through space to explain how energy transfers from an antenna to distant charged particles (Teacher Edition, pages 87–90 and 94–96). “Discuss revisions of the energy transfer model. Present slide S. Ask students to use evidence and their new ideas to discuss how we would need to change the model in the Energy Transfer from an Antenna poster in order to show: How do changes at one place cause changes at other places in the system? How does the vibrating electron at A cause energy to transfer? What do we call this system of changing electric and magnetic fields? Give students a few minutes to discuss these changes before inviting them to share. Listen for the following ideas: We should add changing magnetic and electric fields as the mechanism behind energy transfer. The vibrating electron changes electric fields, which changes magnetic fields, and so on. Electromagnetic radiation is what we call this system of changing fields” (Teacher Edition, page 98).
- Lesson 5: Students plan an investigation to determine the effect of different materials on energy transfer through microwave. Those materials are derived from human design systems (that interior surface and door of the microwave oven), and from inspecting cross sections of the door. They compare the behavior of light, another form of EM radiation, and its interactions with different materials and the interaction of visible light is used to draw comparison about how they could detect what is happening if microwaves interact with different materials (Teacher Edition, pages 111–112). “Ask students, if we are manipulating the foil around one bowl and observing temperature changes, how could we tell if these changes were caused by the foil and not something else? How would we know if adding the foil was actually affecting the energy transfer and if the foil is absorbing, reflecting, or transmitting the microwave radiation?” (Teacher Edition, page 117).
- Lesson 6: Students suggest cause and effect relationships between the concentrations of greenhouse gases and global temperature by examining the interactions between EM radiation and matter on Earth. “Scientists are concerned about the impact of greenhouse gases on global temperatures. They argue that if we fail to reduce the emission of these gases by 2030, it will become increasingly challenging for future generations to reduce their effects on global temperature. Based on the data in the graph and the table, explain which greenhouse gas will have the greatest effect on future generations, and why” (Lesson 6, Assessment – Explaining Temperature Rise).
- Lesson 7: Students identify that the charge distribution of a particle affects its interaction with the changing electric field. Students use these interactions between changing fields and polar and nonpolar particles to explain changes in temperature at the macroscopic scale. “Lead a building understanding discussion about the behavior of water particles. Present slide H. Encourage students to use their answers from Field-Particle Interactions during this discussion. Use the slide prompts to elicit student ideas… What changes in the water molecule were caused by changing the electric field? Does this indicate that waves absorb into, transmit through, or reflect off the water? How do you know? How does this help explain some of the macroscopic

changes we observed in our microwave oven experiments?" (Teacher Edition, page 142)

- Lesson 8: Students suggest cause and effect relationships between wave interference and heat distribution inside the microwave by examining force interactions between two waves. "Revise models for patterns observed in cheese and lights. Keep students in their groups with access <the simulation>. Present slide U. Read the instructions for this task out loud: Revise your model, using words and drawings, to explain the patterns in the cheese and the little light bulbs. Be sure to include details about matter, energy, and forces in your model" (Teacher Edition, pages 162–165).
- Lesson 10: Using the photon model of light, students conclude that EM radiation tends to only cause ionization if each individual photon has sufficient energy to eject an electron. This explains why infrared light doesn't cause current from a solar cell, and why visible light tends not to increase skin cancer risk (Teacher Edition, pages 205–207).
- Lesson 13: Students answer reflection questions designed to get them thinking about how investigations across the unit helped predict macroscopic cause and effect relationships through examining smaller scale mechanisms within larger systems. "Identify two effects that the first poster claims 5G can have on human health and record them in the first column of the table below. Identify the mechanism that the first poster claims will cause the effect you identified in question 3 and record them in the second column of the table below. Is this mechanism consistent with science ideas we have figured out in class? Why or why not? Record your ideas in the third column of the table below" (Lesson 13, Assessment – Evaluating 5G Safety, page 6).

- *Systems can be designed to cause a desired effect.*
  - Lesson 12: Students explain how computers can translate binary code to and from text, audio, video, and location information and how wireless messages are designed, so that only the intended receiver can decode the information space (encrypted). "Discuss the prompt on the slide: What did we change in the system to transfer different amounts of energy from the transmitting antenna to the receiving antenna? Listen for the following ideas: We changed the amplitude. We changed the frequency. We changed the speed of the electron in both cases…Discuss the prompt on the slide: What did we change in the system to transfer different amounts of energy from the transmitting antenna to the receiving antenna? Listen for the following ideas: We changed the amplitude. We changed the frequency. We changed the speed of the electron in both cases" (Teacher Edition, page 225).

Systems and System Models

- *Systems can be designed to do specific tasks.*
  - Lesson 2: Students review the specific design features of a magnetron and a microwave oven from the technical manual and later a video on a magnetron dissection to explain how the motion of electrons in an antenna generates changing electric fields in the microwave oven (Teacher Edition, pages 45–46).

- Lesson 9: Students develop an explanation of how different EM radiation technologies are designed for specific tasks, but do not engage with the concept of systems in this lesson.

- *Models can be used to simulate systems and interactions, including energy, matter, and information flows within and between systems at different scales.*
  - Lesson 12: Students use a computer model to develop and test a coding system for transferring information using EM waves. They develop a class consensus model of the system and use a slinky spring (physical representation) to simulate information transfer with digital code using frequency key and amplitude key modulated signals at one of the four stations and interpret graphs that represent these two signal structures (Teacher Edition, pages 228–229).

Energy and Matter

- *The total amount of energy and matter in closed systems is conserved.*
  - Lesson 5: Students build a model to explain why: 1) a bowl of water increases in temperature but a foil-covered one with and without holes does not and 2) an uncovered amount of water also increases in temperature, but when some of the water is covered, the remaining water undergoes a greater temperature increase (Teacher Edition, Lesson 4: Students are expected to begin to predict a cause and effect relationship, pages 121–122). However, it's not clear how students use the idea of energy conservation explicitly in the lesson activities to explain differences in heating. There is not explicit verbiage about matter being conserved in a closed system.
- *Changes of energy and matter in a system can be described in terms of energy and matter flowing into, out of, and within that system.*
  - Lesson 1: Students create initial models that describe matter changes and energy transfer in a microwave oven as it heats food, and when it affects wireless signals such as those between an electronic device and a Bluetooth speaker. "Elicit ideas about energy transfer and forces. Once the important components of the system are sketched out (e.g., the microwave oven's basic structure, the electric cord, something electronic behind the keypad, and so forth), ask students about the interactions they represented in their models: Clarify after each suggestion whether they are describing energy or forces, or aren't sure. Use purple to represent forces and green to represent energy, to match the M-E-F model built previously. When students describe how these interactions change matter (heating, deforming, and so forth), use red to show how the matter changes" (Teacher Edition, page 36).
  - Lesson 3: Students use their data to consider how energy transfer across a wave system can be described by changes in matter in a string and changes in energy in the bonds between the string particles. "Make sure you attend to the last two prompts in the electronic exit ticket before next class: How do you think this might be similar to or different from how energy transfers from the magnetron to the food inside the microwave oven? An earthquake is caused by unbalanced forces at a fault (boundary)

between two pieces of Earth's crust. What [sic] might the unbalanced forces be causing energy transfer in the microwave oven?" (Teacher Edition, page 78).

- Lesson 5: Students represent energy transfers into, out of, and within different parts of the microwave oven system. "Connect to energy conservation in any process. Remind students that in prior units we've developed many different ways to show that all of the energy must be accounted for in a system, or when energy transfers from one system to another, so it might be important for us to capture that important concept to for waves too. Suggest that one way to express that energy relationship between these three different matter interactions could be in this way: Energy of a wave (that reaches a new material) = energy reflected + energy absorbed + energy transmitted" (Teacher Edition, page 110). Paths within the microwave oven system indicate different matter interactions such as reflection or absorption for different parts of the system to account for changes in thermal energy of the water in different conditions (Teacher Edition, pages 121–122).
- Lesson 6: Students analyze the flow of energy into Earth's atmosphere, back out of Earth's surface, and the flows within Earth's atmosphere to explain the increase in global temperatures since the onset of climate change. "Do the data in the graphs above indicate that electromagnetic radiation leaving Earth's systems (output) has been increasing, decreasing, or staying the same? Over what timescale, and how do you know?" (Lesson 6, Assessment – Explaining Temperature Rise).
- Lesson 8: Students revise their initial consensus model using the anchor model, which now includes how energy is transferred within the microwave oven system. "As students are developing their models, use this opportunity as a pre-assessment moment of ideas that have been built throughout the unit and students should be including. Look for these key model ideas: Include the components of the microwave oven that influence energy transfer, such as the magnetron, the walls, or the objects inside. Cause and effect relationships that connect different parts of the model. Connections between the structure of the microwave 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)" (Teacher Edition, page 172).

- *Energy cannot be created or destroyed — it only moves between one place and another place, between objects and or fields, or between systems.*
  - Lesson 8: Students use the idea of wave interference to explore how energy is transferred through EM radiation. "Explain interference using matter, energy, and forces. Present slide M. Ask students to work in pairs, using their work on Wave Interactions to answer the prompts on the slide: What pattern do we see with how the matter of the waves behaves? What happens to the total energy in the system?" (Teacher Edition, pages 161, 169, and 171). While students are asked about the total energy of the system in this prompt, students do not discuss or demonstrate understanding that energy is not created or destroyed and that it moves between objects, fields, and/or systems.

Structure and Function

- *Investigating or designing new systems or structures requires a detailed examination of the properties of different materials, the structures of different components, and the connections of components to reveal its function and/or solve a problem.*
    - Lesson 2: Students investigate the structure of a magnetron in a diagram in a technical manual, in a video, and in the microwave oven in their classroom. “Say, I have a video showing a magnetron dissection that might give us a few clues. Present slide B. Tell students to continue recording what they notice and wonder as they watch the video. Emphasize the question on the slide: What parts or materials seem especially important?... Say, Let’s look inside the microwave oven for any visible evidence that our magnetron is similar to the one in the video. What parts of the magnetron would you expect to be able to see from the oven’s cooking area?” (Teacher Edition, page 46). Students might therefore begin to implicitly build an understanding of this element.
    - Lesson 11: Students read about radiography to explore how EM radiation and its interactions with different materials can be used to create and store digital information. “An X-ray digital detector is made up of a set of many individual sensors whose function is to convert the X-ray photons that are absorbed into electric currents that determine the darkness of each pixel, or small square, of the resulting digital image (see image below). In the image below, the X-ray digital detector has 21 rows and 15 columns of sensors, which add up to 315 individual sensors in this detector. Each sensor corresponds with a pixel that will be part of the digital image the doctor and patient will see on the screen. The number of sensors in an X-ray detector, and therefore pixels in the resulting image, vary depending on the size and type of detector” (Lesson 11, Handout – Radiography Conventional vs. Digital). Students might therefore begin to implicitly build an understanding of this element.
    - Lesson 13: Students answer reflection questions designed to get them thinking about how investigations over the course of the unit helped them understand the properties of different materials and the structures of different components and how both can affect the way technology functions (Teacher Edition, page 237).
- *The functions and properties of natural and designed objects and systems can be inferred from their overall structure, the way their components are shaped and used, and the molecular substructures of its various materials.*
    - Lesson 1: Students consider how they can answer their questions about the structure and function of designed objects, including the Bluetooth speaker, the wireless device, and the microwave oven. “In this unit, students will be looking closely at the structures of several different kinds of objects to infer their function, which is to produce or receive electromagnetic radiation. Here, we set students up to be thinking about structure and function in the unit by asking them to consider how we can answer our questions about the structure and function of designed objects (a Bluetooth speaker, a wireless device, and a microwave oven)” (Teacher Edition, page 40). “Once the important components of the system are sketched out (e.g., the microwave oven’s basic structure, the electric cord, something electronic behind the keypad, and so

forth), ask students about the interactions they represented in their models" (Teacher Edition, page 36). "What is an investigation we could do that could help us understand more about the structure of a microwave oven? What could this investigation tell us? What is an investigation we could do that could help us understand more about the function of a microwave oven? What could this investigation tell us?" (Teacher Edition, page 40).

- Lesson 6: Students ask new questions to continue investigating the relationship between the structure of the microwave oven and its interactions with different types of matter (Teacher Edition, page 131). Students analyze data on the molecular materials found in Earth's atmosphere in order to explain its properties and effects on the Earth system temperature. "Concentrations of greenhouse gases in our atmosphere have been increasing drastically over the past few hundred years due to human industry, as shown in the graph below. The data table to the right provides residence data for greenhouse gases in our atmosphere. Residence data explains how long the gases that are released into the atmosphere stay there before they transition into a different Earth system, such as the biosphere (life), geosphere (crust), or the hydrosphere (ocean and other water). Scientists are concerned about the impact of greenhouse gases on global temperatures. They argue that if we fail to reduce the emission of these gases by 2030, it will become increasingly challenging for future generations to reduce their effects on global temperature. Based on the data in the graph and the table, explain which greenhouse gas will have the greatest effect on future generations, and why" (Lesson 6, Assessment – Explaining Temperature Rise).
- Lesson 7: Students explain how the polar and nonpolar structure of molecules can account for temperature and heating differences as food is exposed to changing fields in a microwave oven. Students also read about how electrons move freely in the aluminum, and this can cause large electric fields to build up at the edges of metal which can cause arcing. "This reading also refers explicitly about the use of food containers with a thin metallic layer under a non-metallic lid to speed up the cooking of the food inside. Encourage students to consider how the structure of this container can affect how energy transfers into the food when assessing the validity and reliability of this claim" (Teacher Edition, pages 146–147). "For each matter type, use the questions to connect the conclusions we reached about energy transfer at a macroscopic scale to the observations you made in the simulation. If you notice any limitations of your model or explanation, write a '?' to show this. What happens on a macroscopic scale to matter of each type when we expose them to EM radiation in the microwave oven? What particle-scale observations from the simulation help us to explain this observation?" (Lesson 7, Handout – Field Particle Interactions).
- Lesson 8: Students investigate how the structure of a microwave oven influences energy transfer through wave interference and use the revised consensus model to make inferences about the role of the turntable inside the microwave. "Say, Last class, we made sense of why there are hot and cold spots in the microwave. However, with both the nachos and light bulbs, we had removed the 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, what do you predict will happen?" (Teacher Edition, page 171).

Suggestions for Improvement

General

- In all three dimensions, consider ensuring that students are engaging with the elements claimed in the lessons where the element is called out in the unit overview documents. Alternately, consider removing some of the claims that do not match the student activities or revising the student activities and prompts to better match the claims.
- Consider using language from the element in the student prompts and resources whenever explicit student learning and understanding is a goal.

Science and Engineering Practices

- Lesson 3: Students are asked to plan their investigation, but in their planning, it's not made clear to them why multiple trials are necessary or appropriate. Consider revising the student procedure to make this more explicit to students. After students develop a computational relationship of wave speed, frequency, and amplitude, consider giving them the opportunity to test out the relationship quantitatively. A following investigation where they gather data and then determine the efficacy of their computational model would strengthen the connection to this SEP element.
- Lesson 5: A good deal of instructional time in this lesson is dedicated to students arguing for and against different types of investigations to determine how microwaves interact with different types of matter (Teacher Edition, pages 118–119). Yet, this practice is not currently mentioned in the Elements of NGSS Dimensions document. Consider including SEP **7.3** in this document.
- Consider including explicit prompting for students to consider the validity and reliability of information provided in Lesson 12, similar to the wording of question 2b on the transfer task in Lesson 13.

Disciplinary Core Ideas

- In general, the reviewers found a good match between claimed DCIs and the activities in which students engage in the lessons. In a few cases, the DCI element is incompletely or not at all addressed. Consider removing those claimed elements or partial elements.

Crosscutting Concepts

- Consider adding explicit verbiage for teacher to use in addressing conservation of matter in a closed system, or adjusting claims to clarify that conservation of matter is not a learning goal in this unit.
- Lesson 8: Total energy conservation is not called out explicitly. Consider asking students to consider how energy flows (transfers and transformations) would result in energy conservation within a system.

I.C. INTEGRATING THE THREE DIMENSIONS

Student sense-making of phenomena and/or designing of solutions requires student performances that integrate elements of the SEPs, CCCs, and DCIs.

Rating for Criterion I.C. Integrating the Three Dimensions	Extensive

The reviewers found extensive evidence that student performances integrate elements of the three dimensions in service of figuring out phenomena or designing solutions to problems because, throughout the unit, students are expected to figure out how or why microwave ovens and related phenomena work the way they do. They're sometimes expected to do this in ways that require them to use grade-appropriate elements of the three dimensions simultaneously. The three dimensions are not used in isolation, but instead in tandem with each dimension supporting understanding of the others.

In most activities in the unit, students are expected to figure out something in ways that require the use of three dimensions working together at grade level. Some examples are listed below.

- Lesson 3: Building on Lesson 2 in which they studied a MICROWAVE OVEN manual and watched a video, students wonder how changing electric fields are connected to waves. These questions are used to motivate students to plan and conduct an investigation to gather data that serves as evidence to support their claims about how certain wave properties affect energy transfer in waves. They also develop a mathematical model to identify and test the relationships among frequency, wave speed, and wavelength (Teacher Edition, page 55).
    - SEP: **3.2**. *Plan and conduct an investigation to produce data to serve as the basis for evidence, and in the design: decide on types, how much, ~~and accuracy of data needed to produce reliable measurements and consider limitations on the precision of data and refine the design accordingly.~~*
    - DCI: **PS4.A**. *The wavelength and frequency of a wave are related to one another by the speed of travel of the wave, which depends on the type of wave and the medium through which it is passing.*
    - CCC: **1.4**. *Mathematical representations are needed to identify some patterns.*
- Lesson 8: Students ask questions about the structure and function of technologies that rely on EM radiation. Students collaboratively revise a model of a microwave oven to explain how the components of this system function to heat food and how these structures affect a Bluetooth signal from a wireless device (Teacher Edition, page 152).
    - SEP: **2.3**. *Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationship between systems or between components of a system.*

- DCI: **PS4.B**. *Electromagnetic radiation 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.*
- CCC: **2.2**. *Cause and effect relationships can be suggested and predicted for complex natural and human design systems by examining what is known about smaller scale mechanisms within the system.*

- Lesson 11: Students integrate scientific information to determine the advantages and disadvantages of creating X-ray images using digital transmission and storage of information (Teacher Edition, page 209).
    - SEP: **8.2**. *Compare, integrate and evaluate sources of information presented in different media or formats as well as in words in order to address a scientific question or solve a problem.*
    - DCI: **PS4.A**. *Information can be digitized; In this form, it can be stored reliably in computer memory and sent over long distances as a series of wave pulses.*
    - CCC: **6.1**. *Investigating or designing new systems or structures requires a detailed examination of the properties of different materials, the structures of different components, and the connections of components to reveal its function and/or solve a problem.*
- Lesson 12: Students integrate information of various formats and a model to communicate how modern electronic devices use principles of wave behavior and wave interactions to transmit and capture so much and so many different types of information reliably (Teacher Edition, page 219).
    - SEP: **8.2**. *~~Compare,~~ integrate ~~and evaluate~~ sources of information presented in different media or formats as well as in words in order to address a scientific question or solve a problem.*
    - DCI: **PS4.C**. *Multiple technologies based on the understanding of waves and their interactions with matter are part of everyday experiences in the modern world and in scientific research. They are essential tools for producing, transmitting, and capturing signals and for storing and interpreting the information contained in them.*
    - CCC: **4.3**. *Models can be used to simulate systems and interactions, including energy, matter, and information flows within and between systems at different scales.*

Suggestions for Improvement

None

I.D. UNIT COHERENCE

Lessons fit together to target a set of performance expectations.

i. Each lesson builds on prior lessons by addressing questions raised in those lessons, cultivating new questions that build on what students figured out, or cultivating new questions from related phenomena, problems, and prior student experiences.

ii. The lessons help students develop toward proficiency in a targeted set of performance expectations.

Rating for Criterion I.D. Unit Coherence	Extensive

The reviewers found extensive evidence that lessons fit together coherently to target a set of Performance Expectations (PEs). The lessons fit together in a way that builds upon prior lessons and there is teacher guidance on prompts and phrasing to use to help students see the connections between lessons and why the unit is progressing in this way.

Lessons provide sufficient opportunities for students to build proficiency in most of the learning targeted for all three dimensions. Every lesson in the unit relies on physical science core ideas in order to address how microwave ovens heat food and how modern technologies in health care and communication rely on EM radiation in order to function. For example:

- Lesson 1: Students create initial models that describe matter changes and energy transfer in a microwave oven as it heats food, and when it affects wireless signals such as those between an electronic device and a Bluetooth speaker (Teacher Edition, page 35).
- Lesson 3: Students use mathematical reasoning and representations to identify the pattern that connects frequency, wave speed, and wavelength (Teacher Edition, page 93).
- Lesson 4: Using two different simulations, students examine electric field and magnetic field propagation through space to explain how energy transfers from an antenna to distant charged particles (Teacher Edition, pages 87–90 and 94–96).
- Lesson 5: Students plan an investigation to determine the effect of different materials on energy transfer through microwave; those materials are derived from human-designed systems (that interior surface and door of the microwave oven), and from inspecting cross sections of the door. They compare the behavior of light, another form of EM radiation, and its interactions with different materials. The interaction of visible light is used to draw comparison about how they could detect what is happening if microwaves interact with different materials (Teacher Edition, pages 111–112).

- Lesson 6: Students suggest cause and effect relationships between the concentrations of greenhouse gases and global temperature by examining the interactions between EM radiation and matter on Earth (Lesson 6, Assessment – Explaining Temperature Rise).
- Lesson 7: Students identify that the charge distribution of a particle affects its interaction with the changing electric field. Students use these interactions between changing fields and polar and nonpolar particles to explain changes in temperature at the macroscopic scale (Teacher Edition, pages 142–145).
- Lesson 8: Students suggest cause and effect relationships between wave interference and heat distribution inside the microwave by examining force interactions between two waves (Teacher Edition, pages 162–165).
- Lesson 9: Students use patterns in information provided in a card sort to evaluate different types of EM radiation and argue which types are most likely to cause harm to humans (Teacher Edition, pages 180–182).
- Lesson 10: Using the photon model of light, students conclude that EM radiation tends to only cause ionization if each individual photon has sufficient energy to eject an electron. This explains why infrared light doesn't cause current from a solar cell, and why visible light tends not to increase skin cancer risk (Teacher Edition, pages 205–207).
- Lesson 13: Students answer reflection questions designed to get them thinking about how investigations across the unit helped predict macroscopic cause and effect relationships through examining smaller scale mechanisms within larger systems.
- Several targeted elements of the targeted NGSS PEs are not addressed in student activities and prompts. See non-example evidence in Criterion I.B.

Lessons build on prior lessons by addressing previous questions and cultivating new questions based on what students figured out or related phenomena, problems, and student experiences. Lessons are built on what students learned in previous lessons. Related evidence includes:

- The DQB is developed in Lesson 1 and used to brainstorm questions, investigations, and sources of data that could help figure out the phenomenon. Students return to the DQB in lessons throughout the unit. This routine links questions from the lessons and prior experiences from the perspective of the student.
- The “Navigation” sections at the beginning and end of each lesson make the learning connections between lessons very clear to students and allow the unit to flow logically. This often includes checking the DQB, preliminary models, or discussing what the class has learned so far.

Suggestions for Improvement

- Consider providing more opportunities for students to build proficiency in all of the elements from the targeted PEs for the unit.

I.E. MULTIPLE SCIENCE DOMAINS

When appropriate, links are made across the science domains of life science, physical science and Earth and space science.

i. Disciplinary core ideas from different disciplines are used together to explain phenomena.

ii. The usefulness of crosscutting concepts to make sense of phenomena or design solutions to problems across science domains is highlighted.

Rating for Criterion I.E. Multiple Science Domains	Adequate

The reviewers found adequate evidence that links are made across the science domains when appropriate because the microwave oven phenomenon that students are figuring out can be fully addressed within the domain of physical science. There is a transfer task in which there are connections to Earth science DCIs to apply the DCIs developed and used in the unit. There are a few explicit connections to CCCs across science domains, although there are relatively few for the size and scope of the unit.

The unit has connections to previous units when applicable that have differing DCIs. There is guidance to connect content from these units to the phenomena from this unit. Every lesson in the unit relies on physical sciences core ideas in order to address how microwave ovens heat food and how modern technologies in health care and communication rely on EM radiation in order to function. Related evidence includes:

- Lesson 3: There is a connection to Earth's Interior Unit. "Remind students that we saw waves in Earth's Interior Unit, called seismic waves, moving through Earth. Ask, 'What kinds of force interactions are needed to initiate seismic waves, and how do they transfer energy?' Listen for student ideas such as: Tectonic plates push on each other during an earthquake. They use the bond between the particles of matter" (Teacher Edition, page 64). The Exit Ticket has connections to Earth Systems through seismic waves.
- Lesson 6: There is guidance to connect different science disciplines to energy transferring through systems and the assessment task. "Remind students that this is not the only context where we have been investigating energy transfer through systems. But this is the first time we have included electromagnetic radiation as a part of our models. Display slide D. Ask students the prompt on the slide: What other systems have we investigated where electromagnetic radiation might be an important part of explaining phenomena? Accept all ideas, but look for ideas about sunlight, for example in the context of ecosystems, weather, or climate change. If sunlight does not emerge, suggest it by saying, What about the radiation from the Sun? What systems have we investigated where modeling sunlight as electromagnetic radiation might help us explain phenomena? Introduce a new context. Say, 'Before we go back to the microwave

system, and other technologies that use EM radiation, let's pause to consider how our understanding of electromagnetic radiation can inform some of our models for Earth's systems. In particular, maybe these models can help us better explain why the Earth's surface is warming'" (Teacher Edition, page 132). There is teacher guidance to help students make connections from prior learning from chemistry and biology with regard to carbon dioxide, wildfires, and climate change.

- Lesson 7: There are connections to a previous unit with physical sciences and Earth Sciences DCIs. "In OpenSciEd Unit C.3: How could we find and use the resources we need to live beyond Earth? (Space Survival Unit), students were introduced to properties of water. Students who have done this unit will know more about water as a 'polar molecule'" (Teacher Edition, page 140).
- The unit is focused on developing physical science DCIs. The transfer task in Lesson 6 connects in an Earth and space science DCI, *The foundation for Earth's global climate systems is the electromagnetic radiation from the sun, as well as its reflection, absorption, storage, and redistribution among the atmosphere, ocean, and land systems, and this energy's re-radiation into space*. The connection to this DCI element helps to connect content across multiple science domains.

The usefulness of CCCs to make sense of phenomena is pointed out to students. Grade-appropriate elements of CCCs are explicitly used to make connections among physical science DCIs. However, there are relatively few connections for a long unit of 13 Lessons. For example:

- Lesson 5: There is guidance to help the teacher support students in developing and using the CCC of **Energy and Matter** as they make sense of how waves interact with materials. Specifically, there is a reference back to learning from middle school and a previous unit from another science domain. "Reintroduce the terms absorption, reflection, and transmission from elementary/middle school…sound. If students have experienced the Earth's Interior Unit, ask them what seismic waves do when they encounter matter to help them make connections across disciplines…This is an explicit reference to prior use of these two related elements of this crosscutting concept. Such references can help students recognize the utility of this crosscutting concept, across different contexts: The total amount of energy and matter in closed systems is conserved. Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system" (Teacher Edition, page 109).
- Lesson 6: There is support for students to use CCCs to connect across science domains. "Before we go back to the microwave system, and other technologies that use EM radiation, let's pause to consider how our understanding of electromagnetic radiation can inform some of our models for Earth's systems. In particular, maybe these models can help us better explain why the Earth's surface is warming" (Teacher Edition, page 132). Callouts in the margins help teachers to better support sense-making using the CCCs of **Energy and Matter** as well as **Cause and Effect**.

Suggestions for Improvement

Although some places in the Teacher Edition call out certain CCCs to emphasize with students, only their connections to previous physics and chemistry units are highlighted. Explicitly highlighting connections with these CCCs to life sciences or Earth sciences could help students understand their usefulness across all science domains. Consider adding more connections to other CCCs that are developed in other prior units to better facilitate student understanding of the usefulness of CCCs in sense-making across science domains.

I.F. MATH AND ELA

Provides grade-appropriate connection(s) to the Common Core State Standards in Mathematics and/or English Language Arts & Literacy in History/Social Studies, Science and Technical Subjects.

Rating for Criterion I.F. Math and ELA	Extensive

The reviewers found extensive evidence that the materials provide grade-appropriate connections to the Common Core State Standards (CCSS) in mathematics, English language arts (ELA), history, social studies, or technical standards because speaking and listening to peers in the classroom and scientific reading and writing skills are used multiple times throughout the unit to explain and communicate their understanding of scientific concepts, phenomena, and the results of their investigations. The Teacher Edition for each lesson explicitly state the ELA and mathematics standards that are used by students.

Students are expected to synthesize information from a range of sources including diagrams, text, and videos in order to develop a coherent explanation of how a microwave oven can be used to heat food or disrupt the digital signals from wireless devices. Later, they extend their understanding of waves to evaluate other sources of information about human uses of EM radiation. Students have daily opportunities for speaking and listening to peers to communicate their emerging understanding and questions about the phenomenon. The opportunities include paired, small group, and whole class discussion. For example:

- Lesson 1: Students use a close reading protocol to read a modified version of a microwave oven manual and then use this to discuss safety precautions when using a MICROWAVE OVEN: “Ask students what they figured out from the manual about any safety precautions we should take. Title a piece of chart paper ‘Precautions Before Using the Microwave Oven’ and create a public record of their ideas” (Teacher Edition, page 33).
- Lesson 2: Students watch a YouTube video showing a magnetron dissection to answer the question: “What parts or materials [in the magnetron] seem especially important?” (Teacher Edition, page 46). Next, students engage in a technical reading about the magnetron and answer text dependent questions (Lesson 2, Handout – The Magnetron). The teacher uses the reading to lead a discussion about how electric fields affect energy transfer inside and outside the magnetron (Teacher Edition, page 47). These activities are related to **CCSS.ELA-LITERACY.RST.11-12.9.**

- Lesson 6: Students compare and integrate a variety of sources in text and graphical form to explain how the radiation interacting with greenhouse gases contributes towards the increased global temperatures on Earth. This is related to **CCSS.ELA-Literacy.R1.11-12.7** "Integrate and evaluate multiple sources of information presented in different media or formats as well as in words in order to address a question or solve a problem."
- Lesson 7: Students evaluate information regarding the use of aluminum foil inside the microwave from two different sources. Their evaluation focuses on the validity and reliability of the claims presented in the sources. The molecule cutouts are intended to be a source of support evaluating these and later claims. These activities are related to **CCSS.ELA-Literacy.R1.11-12.7** "Integrate and evaluate multiple sources of information presented in different media or formats as well as in words in order to address a question or solve a problem" (Teacher Edition, page 149).
- Lesson 10: Students ask questions about whether increases in energy of waves occur through higher frequency or higher amplitude and how this contributes to increased risk of cancer. Students use evidence from the cards from Lesson 9 and two readings related to health and wellness information, and a solar cell to find patterns and determine that higher frequency EM radiation can cause skin cancer (Teacher Edition, pages 200–207). These activities are related to **CCSS.ELA-Literacy.R1.11-12.7** "Integrate and evaluate multiple sources of information presented in different media or formats as well as in words in order to address a question or solve a problem."
- Lesson 11: "As students read about how digital and conventional radiography work, they need to synthesize the process through which EM radiation is used to create images of the internal structure of the body" (Teacher Edition, page 217). This activity is related to **CCSS.ELA-Literacy.R1.11-12.7** "Integrate and evaluate multiple sources of information presented in different media or formats as well as in words in order to address a question or solve a problem."
- Lesson 12: Students gather information from multiple sources in various formats from four different stations. They integrate this information with our model to summarize how wireless electronic devices are designed to use EM waves to reliably communicate different types of information. Students write an informative text that integrates information about multiple technical processes as well as fundamental scientific mechanisms related to wave behavior when they complete their summary on Gather Station Information (Teacher Edition, page 232).
- Lesson 13: There is an explicit connection to literacy. **CCSS.ELA Literacy.SL.11-12.1.D**: "Respond thoughtfully to diverse perspectives; synthesize comments, claims, and evidence made on all sides of an issue; resolve contradictions when possible; and determine what additional information or research is required to deepen the investigation or complete the task." When students complete the final assessment, they need to identify the claims presented by two social media posts and discuss what parts of each post they agree and disagree with, considering the types of evidence used to support the post (Teacher Edition, page 239). However, note that students do not speak or listen in this assessment. They read and thoughtfully respond through writing, which does not align fully to this SL standard.

There is a reasonable match between the scientific subject matter of the unit and the mathematical skills used by students for sense-making. For example:

- Lesson 3: Students use a physical manipulative to help identify where energy is stored and transferred as a wave moves across a spring. These identified quantities are then used to build a descriptive model of how energy is transferred in a wave (**CCSS.MATH.CONTENT.HSN.Q.A.2**, Teacher Edition, page 79). Students identify the mathematical relationships between frequency, cycles, time, and distance. For example, students express period as time/cycle to make sense of the inverse relationship between frequency and period. They use these relationships to develop a mathematical model that shows how an emergent property of the system (wavelength) is related to two variables: a property of the medium (wave speed) and an independent input property of the wave (frequency) (**CCSS.MATH.CONTENT.HSA.SSE.B.3**).
- Lesson 9: Students use scientific notation to compare how much greater the difference is in wavelength and frequency between different types of EM radiation. "In this lesson, students will use scientific notation to compare how much greater is the difference in wavelength and frequency between the different types of EM radiation. This is an 8th grade CCSS. If you want to provide additional practice, you can remove the values written in scientific notation from the Electromagnetic Radiation Cards and ask students to express the values in scientific notation." They also use the expression that they developed in Lesson 3 to estimate the speed of a wave based on frequency and wavelength of different types of EM radiation, which aligns to **CSS.MATH.CONTENT.HSA.SSE.B.3** (Teacher Edition, page 183).

Suggestions for Improvement

Consider revising the claimed CCSS-ELA standards addressed in the Lesson 13 transfer task. Students are not currently expected to speak or listen in this assessment, only read, and respond in writing.

OVERALL CATEGORY I SCORE: **2** (0, 1, 2, 3)	
Unit Scoring Guide – Category I	
Criteria A-F	
3	At least adequate evidence for all of the unit criteria in the category; extensive evidence for criteria A–C
2	At least some evidence for all unit criteria in Category I (A–F); adequate evidence for criteria A–C
1	Adequate evidence for some criteria in Category I, but inadequate/no evidence for at least one criterion A–C
0	Inadequate (or no) evidence to meet any criteria in Category I (A–F)

CATEGORY II

NGSS INSTRUCTIONAL SUPPORTS

II.A. RELEVANCE AND AUTHENTICITY

II.B. STUDENT IDEAS

II.C. BUILDING PROGRESSIONS

II.D. SCIENTIFIC ACCURACY

II.E. DIFFERENTIATED INSTRUCTION

II.F. TEACHER SUPPORT FOR UNIT COHERENCE

II.G. SCAFFOLDED DIFFERENTIATION OVER TIME

II.A. RELEVANCE AND AUTHENTICITY

Engages students in authentic and meaningful scenarios that reflect the practice of science and engineering as experienced in the real world.

i. Students experience phenomena or design problems as directly as possible (firsthand or through media representations).

ii. Includes suggestions for how to connect instruction to the students' home, neighborhood, community and/or culture as appropriate.

iii. Provides opportunities for students to connect their explanation of a phenomenon and/or their design solution to a problem to questions from their own experience.

Rating for Criterion II.A. Relevance and Authenticity	Extensive

The reviewers found extensive evidence that the materials engage students in authentic and meaningful scenarios that reflect the real world because the anchor phenomenon is widely relatable — microwave ovens heat food — and students experience the phenomenon firsthand and through different representations, which include models, texts, simulations, and firsthand investigations of a microwave heating matter in different conditions. The curriculum materials provide supports for teachers for cultivating students' questions and ideas based on their background knowledge and what they've learned in the unit. Students experience the anchor phenomenon firsthand and through various media representations.

Students experience phenomena as directly as possible, and the navigation routine in many lessons provides opportunities for connections between the instruction and students' own experiences. The Teacher Edition often provides guidance to the teacher on how to elicit students' background knowledge and questions. Related evidence includes:

- Lesson 1: Students directly observe two classroom demonstrations using a microwave: the speaker demonstration and the nachos demonstration. "Make observations of a speaker paired to a device that is inside an unplugged microwave oven…Heat a plate of nachos inside the microwave oven and make observations" (Teacher Edition, page 26).
- Lesson 2: Students directly observe a lightbulb in a microwave. "Heat a light bulb in the microwave oven to test for electric fields" (Teacher Edition, page 42).
- Lesson 6: Students revisit what they've learned thus far about EM radiation and matter interactions. They have the opportunity to pose new questions to add to the DQB (Teacher Edition, page 131). Later, they show their understanding of the ways in which EM radiation and matter interact on Earth through a transfer task that asks them to explain the increase in global average temperature as a result of greenhouse gas emissions (Lesson 6, Assessment – Explaining

Temperature Rise). Students are therefore supported to see how the instruction is relevant to humans.
- Lesson 8: The microwave oven is used to do a demonstration with hot and cold spots in the oven. “Lead a whole group safety discussion about the small light bulbs in the microwave oven, then run the experiment as a demonstration to the whole class…Lead a whole group safety discussion about adding the turntable to the lightbulb experiment, then run the experiment as a demonstration to the whole class” (Teacher Edition, pages 153–154).
- Lesson 13: Students use their understanding of waves, EM radiation (energy), and its effects on matter to evaluate the validity and reliability of claims in published materials of the relative dangers of 5G technology commonly used in today’s cell phones (Teacher Edition, page 238). Students are therefore supported to see how the instruction is relevant to humans.

The unit includes suggestions for how to connect instruction to the students’ homes, neighborhoods, communities, or cultures as appropriate. For example:
- Lesson 1: In home learning, students talk to family members about their experiences with MICROWAVE OVENs and their experiences with wireless signals being distorted (Teacher Edition, page 37). In the next class, students debrief about their home learning and then brainstorm and record related technology. “Present slide R. Title the right side of the T-chart poster ‘Related Technology’, and use the prompts on the slide to complete it with students’ ideas: What are some other human-made technologies that you think might use similar structures or mechanisms to function? How do you know?” (Teacher Edition, page 37). In relating the phenomena to other experiences and after the at-home learning assignment, there is a chance that students could connect related phenomena and technology to their homes, neighborhoods, communities, and/or cultures. “What related phenomena have we experienced or heard about in which a wireless signal is distorted? What other phenomena related to microwave ovens have we experienced or heard about?... What are some other human-made technologies that you think might use similar structures or mechanisms to function? How do you know?” (Teacher Edition, page 37). A suggestion is provided for students to select the music to play. “Give students the opportunity to bring their authentic selves into the science classroom by eliciting suggestions for what music to play” (Teacher Edition, page 31).
- Lesson 7: Students can connect learning to their own experiences as they consider their knowledge of microwave ovens and what they heat up. “Does every substance that we put in the microwave absorb electromagnetic radiation just like water? What evidence do we have for this? If students are having trouble finding examples here, point them to the investigation we did in Lesson 1 heating up food, or the investigations we did in Lesson 5. They should notice either from these investigations or their own experience that not all the containers and food items heat up as quickly as water does” (Teacher Edition, page 139).
- Lesson 10: In the Teacher Edition, there is guidance for students to develop their own analogies and share them with another pair of students. “What represents ionization in your analogy? What objects absorb and emit photons? How is that similar or different from the water wave analogy? What represents changes in frequency and amplitude? How is that similar or different

from the water wave analogy?" relating to Question 4. The analogy connection allows students to connect content to their own experiences.

- Lesson 11: There is a connection to students' use of devices. "Say, I saw some questions in the DQB about the connection between the bluetooth[sic] speaker and the cellphone, and how our devices shared music with one another. But we know that our devices can communicate more than music. Elicit 1–2 ideas with the prompt: What types of information can we communicate with our current devices?" (Teacher Edition, page 213).

Unit activities provide students with opportunities to connect their explanations of phenomena or their design solutions to a problem to questions from their own experience. For example:

- Lesson 1: When students are given the article about the trend of people storing their phones, keys, and electronic devices in microwaves, the teacher is prompted to ask students, "What do you predict will happen when we try to connect to the device while it is inside the microwave oven (when it is off)? What experiences or ideas support your prediction?" (Teacher Edition, page 31). Before completing the second demonstration, the teacher is prompted to ask students, "What experiences or ideas do you have that suggest microwave technology might pose a risk?" (Teacher Edition, page 32).
- Lesson 1: The DQB is established. "Distribute sticky notes, markers, and pencils to each student. Ask students to develop questions for the DQB on their own, using the resources listed on the slide… Consider the resources you have gathered over the past few days, including: your Notice and Wonder chart, the Microwave Oven Manual, our class consensus model, conversations with friends/family, our Related Technology and, Phenomena poster" (Teacher Edition, page 38). This DQB is revisited multiple times in the unit.

Suggestions for Improvement

Consider suggesting more ways to connect the learning to students' homes, neighborhoods, communities, and cultures. For example, when learning about wireless signals, students could find out where cell phone towers are located in their area or where there might be stronger or weaker signals. Students could ask family members about their experiences with many of the EM technologies they are learning about, etc.

II.B. STUDENT IDEAS

Provides opportunities for students to express, clarify, justify, interpret, and represent their ideas and respond to peer and teacher feedback orally and/or in written form as appropriate.

Rating for Criterion II.B. Student Ideas	Extensive

The reviewers found extensive evidence that the materials provide students with opportunities to both share their ideas and thinking and respond to feedback on their ideas. The materials have numerous, varied opportunities for students to express and clarify their ideas and the reasoning behind those ideas, produce artifacts that show reasoning about core ideas and phenomena, and include supports to guide the teacher in providing feedback to students.

Materials provide support to teachers for listening to students' ideas. There are multiple opportunities for students to express and clarify their reasoning. Each lesson's Teacher Edition provides a "Where are we going" and "Where are we not going." This provides teachers with information about the most salient science ideas in the lesson and how to avoid giving away the key concepts and ideas to students before it's relevant to their learning. The navigation routine in each lesson affords time for teachers and students to discuss what was learned in the previous lesson or elicit student ideas and questions. Lesson supports provide teachers with guidance on how to provide feedback, and the unit overview provides guidance on how to help students give, receive, and respond to peer feedback. In many lessons, students listen to their peers through paired, small group, and whole class discussion. In a few instances, students give constructive feedback to peers. Related evidence includes:

- Lesson 1: There is guidance for teachers to provide oral feedback on student thinking throughout the unit to distinguish "microwave oven" from "microwave radiation." "If they use the word microwave ambiguously, help them clarify their thinking with a question such as, 'When you say *microwave* are you talking about the microwave oven, or about the microwave radiation that is referenced in the manual?'" (Teacher Edition, page 33).
- Lesson 1: Students create initial models, give peer feedback, then incorporate the peer feedback into their models. Students are given 10 minutes to work on initial models. An Initial Modeling Peer Feedback handout is given to students with colored pens to provide feedback with guided questions. "In partners, have students take turns discussing the feedback they gave, and listening carefully to their partner's feedback, for about 5 minutes. Then, have students work individually to incorporate the feedback into their own models" (Teacher Edition, page 35). This is then used to build a class consensus model.
- Lesson 2: There is guidance for helping build understanding in the discussion with students clarifying and justifying their ideas. "Use probing questions such as, 'What do you mean when you say ___?' to get students to elaborate. Ask other students whether they agree, disagree, or have something to add, and encourage them to respond to their classmates' ideas." (Teacher Edition, page 47). Note, however, that the Lesson 2, Handout – Student Procedure, page 5 seems to be more closely associated with the activities in Lesson 3, not Lesson 2. In Teacher Edition, Lesson 2 there is no reference to waves on a string.
- Lesson 3: There is specific guidance for students to represent their ideas in the Wave Simulation Observation. "Encourage them to label parts of the image in whatever way helps them think, and to use the back of the handout for any additional drawings they want to record" (Teacher Edition, page 68). There is guidance for helping students respond to peers in the consensus conversation the next day. "Encourage multiple students to weigh in on collectively deciding how these variables should be defined and visually represented. Have them write or draw consensus ideas on the poster, as you facilitate whether we have consensus around what we are representing and how we are describing it" (Teacher Edition, page 69).
- Lesson 5: After the two microwave investigations, students individually revise the class model before getting feedback from peers and then add things as needed as they work with a partner.

"After 4 minutes, ask students to stand up, pair up, and share with a partner to compare their representations. As students are doing this, encourage students to add any additional annotations or written explanations to their model that help make their thinking more visible around the question they just discussed with a partner" (Teacher Edition, page 123).

- Lesson 7: "If most student work shows clear understanding of key ideas as described in the Field-Particle Interactions Key, then the beginning of day 2 can run as described in this lesson. Students will not need more individual practice modeling if this work shows that they have developed this skill. Give students some targeted feedback on their Exit Tickets, and prepare to hand these back at the beginning of day 2. However, if most students' work does not show understanding of the key ideas described in the Field-Particle Interactions Key, do not simply push through to the consensus model without acknowledging students' confusion. Instead take additional class time to try the following strategy..." (Teacher Edition, page 144).
- Lesson 8: Students have the opportunity to compare their models and give feedback to others. "Describe the activity using the prompts: Add check marks in places of the model that agree with your 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 their peers' models. If students are having trouble identifying the limitations of the models, ask them whether the model they are evaluating explains the patterns of lights on/off inside the microwave oven. Review feedback on models. Ask students to return to their group posters and take a minute to review the feedback on their poster. Let students know that they will have a chance to revise their model after we investigate more causal mechanisms" (Teacher Edition, pages 161–162). "Before the next class, look over students' work and provide written feedback on their matter, energy, and forces reasoning for interactions A and B and scan responses to interactions C and D. If a large portion of the 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" (Teacher Edition, page 164).
- Lesson 9: Students have the opportunity to present an argument they created with their groups, give feedback, and revise their argument. "Once all pairs have been formed, provide them with a set of Electromagnetic Radiation Cards and read the prompts on the slide to describe the task: 1. Each student will have 1 minute to present their argument. 2. The other person will have 1 minute asking questions and giving feedback about the ideas presented…Ask students to go back to their seats. Instruct students to revise their argument by reading the prompt: Based on the discussion you had with your peer, revise your argument in Part 4 of the handout" (Teacher Edition, page 185).
- Lesson 10: Students complete The Photon Model and get feedback from peers and the teacher on Questions 3 and 4. "Ask pairs to join with another pair and give feedback. Display slide T. Circulate around the room as students share. Allow students to ask questions first, but if they are hesitant to contribute, model use of the question starters in your own questioning: What represents ionization in your analogy? What objects absorb and emit photons? How is that similar or different from the water wave analogy? What represents changes in frequency and amplitude? How is that similar or different from the water wave analogy? Listen for groups who are making connections between the evidence and their models. Identify 1–2 groups and point

out that their explanation will be useful to share with the whole group. Ask students permission to raise their models with the whole group on the next slide" (Teacher Edition, page 204). During the class consensus conversation, "Press the class to connect evidence about ionization and solar cell electron output to the particle model. Use this discussion about two models of light to check for understanding about ionization and solar cell details outlined in The Photon Model" (Teacher Edition, page 206).

Suggestions for Improvement

None

II.C. BUILDING PROGRESSIONS

Identifies and builds on students' prior learning in all three dimensions, including providing the following support to teachers:

i. Explicitly identifying prior student learning expected for all three dimensions

ii. Clearly explaining how the prior learning will be built upon.

Rating for Criterion II.C. Building Progressions	Adequate

The reviewers found adequate evidence that the materials identify and build on students' prior learning in all three dimensions. Teacher materials, including the unit storyline, front matter, and each lesson explicitly describe for teachers how each lesson builds on the previous lesson and how it connects to the next lesson. However, learning progressions for SEPs and CCCs within the unit are not described.

The front matter of the unit provides a detailed synopsis of how learning will be built upon on all three dimensions. It also displays through graphical representations where the CCCs and SEPs fit within the courses of this instructional program across high school. "Where we are going and not going" boxes key in on pieces of prior knowledge as well as progressions. Side boxes emphasize focal SEP and CCC progressions. Related evidence includes:

- The materials state DCIs that should have been previously developed in the OpenSciEd High School Biology and Chemistry courses and the previous units in the physics course. There is also a list of DCI elements that indicate prior student learning from the Middle School sequence (Teacher Edition, pages 17–18).
- There is a chart that lists out what CCCs and SEPs categories — but not elements — were developed in previous OpenSciEd High School units. "This unit uses and builds upon high school level Science and Engineering Practices (SEPs) and Crosscutting Concepts (CCCs) that students

should have previously developed in OpenSciEd High School Biology and Chemistry, and will continue to build in future units. The progressions of these practices and concepts across the program are as follows" (Teacher Edition, page 18).

- The "Where are we Going and Not Going" sections of each lesson have guidance on how the DCIs and SEPs are built upon, although similarly clear guidance was not found related to the CCCs. Examples include:
  - Lesson 1: "Because this is the first lesson in a new unit, the goal is not to establish any ideas associated with the relevant DCIs (PS4), but rather to elicit student ideas related to that DCI…Students should already have an understanding of energy transfer and modeling tools to create energy transfer diagrams (as developed in Electricity Unit). Students should also understand that waves transfer energy, and that their speed is affected by the medium they are passing through (ideas developed in Earth's Interior Unit). In the first lesson set of this unit, we review different characteristics of waves that will help students understand how electromagnetic waves work" (Teacher Edition, page 30).
  - Lesson 3: "We support SEP 3.2 through collaboratively identifying independent and dependent variables and providing structures for recording students' process. We further support it by suggesting a number of trials for the first simulation investigation (amplitude) and then provide gradual release of this scaffold, by having students reevaluate and refine their procedure for collecting data in light of limitations they encountered in the first investigation when they plan and carry out the second, third, and fourth investigations (frequency, tension, and damping). We support students in communicating claims by providing a sentence stem that scaffolds clear use of independent and dependent variables. Students will continue to work on planning and conducting investigations in future lessons" (Teacher Edition, page 59).
  - Lesson 4: During exploration of static fields in the PhET simulation the teacher reminds students to consider frequency and amplitude while making sense of the movement of electrons in the two antennae. "Present slide D. Say, 'We noticed that electrons in the magnetron's antenna move up and down, or vibrate. The simulation allows us to control the vibration of the first electron. It allows us to change the amplitude, and the frequency of the motion. Let's think back to our work with the Wave on a String simulation to remember what amplitude and frequency are'. Point to the Physical Wave Properties poster from Lesson 3" (Teacher Edition, page 83).
  - Lesson 5: "In Lesson 4, students also began to create a model for how the microwave radiation interacts with the parts of the microwave system, and refine this model in this lesson. This gives students experience in engaging with Science and Engineering Practice (SEP) 2.3 over time, using their models to make predictions about the relationships between the parts of the system, and revising their models based on data collected in their investigations. While the model of the two bowls are[sic] modeled without a foil covering as a whole class, the students independently construct their models of one of two conditions using foil" (Teacher Edition, page 107).

- Lesson 7: At the beginning of the lesson students draw on their learning from Lesson 6 and then compare representations of water and ethylene molecules. They identify similarities and differences between the structures of the two molecules so they can begin to explain why some types of matter increase in temperature in a microwave, but other types of matter do not (Teacher Edition, page 140). This also connects this previous learning: “In OpenSciEd Unit C.3: How could we find and use the resources we need to live beyond Earth? (Space Survival Unit), students were introduced to the properties of water. Students who have done this unit will know more about water as a ‘polar molecule’. When students use the term polar molecule, take a moment to remind students what that means. Ask, what do you mean by polar molecule? What is it about a water molecule that classifies it as a polar molecule?” (Teacher Edition, page 140).
- Lesson 8: “The coverage of PS4.B.2 and PS4.C.1 build off their initial use in this unit in Lesson 1, when students construct their initial consensus model of how the microwave oven heats food and why the music from the speaker was affected when one device was in the microwave oven. These DCIs will continue to be developed in the second lesson set, where the portions about ionization and information transfer will be covered. PS4.B.2 was also previously developed within Lessons 5 and 7. The first part of PS4.B.1 was established in Lesson 4 and used throughout the first lesson set. The wave model part of this DCI will be covered in Lesson 10" (Teacher Edition, page 157).

Explicit support is provided to teachers to clarify potential alternative conceptions that their students may have while building towards students’ three-dimensional learning. A progression of learning for the SEPs and CCCs across the course and across the high school program is claimed in this section also, but the descriptions rarely include information about how the SEPs and CCCs will be built upon through this unit.

- Unit Overview: On page 20, there is a list of relevant ideas that students may come into the unit with followed by conceptual information to support teachers’ knowledge of key concepts in the unit.
- Front matter: There is a section titled, “What are the three-dimensional ideas in the context of the unit?” However, although this section says that several SEP and CCC categories are intentionally developed, their development is not described. Instead, this section describes what students do with SEPs and CCCs during the unit. From the section: “This unit is designed to introduce students to the concept of electromagnetic radiation in a relevant and familiar context. Developing and using models is intentionally developed in this unit, as students model energy transfer through electromagnetic radiation. Students model how moving charged particles cause changing electric fields that in turn cause changing magnetic fields to understand how electromagnetic radiation can transfer energy to matter at a distance. Students model energy flow inside a microwave oven to explain how the structure of the microwave oven is designed to create patterns of constructive and destructive interference. Students also model particle level interactions with changing fields to explain why some substances heat up more than others in the microwave oven. Students evaluate the merits and limitations of the wave model and photon model to explain the interactions of high frequency EM radiation and

mattern[sic]. Finally, they integrate different sources of information to model how wireless electronic devices use EM waves to reliably communicate different types of digital information. To support using these energy models to make sense of EM radiation, energy and matter and cause and effect are both intentionally developed throughout the unit. Planning and carrying out investigations are intentionally developed in this unit, beginning in Lesson 1 when students brainstorm investigations that they would like to do to answer their questions about the microwave oven and related technology. They will plan and conduct an investigation to support their claims about how frequency and amplitude affect how much energy a wave can transfer. Students will also plan an investigation collaboratively to produce data to determine what happens to the energy transferred by microwave radiation when it reaches different parts of the microwave oven structure. As can be noted, structure and function are intentionally developed as students consider not only how the structure of the microwave oven affects energy transfer, but also how the charge distribution at the particle level can help explain why some substances heat up more than others in the microwave oven. Obtaining, Evaluating, and Communicating Information is intentionally developed over the entire unit. Students evaluate multiple claims from advertisement media to determine the validity and reliability of claims made about the safety of technologies that use EM radiation, and about the interaction of matter with electromagnetic radiation. Students will also have multiple opportunities to integrate multiple sources of information to explain how different applications of modern technologies use principles of electromagnetic radiation and its interaction with matter" (Teacher Edition, page 14).

- Lesson 1: There is guidance regarding the CCC of **Structure and Function**, both what prior learning was done and how it will be built upon. "The crosscutting concept of Structure and Function is intentionally developed across this unit. In grades 6–8, students analyzed complex natural and designed structures and systems to determine how they function. Now, in high school, students should be ready to infer the functions and properties of natural and designed objects and systems from their overall structure, the way their components are shaped and used, and. In earlier units in this course, students considered how the the[sic] molecular substructures of their various materials affect their function in the contexts of breaking/bending rock, and vehicle safety. In this unit, students will be looking closely at the structures of several different kinds of objects to infer their function, which is to produce or receive electromagnetic radiation. Here, we set students up to be thinking about structure and function in the unit by asking them to consider how we can answer our questions about the structure and function of designed objects (a Bluetooth speaker, a wireless device, and a microwave oven)" (Teacher Edition, page 40).
- Lesson 4: There is guidance regarding the CCC of **Cause and Effect** regarding what prior learning was done and what related activities will be done in the unit. Note, however, that development of the CCC is not described. "In grades 6–8, students use cause-and-effect relationships to predict phenomena in natural or designed systems. In high school, students figure out that cause-and-effect relationships can be suggested and predicted for complex natural and human-designed systems by examining what is known about smaller-scale mechanisms within the system. Here, students examine what is known about electric field and magnetic field

propagation through space (a small-scale effect) to explain how energy transfers from an antenna to distant charged particles (a large-scale system)" (Teacher Edition, page 97).

Suggestions for Improvement

- Consider providing a clear description of the expected level of prior learning with individual elements of all three dimensions for the targeted learning in the teacher support materials. For example, some SEP or CCC elements might have been partially developed in a prior unit, so knowing which parts students are expected to understand would be useful to the teacher.
- Consider providing clear descriptions in each lesson's "Where Are We Going" section for how each element of all three dimensions is being built upon (new learning and development) from previous learning.

II.D. SCIENTIFIC ACCURACY

Uses scientifically accurate and grade-appropriate scientific information, phenomena, and representations to support students' three-dimensional learning.

Rating for Criterion II.D. Scientific Accuracy	Extensive

The reviewers found extensive evidence that the materials use scientifically accurate and grade-appropriate scientific information. All science ideas and representations related to electromagnetic radiation are accurate and associated with the three dimensions included in the PEs stated in the materials as aligned to the unit. However, there are some minor areas that may lead to some misleading in student learning.

All science ideas represented in unit materials appear to be accurate and related to the three dimensions outlined in performance expectations aligned to the unit. Related evidence includes:

- The unit provides a Teacher Background section in the Teacher Edition with information about lab safety and how the DCIs are used in the context of this unit (Teacher Edition, pages 10–24). "Additional Guidance" sections throughout the Teacher Edition provide background information for the teacher that is scientifically accurate.
- Lessons 1–2 engage students in learning about electromagnetic radiation with emphasis on microwaves.
- Lesson 3 engages students in learning about wave properties (amplitude, frequency, wavelength) to help them later explain energy transfer in MICROWAVE OVENs.
- Lesson 4 helps students make connections between wave properties and electric and magnetic fields in two simulations in order to develop ideas used in later lessons about how microwaves can be used to heat foods.

- Lesson 5 draws on students' background knowledge about the interaction between visible light and matter and helps them connect it to how microwaves might interact with different types of matter in a microwave oven.
- Lesson 6 engages students in considering other types of electromagnetic radiation, specifically ultraviolet radiation, and x-rays.
- Lessons 7–12 supports students in developing understanding of the relationship between electric forces and magnetic fields.

A suggested teacher prompt in the unit might be misleading for students. In Lesson 7, students use molecule representations (paper cutouts) and a simulation to illustrate relationships between components of a system. The teacher is told, "Pass out one molecule cutout per student while they are working through the Turn and Talk. Encourage students to use the cutouts to consider how different charges would respond in the presence of an electric field. Say briefly, Try using these to help visualize what different parts of each molecule would feel in an electric field" (Teacher Edition, page 141). It is possible that students might interpret this wording to mean that molecules or parts of molecules would perceive feelings.

Throughout the unit, students read articles. These articles are written at a grade-appropriate level, although the source of these articles is not always clear. Students are given opportunities in the unit to use strategies to determine the credibility and accuracy of texts. For example:

- Lesson 4: There is a note about the Luminiferous Ether reading in Lesson 4 and its scientific accuracy. "The idea of the ether through which light must move may not be scientifically accurate, but it is a productive idea that was tested extensively by physicists in the 19th century, leading to a more complete understanding of how light moves through space without a medium. Following the history of these ideas and building explicitly from these ideas to draw connections is a productive pedagogical tool that will help students construct a new, more accurate conceptual model for radiation" (Teacher Edition, page 20). The reading explicitly says scientists now have a very different understanding of light.
- Lesson 11: The X-Ray article is adapted for classroom use from a scientific article. "Make sure you mention to students that the information presented in this reading is based on the following scientific article: Bansal, G. J. (2006). Digital radiography. A comparison with modern conventional imaging. Postgraduate medical journal, 82(969), 425–428. In addition to adapting the information in the original text for classroom use, we added additional text about digital information" (Teacher Edition, page 214).
- Lesson 13: Citations are provided for the two social media posts (Evaluating 5G Safety).

Suggestions for Improvement

Consider providing citations for diagrams, charts, and graphs that are adapted from external sources. Consider providing citations for all articles and texts of information that are from external sources, such as "Light as a Wave," "The Magnetron," and "Electromagnetic Radiation Cards."

II.E. DIFFERENTIATED INSTRUCTION

Provides guidance for teachers to support differentiated instruction by including:

i. Supportive ways to access instruction, including appropriate linguistic, visual, and kinesthetic engagement opportunities that are essential for effective science and engineering learning and particularly beneficial for multilingual learners and students with disabilities.

ii. Extra support (e.g., phenomena, representations, tasks) for students who are struggling to meet the targeted expectations.

iii. Extensions for students with high interest or who have already met the performance expectations to develop deeper understanding of the practices, disciplinary core ideas, and crosscutting concepts.

Rating for Criterion II.E. Differentiated Instruction	Extensive

The reviewers found extensive evidence that the materials provide guidance for teachers to support differentiated instruction because the Teacher Edition explicitly indicates where students might struggle, and this is coordinated with a range of specific strategies to support student success. There are differentiation strategies to support the needs of multilingual learners, students who read below grade level, and struggling students. However, most student supports are general strategies rather than being specifically targeted to the three dimensions of the learning goals. There is also little information on how to support students with disabilities.

Differentiated strategies in the unit address the needs of different groups of learners. Related evidence includes:

- Universal Design for Learning callout boxes are in multiple lessons and support strategies for students with different learning needs. These boxes call the teacher's attention to specific strategies that can help all students. Some examples include:
    - Lesson 3: "This lesson makes use of multiple media with the simulation, handout, and chart of words and images. This provides multiple ways that students see information represented and can express and communicate their understanding. Using multiple forms of media to present and make sense of information provides more access for the diverse learners in your classroom" (Teacher Edition, page 70).
    - Lesson 10: "A focus question and sub questions have been added to the Amplitude/Frequency Evidence. The use of focus questions to[sic] help students engage in the task. These focus questions help students to remember the goals they have established for use of the handout. Further periodic questions also help students to create short term comprehension objectives that guide students towards the overall goal of the handout" (Teacher Edition, page 197).

- Lesson 2: The reading "The Magnetron" has questions that break up the reading into smaller pieces. There is a scaffolding strategy where the first paragraph and questions are done together (Teacher Edition, page 47).
- Lesson 3: Students manipulate a slinky and use paper next to the slinky to create a three-dimensional manipulative model (Teacher Edition, page 64). Students then go to a computer simulation after and compare it to the tactile model. "Point out that though its initial behavior has many similarities to the physical system we used in class, the simulation also has the ability to keep moving the initial particle back and forth" (Teacher Edition, page 67).
- Lesson 7: In the Handout – Field-Particle Investigations, students observe a simulation with a handout to help them express their thinking. "Most prompts in the handout give students the chance to express their thinking in words or pictures. This is intentional, as emergent multilingual learners may find it easier to model their thinking with minimal use of language…If students struggle to put their thinking into words, consider providing them with sentence frames…" (Teacher Edition, page 141).
- There are callouts for "Attending to Equity" where there are supports to help students better access instruction, particularly with language and making sense of the content. Some examples include:
  - Lesson 3: "As students identify frequency as a variable, help them make connections to the everyday ways they use the word" (Teacher Edition, page 69).
  - Lesson 7: "Encourage students to physically move these paper models to make sense of the relationship between changing electric fields, electric charge, and particle motion. Physical action provides multiple means of Action and Expression" (Teacher Edition, page 141).
  - Lesson 12: "Students should be encouraged to record their ideas using linguistic (e.g., written words) and nonlinguistic modes (e.g., drawings, tables, graphs). This is especially important for emerging multilingual students because making connections between written words and nonlinguistic representations helps students generate richer explanations of how digital communication works" (Teacher Edition, page 229).

Support is provided during the unit for emergent multilingual students. For example:

- Lesson 3: "Supporting emergent multilinguals: It can be very helpful for all students, and particularly emergent multilinguals, to break down compound words like microwave. Prompt students to reason about the first part by asking, 'What does *micro* mean to you? What other words have you heard that use the prefix micro?' They will probably say 'microscope'. Encourage them to make connections to uses of the prefix micro in other languages. Then summarize the idea of putting both words together--micro and wave--to make a single compound word indicating that this particular wave is smaller than other waves we may encounter" (Teacher Edition, page 61).
- Lesson 4: "Supporting emergent multilinguals: It can be very helpful for all students, and particularly emergent multilinguals, to express their ideas using nonverbal forms of communication. Use students' hand motions as a check for understanding. It will give you an

idea of how students are appropriating frequency and amplitude to make sense of particle motion" (Teacher Edition, page 87).
- Lesson 7: "Supporting emergent multilingual students: If students struggle to put their thinking into words, consider providing them with sentence frames. For example, a sentence frame for Question 5 could be: 'I think the particle motion of (water / plastic / electrons) could show that energy has (absorbed / transmitted / reflected) because…'" (Teacher Edition, page 141).

Extensions are provided in the unit for students who have already met the PEs of the expected learning. For example:
- Lesson 2: "Extension: Cavity magnetrons are very complicated, and the science ideas needed to explain in detail how they work are far beyond what is expected of high school students. However, some students may be eager to explore circuits and magnetrons or be more engaged by university-level physics topics. As an extension activity, you can have them watch the full video…at home. Ask them to research capacitors and inductors (they can search for information about LC oscillations), or allow them to safely experiment with capacitors and inductors on a breadboard connected to an oscilloscope to produce LC oscillations. They will gain a much more nuanced understanding of the magnetron, as well as the ability to make connections back to the circuitry they worked with in OpenSciEd Unit P.1: How can we design more reliable systems to meet our communities' energy needs? (Electricity Unit)" (Teacher Edition, page 53).
- Lesson 3: "Optional extension: Test the Mathematical Model. If time permits, display slide Y. Assign groups different tensions to set in the simulation, make note of the corresponding wave speed produced, and then test at least two frequencies at that tension setting to see whether the resulting wavelength is predicted by the equation we developed" (Teacher Edition, page 77).
- Lesson 12: "If the majority of the class is demonstrating an organized understanding, challenge students to identify an additional question that was raised in their thinking, related to this summary, and provide them an opportunity to research that further. This independent research is the type of work students will be doing more frequently in the next (and last unit) of this program" (Answer Key – Summarizing Stations).

There is support in the unit for students who are struggling to meet the targeted learning. For example:
- Lesson 1: "What to do: Read through the exit tickets and treat this as a pre-assessment opportunity for the focal crosscutting concept of Structure and Function and the focal practice of Designing Investigations. If students struggle to identify potential investigations, be ready to provide the maximum amount of scaffolding around this practice in future lessons. If they easily identify investigations, consider fading the provided scaffolding more quickly" (Teacher Edition, page 40).
- Lesson 3: "What to do: If students struggle to see the relationships between variables, show the simulation, walk through an example of small amplitude and one of large amplitude, and ask students about the properties on the Physical Wave Properties poster" (Teacher Edition, page 73).
- Lesson 6: "If, during the Turn and Talk, students are struggling to conceptualize how fields affect charged particles, ask them if they have ever seen something push and pull at a distance that

they think might be related to electric charges. Look for examples of electrostatic interactions, and suggest that we try to replicate an example in the classroom. A 'charged' balloon will attract lots of neutral objects, such as hair or small bits of paper. To show students this attraction, you can charge a balloon by rubbing it against your hair (or a student's hair, with their permission), or rub a plastic ruler with felt" (Teacher Edition, page 141).

- Lesson 8: "What to do: Before the next class, look over students' work and provide written feedback on their matter, energy, and forces reasoning for interactions A and B and scan responses to interactions C and D. If a large portion of the 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" (Teacher Edition, page 164).

Suggestions for Improvement

Consider scaffolding strategies or extension opportunities for Lesson 6 and 13 transfer tasks for students with different learning needs. It could be helpful to provide clear supports for learners with special needs or disabilities.

II.F. TEACHER SUPPORT FOR UNIT COHERENCE

Supports teachers in facilitating coherent student learning experiences over time by:

i. Providing strategies for linking student engagement across lessons (e.g. cultivating new student questions at the end of a lesson in a way that leads to future lessons, helping students connect related problems and phenomena across lessons, etc.).

ii. Providing strategies for ensuring student sense-making and/or problem-solving is linked to learning in all three dimensions.

Rating for Criterion II.F. Teacher Support for Unit Coherence	Extensive

The reviewers found extensive evidence that the materials support teachers in facilitating coherent student learning experiences over time because clear and ample guidance is provided for teachers to support linking student learning across lessons. Routines at the beginning of each lesson and embedded within some lessons help make connections among lessons explicit to students. There is also some guidance for helping students see how their learning in all three dimensions is linked and in service of explaining the phenomena for the unit.

The Teacher Edition provides several tools to support teachers in linking student engagement across lessons. For example:

- At the beginning of each lesson in the Teacher Edition there is a "Where We Are Going and NOT Going" statement that explains the summary of what the key points of the lesson are for teachers, what elements are used, and areas they shouldn't go to in that specific lesson.
- The "Learning Plan Snapshot" page(s) at the beginning of each lesson can help the teacher understand how engagement flows across and between lessons.
- The front matter has details that can help with teacher support for unit coherence, such as "How is this unit structured" (Teacher Edition, page 12) and verbiage in "What are the three-dimensional ideas in the context of the unit?" (Teacher Edition, page 14).
- The DQB is developed in Lesson 1 and used to brainstorm questions, investigations and sources of data that could help figure out the phenomenon. Students return to the DQB in Lessons 5, 6, 8, 9, and 13 to add questions or to determine which questions have been answered. However, students do not currently revisit the DQB during Lessons 2, 3, 4, 10, 11, or 12.

There are strategies and guidance for teachers to link student engagement to their use (although not explicit learning) of the SEPs and CCCs across lessons. For example:

- Lesson 3: "Navigate with an electronic exit ticket. Display slide Z. Assign the electronic exit ticket. Before class, make a copy of <Google Form>. Share the link to the copy that you make with students…Make sure you attend to the last two prompts in the electronic exit ticket before next class: How do you think this might be similar to or different from how energy transfers from the magnetron to the food inside the microwave oven? An earthquake is caused by unbalanced forces at a fault (boundary) between two pieces of Earth's crust. What might the unbalanced forces be causing energy transfer in the microwave oven? Suggest that we pick up with those questions next time, and see how we can use the ideas we now have to understand what is happening with these types of waves we can't see" (Teacher Edition, page 78).
- Lesson 4: Students are expected to begin to predict a cause and effect relationship for a complex designed system (MICROWAVE OVEN) by examining smaller scale mechanisms in the system (i.e., changing magnetic field in an electromagnet) in the Changing Fields Demonstration (Teacher Edition, page 97). "This is an opportunity to help students recognize the complex cause-and-effect relationship that explains why electromagnetic waves travel through space without a medium. When building this explanation, it is not important to decide what happens first when the electron moves: changing electric fields, or changing magnetic fields. In this case, the vibration of charged particles causes changes in both electric and magnetic fields that propagate to space. Invite students to use the language of cause and effect in their explanations" (Teacher Edition, page 98).
- Lesson 5: "Remind students that in prior units we've developed many different ways to show that all of the energy must be accounted for in a system, or when energy transfers from one system to another, so it might be important for us to capture that important concept for waves too…This is an explicit reference to prior use of these two related elements of this crosscutting concept. Such references can help students recognize the utility of this crosscutting concept, across different contexts: The total amount of energy and matter in closed systems is conserved. Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system" (Teacher Edition, pages 109–110).

- Lesson 7: There is guidance to help students think back to Lesson 1 and Lesson 5 to help consider what materials absorb electromagnetic radiation. "Does every substance that we put in the microwave absorb electromagnetic radiation just like water? What evidence do we have for this? If students are having trouble finding examples here, point them to the investigation we did in Lesson 1 heating up food, or the investigations we did in Lesson 5" (Teacher Edition, page 139). "Examine Exit Ticket responses for similarities and differences. Return Exit Ticket responses from last time to students. Present slide L. Say, I noticed some differences in how we are thinking about polar and non-polar particles interacting with microwave radiation. Read outloud[sic] the instructions on the slide: Compare sketches from our Exit Ticket last class with a partner. Brainstorm key components we would need in a consensus model that clearly explain: Why does water heat up in the microwave oven? Why doesn't the microwave-safe plastic heat up in the microwave oven? Write your ideas in the science notebook. Give groups about 5 minutes to look at each other's models and record key components in their science notebooks" (Teacher Edition, page 145).
- Lesson 8: There is guidance on connecting structure and function to the lesson investigation on the turntable in the MICROWAVE OVEN. "Given the patterns of energy transfer in the microwave oven students have seen, they should be in a good position to make inferences about the function of the turntable. It is in this lesson that students will be able to connect different ideas about energy transfer and matter interactions within the constraints of the microwave oven structure. Encourage them to use ideas about absorption, reflection and transmission, together with the patterns in the light bulbs they saw the previous day to predict how rotating the matter in the microwave oven can change those patterns" (Teacher Edition, page 171). Students revisit the DQB at the end of the lesson to identify gaps in their explanation about MICROWAVE OVENs. "Use a model to identify gaps in our explanation. Keep students in the Scientist Circle. Display slide AA. Give students a minute or two to take a moment to think on their own about the prompts on the slide: What are the limitations of our consensus model? What questions does our model still not answer?" (Teacher Edition, page 173)
- Lesson 9: There is an opportunity for students to use the slinkies from Lesson 3 to connect to new learning about increases in frequency and amplitude. "It seems like we think both increasing the frequency and increasing the amplitude will increase the energy. I have our slinkies from the wave investigation in Lesson 3. How could we use these to figure out if increasing the frequency or amplitude actually increases the energy of the wave?" (Teacher Edition, page 195).
- Lesson 10: "Say, 'We have 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'. Introduce the exit ticket. Project slide L. Ask students to complete the exit ticket on a scrap piece of paper 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 their exit ticket in at the end of class. Explain that next class period we will look

into what data our class thinks we need in order to figure out why some changes to the energy of a wave increase the risk of skin cancer and some do not" (Teacher Edition, page 199).

Suggestions for Improvement

Consider providing additional prompts for students to revisit the DQB, especially between Lessons 1 and 5 and Lessons 9 and 13 to determine what questions they've answered through lesson activities and what additional questions they have as a result of new learning. Revisiting the DQB sometime in Lessons 2, 3, or 4 and again between Lessons 10, 11, or 12, could provide more linking of student questions and engagement across lessons.

II.G. SCAFFOLDED DIFFERENTIATION OVER TIME

Provides supports to help students engage in the practices as needed and gradually adjusts supports over time so that students are increasingly responsible for making sense of phenomena and/or designing solutions to problems.

Rating for Criterion II.G. Scaffolded Differentiation Over Time	Adequate

The reviewers found adequate evidence that the materials support teachers in helping students engage in the practices as needed and gradually adjusts supports over time because the three focal SEP practices claimed in the materials have scaffolded differentiation over time, either within a lesson or within the unit. However, some of the scaffolding reduction for **Developing and Using Models** and **Planning and Carrying Out Investigations** is unclear.

The SEP category of **Developing and Using Models** is claimed to be developed in the unit (Teacher Edition, page 14). Related evidence includes:

- Lessons 7, 8, 10, and 13: There are margin notes about "Supporting Students in Engaging in Developing and Using Models."
- Lesson 1: Students "Make a model of the parts and interactions in the system that will explain: how the microwave oven heats up liquid and food(sic) why the music was affected when the device was inside the microwave oven, especially when the speaker was farther away" individually in their notebooks (Teacher Edition, page 35). Students then give peer feedback and then incorporate the feedback into their model. A consensus model is then developed using specific colors for matter, energy, and forces.
- Lesson 3: The class develops an energy transfer model. "Motivate developing a diagrammatic model of energy transfer. Suggest that we try to apply our M-E-F thinking to this system, to help use the particle-level model to explain how energy is transferred across solid matter when a wave moves through it. Establish and model how energy is transferred into the system. Display slide E. Use the prompts on the slide and in the table below to establish how energy is

transferred into the system (by a hand or other contact force)" (Teacher Edition, page 64). Students utilize some of the matter, energy, and force ideas from the previous model to this model. This is a model that is co-constructed.

- Lesson 4: There is co-construction of a model. "Use student ideas to develop an initial model of the system on the Energy Transfer from an Antenna poster. Begin by drawing two separate boxes that represent both electrons" (Teacher Edition, page 90). After investigations, they revise models in the unit. "Ask students to use evidence and their new ideas to discuss how we would need to change the model in the Energy Transfer from an Antenna poster in order to show: How do changes at one place cause changes at other places in the system? How does the vibrating electron at A cause energy to transfer? What do we call this system of changing electric and magnetic fields? Give students a few minutes to discuss these changes before inviting them to share. Listen for the following ideas: We should add changing magnetic and electric fields as the mechanism behind energy transfer. The vibrating electron changes electric fields, which changes magnetic fields, and so on. Electromagnetic radiation is what we call this system of changing fields. Record student ideas on the Energy Transfer from an Antenna poster. Your finished model may look something like the example below" (Teacher Edition, page 98).
- Lesson 5: Students develop models of the three ways of interaction. "After a few examples have been given for each row of the EM Radiation Interactions Chart, turn attention to the first column. Suggest that if we can model this, maybe we can more easily use our representations to think about how similar interactions may be happening with microwave radiation in our microwave oven system. Suggest that the class use these examples to model how light interacts with the matter in these three ways. Create models of how light is absorbed, reflected, or transmitted. Project slide C. Direct student[sic] to look at their examples in the first row and consider how light is interacting as it is absorbed by the items identified in the room. Guide students to create a model similar to the example included in the chart to the right. From there, move on to create models for reflection and transmission, following the same process" (Teacher Edition, page 109). It is unclear how much responsibility is placed on the students to develop the model versus being teacher led. Later in the lesson, students are prompted to revise their models from Lesson 4. "Update models with how light is interacting with the microwave system. Present slide H. Ask students to look back at their models from the end of Lesson 4 and add in or update how we now think that microwave radiation is interacting with the parts of the system we have identified as a class. If there is time, allow students to quickly share their models with a partner and provide feedback on the potential interactions" (Teacher Edition, page 112). Co-construction of a class model is done after the investigations. "Use a piece of chart paper to co-develop a model to explain 'Where did the energy in the system come from to increase the temperature of the matter in our control?' Title the paper with this question. Use the prompts below to co-develop the parts of the model. Add the corresponding part of the model to the poster as you get each response" (Teacher Edition, page 122). Then, there is scaffolding reduction as students add to the class model and get peer feedback on it. "Distribute notebook paper to students. Explain that students will now have a chance to add, remove, or change new components and interactions in our class model for the control to explain our results with the solid or the hole-punched aluminum foil. Give students 4 minutes to revise the class model to

explain the results from our tests. Tell students that this paper will be handed in at the end of class. Share and get feedback on models. Project slide AA. After 4 minutes, ask students to stand up, pair up, and share with a partner to compare their representations. As students are doing this, encourage students to add any additional annotations or written explanations to their model that help make their thinking more visible around the question they just discussed with a partner" (Teacher Edition, page 123).

- Lesson 6: Students have the opportunity to use models independently on the assessment if they choose to use diagrams and symbols in their explanation. "Use any combination of words, diagrams, and symbols" (Explaining Temperature Rise).
- Lesson 8: Students are in small groups to develop initial models of hot and cold spots in the microwave. They complete a gallery walk and gather more information from wave on a string simulation before revising their small group model. Students have less scaffolding during this process as the teacher is prompted to ask guiding questions. "While students are working, walk through the classroom and use guiding questions to support student modeling. An example model and guiding prompts for specific parts of the model are provided in Example Interference Model" (Teacher Edition, page 169). There is guidance to help support students in developing and using models by using them to make predictions. "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." They also revise the anchor consensus model.
- Lesson 12: A class consensus model is created and revised. Later in the lesson they add ideas individually. "Review the redirections on Communicate Information. Cue the students to use about 20 minutes to complete their individual written responses on this, referencing their notes on Gather Station Information. Encourage students to include diagrams or sketches to help illustrate their thinking if it helps augment their written summary. Collect both Communicate Information and Gather Station Information" (Teacher Edition, page 231). Although there is a note that students could use modeling elements like diagrams or sketches in their argument, there is not an opportunity to have students revise the model more directly and develop more independence in the practice.

The SEP category of **Planning and Carrying Out Investigations** is claimed to be developed in the unit (Teacher Edition, page 14).

- Lesson 3: Students carry out an investigation of waves. It is heavily directed by the teacher and unit materials. "Read the directions aloud: Pull the first particle on the slinky spring to the tape line. Move it back and forth along the tape once to try to make a single wave travel down the slinky spring. Repeat this a few times and discuss: 1. What is the shape of the wave? 2. How did the particles along it move? 3. What was transferred to the end of the slinky spring? Ask a few students to revoice the goal for the investigation. Listen for them to suggest re-creating a wave using the slinky spring and observing how it transfers energy. Remind students that because their group also needs to discuss the three questions in the relatively short time available for the investigation, they should try to have a different group member take a turn every minute or so to ensure everyone has an opportunity to explore the spring's behavior. Carry out the wave investigation. Assign students to small groups and send them to their stations to complete the investigation as described on the slide" (Teacher Edition, page 62). Students predict relationships between wave properties before carrying out an investigation to test them. "Instruct students to carry out their investigations of amplitude in partners using Wave Property Relationships" (Teacher Edition, page 71). They refine the investigation. "Remind students to keep the settings on 'Oscillate' and 'No End'. Ask them to take a moment to consider the limitations of time and the number of trials needed to establish relationships, and to refine their investigation design given that they will only have about 4 minutes to collect data on frequency. Give students the 4 minutes to carry out the investigation and record their results in column D of the table on Wave Property Relationships" (Teacher Edition, page 73). "Ask them once again to take a moment to consider the limitations of time and the number of trials needed to establish relationships, and to refine their investigation design given that they need to collect data for two variables (damping and tension) in 5 minutes. Give partners the 5 minutes to carry out the investigations and record their results in column D of the table on Wave Property Relationships" (Teacher Edition, page 74). Therefore, there is scaffolding reduction within this lesson.

- Lesson 5: There is brainstorming of an investigation plan. This is primarily teacher-led and considers safety concerns. Students in small groups consider an investigation plan. The teacher leads the idea of conducting a control experiment. "Remind students that even though we want to do several investigations, we all need to be comparing each condition to the same baseline, or controlled condition. Point out that in most investigations that were reviewed, students were using a two-bowl system with changes to the foil around one bowl" (Teacher Edition, page 117). Students engage in arguments about their investigation plans to come to a consensus on which to test. "Once the test(s) are agreed upon, take a brief second pass through the plan for these tests, asking new students to verbally share their responses from the first two questions on page 2 of Microwave Oven Investigation. This should be a faster moving discussion than before and will be easier to establish consensus on. As[sic] student volunteers to help record the ones the class agrees on and any related data from subsequent tests on the board" (Teacher Edition, page 119). Students then complete investigations as a class. In this lesson, planning an investigation has more independence placed on the student, but note that carrying out the investigation is still teacher — rather than student — led.

There is clear scaffolding reduction in students' use of the **Obtaining, Evaluating, and Communicating Information** element: *Compare, integrate and evaluate sources of information presented in different media or formats (e.g., visually, quantitatively) as well as in words in order to address a scientific question or solve a problem*. For example:

- Lesson 7: This practice is used with explicit scaffolding. "To scaffold the engagement with this practice, students will be introduced to the Evaluating Information Checklist, a tool that will help them quickly assess the validity and reliability of claims from sources they evaluate. This tool, together with examples for how to use it, are intended to help students engage in this practice as needed. Throughout the rest of this unit, these supports will be adjusted and gradually removed so that students become increasingly responsible for evaluating the validity and reliability of the information they explore. In OpenSciEd Unit P.6: Earth's History and the Big Bang (Cosmology Unit), students will continue using different elements of this SEP" (Teacher Edition, page 138). This tool is modeled through the reading of the first paragraph together (Teacher Edition, page 146). Note that there is only clear evidence that students evaluate sources of information twice during the unit, so the claim of supports for evaluating sources of information being adjusted and gradually removed may be misleading.

- Lesson 13: Students engage with this SEP in the final assessment individually with minimal scaffolding in the assessment prompts and no assistance from a partner or group. "2a. Fill in the table below by doing the following: a. Identify two effects that the first poster claims 5G can have on human health and record them in the first column of the table below. b. Identify the mechanism that the first poster claims will cause the effect you identified in question 3 and record them in the second column of the table below. Is this mechanism consistent with science ideas we have figured out in class? Why or why not? Record your ideas in the third column of the table below." "2b. Valid claims are supported by evidence and consistent with scientific ideas. Reliable claims use evidence that comes from credible sources, and can be verified either against data sets, or additional experiments. Is the first post valid and/or reliable? Why or why not?" (Evaluating 5G Safety).

Suggestions for Improvement

- Consider implementing more explicit reduction of scaffolding for targeted elements of **Developing and Using Models** and **Planning and Carrying Out Investigations**.
- Consider providing clear supports for students with diverse needs and abilities in building toward the SEPs.

OVERALL CATEGORY II SCORE: 3 (0, 1, 2, 3)	
Unit Scoring Guide – Category II	
Criteria A-G	
3	At least adequate evidence for all criteria in the category; extensive evidence for at least two criteria
2	Some evidence for all criteria in the category and adequate evidence for at least five criteria, including A
1	Adequate evidence for at least three criteria in the category
0	Adequate evidence for no more than two criteria in the category

CATEGORY III

MONITORING NGSS STUDENT PROGRESS

III.A. MONITORING 3D STUDENT PERFORMANCES

III.B. FORMATIVE

III.C. SCORING GUIDANCE

III.D. UNBIASED TASK/ITEMS

III.E. COHERENT ASSESSMENT SYSTEM

III.F. OPPORTUNITY TO LEARN

III.A. MONITORING 3D STUDENT PERFORMANCES

Elicits direct, observable evidence of three-dimensional learning; students are using practices with core ideas and crosscutting concepts to make sense of phenomena and/or to design solutions.

Rating for Criterion III.A. Monitoring 3D Student Performances	Extensive

The reviewers found extensive evidence that the materials elicit direct, observable evidence of students using practices with DCIs and CCCs to make sense of phenomena or design solutions. Students have regular opportunities to individually demonstrate grade-level, three-dimensional performances over the course of the unit. Nearly all labeled assessments in the unit are three-dimensional. However, student prompts occasionally do not assess student learning of the targeted grade-level SEP or CCC. Assessments and student performances link directly to the unit phenomena or introduce a new phenomenon for student sense-making. Some key opportunities to demonstrate individual student learning are missed as no student artifact is produced, specifically after Turn and Talks and some whole class discussions.

Related evidence includes:

- Lesson 1: The teacher elicits direct observable evidence of students' abilities to develop an initial model of the structure and function of microwave ovens in relation to disrupting a Bluetooth signal from a wireless device and heating food. “Create initial models. Present slide J. Read the directions aloud: Make a model of the parts and interactions in the system that will explain: how the microwave oven heats up liquid and food; why the music was affected when the device was inside the microwave oven, especially when the speaker was farther away. Give students 10 minutes to work on their models individually in their notebooks… Building toward: 1.A.1 Develop and revise a model of a microwave oven that explains how the components of the system function to heat liquid/food, and how and why these structures could affect a Bluetooth signal. (SEP: 2.3; CCC: 6.2; DCI: PS4.B.2, PS4.C.1)” (Teacher Edition, page 35).
- Lesson 1: At the end of the lesson teachers are directed to distribute an Exit Ticket to students that asks them to pose potential investigations that would help them understand the structure and function of microwave ovens. This serves as a pre-assessment for teachers as it relates to the CCC of **Structure and Function** and the practice of **Planning and Carrying Out Investigations**. The teacher is given this guidance: “What to do: Read through the exit tickets and treat this as a pre-assessment" (Teacher Edition, page 40). Note, however, that students are only asked to propose investigation topics rather than use a high school level SEP element related to planning investigations.
- Lesson 3: Wave Property Variables: “Take one of these independent variable cards and make a prediction about what would happen if you increased or decreased it: Identify all the other variable cards that would be affected by this change and add them to column B. Record the

remaining variables that would not be affected by this change in column C. Put an up or down arrow next to the independent variable in column A to indicate if you are making a prediction for an increase or for a decrease in it. Put an up or down arrow next to each of the dependent variables in column B to indicate the predicted effect on it." The electronic Exit Ticket at the end of Lesson 3 would provide teachers with evidence of student proficiency along all three dimensions. The Exit Ticket serves as a transfer task of students understanding of energy and matter during earthquakes which cause waves in the earth's crust. In the first two questions of the Exit Ticket students have to use mathematics and computational thinking in order to successfully respond (Lesson 3, Answer Key – L3 Electronic Exit, page 5).

- Lesson 4: Students' responses to the prompts on the three handouts (Lesson 4, Handout – Arrows and Line; Lesson 4, Handout – Full Field Visualization, and Lesson 4, Static Field Visualization) provide evidence of their understanding of the patterns in electric and magnetic fields and the effect of those fields propagated from EM radiation on distance objects — in this case, a distant antenna. In the Field Visualizations Key an "organized understanding" is described as, "**Look for:** Use evidence from the simulation about changing patterns in magnitude and direction to describe the patterns of changing electric fields as energy transfers from the antenna. (SEP: 2.4; CCC: 1.5; DCI: PS4.B) **AND** Use evidence from the simulation about the motion of electrons and the magnitude of forces over distance to suggest mechanisms that account for the damping of energy transferred from the transmitting antenna. (SEP: 2.4; CCC: 1.5; DCI: PS4.B)." Note that there is not clear evidence that students are required to use the claimed CCC to respond to this assessment prompt.
- Lesson 7: Students' responses to the Field-Particle Interaction prompts provide teachers with information about their understanding of the interactions of matter and electric fields (Teacher Edition, pages 142 and 144). Guidance is provided on how to assess student skills for evaluating the validity and reliability of claims made by authors (Teacher Edition, page 147). The lesson level claim for this assessment is "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)" (Teacher Edition, page 135).
- Lesson 8: Students responses to the prompts on the Wave Interactions handout provides evidence of student performance of DCIs related to waves and wave energy, and CCCs of **Cause and Effect** and **Matter and Energy** (Teacher Edition, page 164).
- Lesson 8: Students' revised models of the effect of microwaves on matter provides evidence of three-dimensional student performance and help them build towards an explanation for how microwave ovens heat food and can interrupt digital signals. "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 causes 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)" (Teacher Edition, page 170).
- Lesson 9: Students construct an argument about why EM radiation can be used in multiple technologies to serve specific functions based on frequency, wavelength, and interactions with matter. "Develop an argument about why EM radiation can be used in multiple technologies to

do specific tasks based on its frequency, wavelength, and interactions with matter. (SEP: 7.4; CCC: 4.1; DCI: PS4.B.2, PS4.C.1)" (Teacher Edition, pages 185–186).

- Lesson 10: At the end of day 1, students complete an Exit Ticket that requires them to consider patterns in frequency and amplitude of different types of EM radiation and its potential effect on human beings and solar cells to evaluate their current explanation of wave energy. "Introduce the exit ticket. Project slide L. Ask students to complete the exit ticket on a scrap piece of paper 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?" (Teacher Edition, page 199)

In Assessment Opportunity boxes, guidance is given on what to look/listen for in multiple dimensions. There are also explicit callouts for the teacher to directly collect the evidence, promoting opportunities for observation and feedback on the artifacts. This occurs in many places throughout the unit including in Lesson 1 (Teacher Edition, page 40), Lesson 3 (Teacher Edition, page 76), Lesson 4 (Teacher Edition, page 99), Lesson 7 (Teacher Edition, page 144), and Lesson 9 (Teacher Edition, page 184).

Some key assessment opportunities for students to show understanding verbally would not yield full monitoring opportunities where the teacher is able to garner student understanding from all students in all dimensions. Examples where teachers are not prompted to collect individual-level student artifacts include the class discussion in Lesson 4 (Teacher Edition, page 92) and Lesson 11 where students turn and talk and the class creates a consensus model (Teacher Edition, page 215). The class in Lesson 4 discussion pulls a lot of important ideas and there is a break in the lesson from Day 1 to Day 2. The consensus model and Turn and Talks connect important content about advantages and disadvantages of creating and storing digital images.

Suggestions for Improvement

Consider opportunities for more short individual reflections after key Turn and Talks and whole-group discussions.

III.B. FORMATIVE	
Embeds formative assessment processes throughout that evaluate student learning to inform instruction.	
Rating for Criterion III.B. Formative	Extensive

The reviewers found extensive evidence that the materials embed formative assessment processes throughout that evaluate student learning and inform instruction. Formative assessment processes in the unit routinely provide varied support for student thinking across all three dimensions and are directly embedded into instructional activities. For each formative assessment, guidance is provided to teachers on what to do if students struggle with one or more dimensions. This is especially true for SEPs and DCIs, less so for CCCs. Formative assessments in the unit attend to some issues of student equity.

Instructional materials for every lesson include explicit, frequent, and varied supports for formative assessment processes. Most formative assessment opportunities in the curriculum require teachers to actively listen to and probe student thinking during investigations and other lesson activities. These formative assessment opportunities are organized such that students will actively share their thinking as the lesson unfolds. Related evidence includes:

- Lesson 1: "What to do: If the model is missing components that explain how the oven heats liquid/food, ask students to consider how the device's structure might determine how it performs that function. If the model is missing an explanation of what is affecting the Bluetooth signal, ask students how the function of the microwave oven might determine what its structures are" (Teacher Edition, page 36).
- Lesson 2: After students engage in the technical reading about how a magnetron works, the teacher is given guidance on what to look for and listen for during this discussion including the movement of electrons within the magnetron, the creation of electric fields, and how the electric field might change inside the cooking area. Guidance is given to the teacher on what to do if students do not identify relationships among matter, energy, and forces in the reading (Teacher Edition, page 48). "If students' explanations or sketches do not include electric fields in any way, emphasize electric fields during the navigation into the next lesson. If many sketches show wavy lines or mention 'waves' with no reference to electric fields, ask the class explicitly about this at the beginning of Lesson 3" (Teacher Edition, page 51).
- Lesson 3: During the scientists' circle in which the teacher and students operationally define wave variables, guidance is given to the teacher about what to look or listen for regarding key concepts related to waves such as frequency, wavelength, and wave speed. Guidance is provided on what to do if students don't come up with these concepts or represent the variables in a way that makes sense (Teacher Edition, page 70).

- Lesson 3: There is guidance to teachers on what to look and listen for when students are investigating the properties of waves through the wave simulation. The Teacher Edition provides some limited notes on what to do if students' work reveals that they are struggling with the relationships among variables related to waves. "Read through students' work on Wave Property Relationships and provide written feedback. If students still struggle with the relationships, take time at the beginning of the next class to review the Relationships Between Physical Wave Properties poster, with an emphasis on the energy transfer connections" (Teacher Edition, page 77). For the Exit Ticket at the end of the lesson, "If students struggle to engage in algebraic thinking to respond to the first two questions, consider having them individually write out the variables in fraction form on whiteboards or pieces of paper, and try various operations between the variables to see what results. If students struggle with understanding the relationships represented by the mathematical model, you can give them the Wavelength Reference and use the images to help them further understand the relationships within the developed equation for wavelength. If students are not recognizing the relationship between amplitude and energy transfer in the second question, spend more time going over the relationships on the poster" (Teacher Edition, page 78). Note, however, that this formative assessment guidance is marked as being related to CCC **1.4** but is more related to the SEP element: *Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations.*
- Lesson 4: During this lesson, the teacher has several informal assessment opportunities during the lesson to look for and listen for related DCIs and CCCs in relationship to EM radiation and electric and magnetic waves (Teacher Edition, pages 91, 92, and 97). There is guidance on what do to if students are not making key connections indicated in the lesson. "The three visualizations will look different, but in order for the 'jigsaw' discussion to be robust, it's important for students to study the visualization they were assigned…What to look for/listen for in the moment: Visualization 1: Static Field Shows that the static electric field changes in magnitude and direction near the antenna. Energy decreases because the field decreases. Visualization 2: Arrows and Line Field Shows that the radiated electric field changes in magnitude and direction near the antenna, and this change moves away from the antenna like a wave in a wavy line pattern. Energy decreases because the arrows get shorter. Visualization 3: Full Field Shows that the radiated electric field changes in magnitude and direction near the antenna, and this change moves away from the antenna, sort of like ripples in a pond. Energy decreases because the arrows get shorter…" (Teacher Edition, page 91).
- Lesson 7: The Field-Particle Interactions Key provides teachers with guidance about the nature of student responses to the prompts. Additional guidance is provided to support teachers. "If most student work shows clear understanding of key ideas as described in the Field-Particle Interactions Key, then the beginning of day 2 can run as described in this lesson. Students will not need more individual practice modeling if this work shows that they have developed this skill. Give students some targeted feedback on their Exit Tickets and prepare to hand these back at the beginning of day 2..." (Teacher Edition, page 144).
- Lesson 7: What to do (Question 4): "If students in some groups are struggling to see the interactions of specific molecules and changing electric fields, direct them to the water

molecule cutouts. Assign two students to push with a finger on the positively charged and negatively charged parts of the molecule, respectively. Then agree on a direction for the electric field. Say, Let's assume that the electric field points toward the whiteboard. Let's see what happens to the motion of the molecule. Then direct students' attention to the plastic molecule. Say, 'Now try the same thing with the plastic molecule. What differences do you see?'" (Teacher Edition, page 290).

- Lesson 8: There is guidance on what to do with student responses to the prompts. For example, "Before the next class, look over students' work and provide written feedback on their matter, energy, and forces reasoning for interactions A and B and scan responses to interactions C and D. If a large portion of the 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" (Teacher Edition, page 164).
- Lesson 9: The Teacher Edition provides information on what to do if students have difficulty constructing their arguments (Teacher Edition, page 184).

Formative assessment tasks sometimes attend to student equity through "Attending to Equity" side boxes. Several examples are provided below:

- Lesson 3: "Supporting emergent multilinguals: It can be very helpful for all students, and particularly emergent multilinguals, to break down compound words like microwave. Prompt students to reason about the first part by asking, 'What does *micro* mean to you? What other words have you heard that use the prefix micro?'" (Teacher Edition, page 61).
- Lesson 3: "Universal Design for Learning: This lesson makes use of multiple media with the simulation, handout, and chart of words and images. This provides multiple ways that students see information represented and can express and communicate their understanding. Using multiple forms of media to present and make sense of information provides more access for the diverse learners in your classroom" (Teacher Edition, pages 69–70).
- Lesson 4: "Supporting emergent multilinguals: It can be very helpful for all students, and particularly emergent multilinguals, to express their ideas using nonverbal forms of communication. Use students' hand motions as a check for understanding. It will give you an idea of how students are appropriating frequency and amplitude to make sense of particle motion" (Teacher Edition, page 87).
- Lesson 7: "Universal Design for Learning: Encourage students to physically move these paper models to make sense of the relationship between changing electric fields, electric charge, and particle motion. Physical action provides multiple means of Action and Expression. As you listen to students, encourage them to present their ideas about forces acting on the molecule due to its charge distribution. This will help them explain the particle's motion, beyond just using written descriptions. Providing learners with multiple modalities to show their thinking creates a clear, accessible, equitable pathway for all students to express themselves and communicate" (Teacher Edition, page 141).
- Lesson 8: "Supporting Emergent Multilinguals; Priming some groups before a discussion not only signals to them that they are expected to share their ideas in public, but also gives students an opportunity to prepare for it ahead of time. This strategy is particularly effective with quiet

students and emergent multilingual students, who will gain confidence from the additional time to organize their ideas before sharing them with others" (Teacher Edition, page 169).

Suggestions for Improvement

- For the Exit Ticket at the end of Lesson 4, consider providing guidance to teachers about what to look for in students' responses and how to use those responses to adjust instruction in subsequent lessons, but especially Lesson 5.
- Consider having more guidance about ways to respond to differing levels of student proficiency on formative assessments, similar to Lesson 4, Field Visualizations Key, to help teachers better respond to different levels of proficiency.

III.C. SCORING GUIDANCE

Includes aligned rubrics and scoring guidelines that provide guidance for interpreting student performance along the three dimensions to support teachers in (a) planning instruction and (b) providing ongoing feedback to students.

Rating for Criterion III.C. Scoring Guidance	Extensive

The reviewers found extensive evidence that the included aligned rubrics and scoring guidelines help the teacher interpret student performance for all three dimensions because scoring guidance provides connections among the assessment activity, the targeted three-dimensional learning goals, and the learning experiences of students in previous lessons and units. However, explicit guidance to support students in interpreting their own progress toward most of the targeted learning goals is not provided.

Assessment targets for individual tasks are clearly stated and incorporated into the scoring guidance, although note that assessment opportunities state that they are "building toward" larger three-dimensional assessment targets, but do not clarify to what extent those targets are built toward in the individual assessment opportunities. There is explicit guidance for teachers to interpret student progress and for students to interpret their own progress in relation to the targeted standards and learning performances. A range of student responses is often indicated in scoring guidance, which provides teachers with support in interpreting and responding to students' levels of proficiency. Related evidence includes:

- Keys with one response or ideal responses are provided for: L3 Electronic Exit Ticket, L5 EM Radiation Interactions, L5 Explaining What Happened, L8 Wave Interactions, L9 EM Radiation Applications, L10 Photon Model, and L10 Wave Analogy.
- Lesson 1: When students exchange peer feedback on their initial models the teacher is given tips on what to look for and listen for as students give this feedback. The teacher is given

guidance specifically around what to listen for regarding matter, energy, and forces in students' initial models and then help students focus on these elements in their revision (Teacher Edition, page 35). Later as the teacher facilitates a whole class discussion to produce the class consensus model, the teacher is given guidance on what to listen for as students suggest components and interactions as part of that consensus model. "What to look for/listen for in the moment: Listen for students to suggest the following components and interactions as part of the model..." (Teacher Edition, page 36).

- Lesson 3: The answer key for the electronic Exit Ticket at the end of Lesson 3 provides clear scoring guidance. "What to look for" is written for teachers to help them understand the progression of students' knowledge and skills related to the three dimensions in this unit (Lesson 3, Answer Key – Electronic Exit Ticket).
- Lesson 8: The answer key for the electronic Exit Ticket at the end of Lesson 8 provides clear guidance about how to evaluate students' responses. "What to look for" is written for teachers to help them understand the progression of students' knowledge and skills related to the three dimensions in this unit. (Lesson 8, Answer Key – Electronic Exit Ticket).
- Lesson 6: The summative transfer task assesses PE **HS-ESS2-4**. There is scoring guidance on how to evaluate student responses to individual items in the Lesson 6, Assessment – Answer Key related to student performance on all three dimensions.
- Lesson 10: The three teacher keys related to student handouts provides guidance on typical student responses to activities related to the wave model and the photon model of EM radiation and the ways in which these models can be used to explain the effects of EM radiation (Lesson 10, Answer Key – Radiation Chart Key, Lesson 10, Answer Key – Photon Model KEY, and Lesson 10, Answer Key – Wave Analogy Key).
- Lesson 13: The summative transfer task assesses PE **HS-PS4-4**. Clear scoring guidance on how to evaluate student responses to individual items is directly related to item content (rather than being generic scoring guidance) (Lesson 13, Answer Key – Evaluating 5G Safety).
- While students are able to use tools, such as the Progress Tracker, to measure their progress, these are not directly related to specified learning outcomes or targeted elements in the lesson, and guidance is not provided for how students can use these tools to measure progress toward learning.

Suggestions for Improvement

- Consider providing teacher support similar to that currently found in Lesson 6 and Lesson 13 in other important assessment opportunities. Detailed rubrics would be helpful for key formative assessments in addition to Lesson 6 and 13 summative assessments.
- Consider developing more examples of student responses with differing levels of understanding. This might be especially helpful for Lesson 5, Explaining What Happened, and the arguments students construct in Lesson 9.

III.D. UNBIASED TASK/ITEMS

Assesses student proficiency using methods, vocabulary, representations, and examples that are accessible and unbiased for all students.

Rating for Criterion III.D. Unbiased Task/Items	Extensive

The reviewers found extensive evidence that the materials assess student proficiency using accessible and unbiased methods, vocabulary, representations, and examples because: (1) vocabulary and text volume are grade appropriate, (2) representations and scenarios are fair and unbiased, and (3) assessment tasks provide some scaffolds for successful student completion.

"Attending to Equity" sidebars help support teachers in ensuring that tasks are unbiased and accessible for all students and offer suggestions for modifications to tasks. A few examples include:

- Lesson 3: "The Wave Simulation Observations handout provides a graphic and concept organizer to guide student noticing and comprehension throughout working with the simulation and discussing the variables. This structuring of representations of information aids students in distinguishing important and unimportant information" (Teacher Edition, page 67). "This lesson makes use of multiple media with the simulation, handout, and chart of words and images. This provides multiple ways that students see information represented and can express and communicate their understanding" (Teacher Edition, page 69).
- Lesson 4: "It can be very helpful for all students, and particularly emergent multilinguals, to express their ideas using nonverbal forms of communication. Use students' hand motions as a check for understanding. It will give you an idea of how students are appropriating frequency and amplitude to make sense of particle motion" (Teacher Edition, page 87).
- Lesson 12: "Students should be encouraged to record their ideas using linguistic (e.g., written words) and nonlinguistic modes (e.g., drawings, tables, graphs). This is especially important for emerging multilingual students because making connections between written words and nonlinguistic representations helps students generate richer explanations of how digital communication works" (Teacher Edition, page 229).

Student responses utilize a variety of modalities across the lessons (verbal responses, drawn models, annotating notes, written responses), and students have some choice in modality of response. Some examples include:

- Lesson 2: "Administer the exit ticket. Distribute a piece of paper to each student Say, On your exit ticket, use words or pictures to jot down your thoughts about the question on the slide: What do you think is happening between the magnetron antenna and the light bulb to transfer energy all the way across the microwave oven?" (Teacher Edition, page 51).

- Lesson 4: “Complete exit ticket. Present slide V. Distribute a piece of paper to each student. Read the directions aloud: Use words and or pictures to make a prediction about what microwave radiation would do when it encounters matter. Give them the remaining time to complete this task, and collect exit tickets as they leave the classroom” (Teacher Edition, page 99).
- Lesson 6: The transfer task allows students to, “Use any combination of words, diagrams, and symbols” and to “develop an explanation for how interactions between electromagnetic radiation and greenhouse gases could cause an increase in Earth’s temperature” (Explaining Temperature Rise).
- Lesson 7: “Make sure each group of students has a computer and Field-Particle Interactions, and give them about 13 minutes to complete this handout…Most prompts in the handout give students the chance to express their thinking in words or pictures” (Teacher Edition, page 141)
- Lesson 7: “Students may sketch a version of the consensus model, or simply write an explanation of the behavior of polar and non polar[sic] molecules in response to microwave radiation” (Teacher Edition, page 148).
- Lesson 12: “Review the redirections on Communicate Information. Cue the students to use about 20 minutes to complete their individual written responses on this, referencing their notes on Gather Station Information. Encourage students to include diagrams or sketches to help illustrate their thinking if it helps augment their written summary” (Teacher Edition, page 231).

Suggestions for Improvement

Consider providing more opportunities for students to utilize multiple modalities, including student choice of modality, in their assessment responses.

III.E. COHERENT ASSESSMENT SYSTEM

Includes pre-, formative, summative, and self-assessment measures that assess three-dimensional learning.

Rating for Criterion III.E. Coherent Assessment System	Extensive

The reviewers found extensive evidence that the materials include pre-, formative, summative, and self-assessment measures that assess three-dimensional learning, connect to learning goals, and require students to apply grade-appropriate elements of all three dimensions. Pre-, formative, and summative assessments are clearly present in instructional materials and there are regular opportunities for students to self-assess and provide peer feedback. While there is support provided to teachers on how to adjust instruction based on information gathered from students, there is less guidance on how assessment outcomes should be used by students to inform their own learning.

As indicated in Criteria III.A, III.B, and III.C, there are numerous opportunities for formative and summative assessments of student learning before, during, and after the unit. These assessment opportunities work together to provide evidence of growth in student proficiency over time. The assessment system components are generally coherent, working together to provide information about the progress of student learning.

Pre-assessment

- Lesson 1: Initial Models and the DQB are used as a pre-assessment. “The student work in Lesson 1 available for assessment should be considered a pre-assessment. It is an opportunity to learn more about the ideas your students bring to this unit. Revealing these ideas early on can help you be more strategic in how to build from and leverage student ideas across the unit. The initial model is a good opportunity to pre-assess student understanding of wave properties and energy transfer across space. The Driving Question Board is another opportunity for pre-assessment. Reinforce for students to generate open-ended questions, such as how and why questions and to post to the board. However, any questions students share, even if they are close-ended questions, can be valuable…” (Teacher Edition, page 242).
- Assessment System Overview: “The initial model is a good opportunity to pre-assess student understanding of wave properties and energy transfer across space.” This can assess student’s prior skills and knowledge of the SEPs and CCCs related to the development of the initial model.
- There is not pre-assessment for all of the key targeted learning in all three dimensions. In this unit pre-assessment explicitly emphasizes DCIs and SEPs with little or no explicit emphasis on CCCs.

Formative assessment

- Assessment System Overview: The unit states multiple opportunities for formative assessments, listing Lessons 2, 3, 4, 5, 7, and 8. There is not assessment information in the Assessment System Overview for Lessons 9–12.
- “Assessment Opportunity Boxes” within the lessons allow for formative assessment throughout the unit. See additional evidence under Criterion III.B.
- Lesson 4: Students are given a Progress Tracker. “Present slide U and distribute Progress Tracker. Remind students that throughout this course, we have been keeping track of our thinking using a Progress Tracker. Explain that the tracker is not intended to be a record of the ‘right’ answers--it is a record of our changing thinking over the course of a unit, and should be a place where students feel comfortable reflecting on what they do not know or do not yet understand” (Teacher Edition, page 99). Students add to the Progress Tracker in Lessons 5, 7, 8, 9 and 11.

Summative assessment

- Lesson 3: The three-dimensional Exit Ticket is cited as a summative assessment. "This electronic exit ticket addresses 3D elements associated with the lesson-level performance expectations from Lesson 3. The first three questions on this assessment are designed to make it easy to gather information about where your students are still struggling to understand wave characteristics" (Teacher Edition, page 242).
- Lesson 6: "In this assessment, students apply what they have figured out about interactions of electromagnetic radiation and materials to design ways to explain global temperature rise over the past several decades. This assessment addresses HS-ESS2-4" (Teacher Edition, page 243).
- Lesson 8: "The Electronic Exit Ticket addresses 3-D elements associated with the lesson-level performance expectations from Lessons 7 and 8. This assessment is designed to make it easy to gather information about students' current understanding" (Teacher Edition, page 243).
- Lesson 13: "At the end of this final lesson, students will have the opportunity to demonstrate their competence with a transfer task. This task is robust, and will take approximately 45 minutes. This assessment addresses HS-PS4-4" (Teacher Edition, page 244).

Self-Assessment

- Lesson 4, 5, 7, 8, 9, and 11 make use of the Progress Tracker as a means for students to reflect on their learning and self-assess in relation to the unit phenomena.
- There is a Self-Assessment in the unit's front matter. "The Student Self-Assessment Discussion Rubric can be used anytime after a discussion to help students reflect on their participation in class that day. Use this at least once a week or once every other week. Initially, you might give students ideas for what they can try to improve on next time, such as sentence starters for discussions. As they gain practice and proficiency with discussions, ask for their ideas about how the classroom and small-group discussions can be more productive" (Teacher Edition, page 244). However, this rubric only relates to participation rather than progress toward learning goals. Although students have opportunities to consider how their thinking has changed, self-assessment is not directly and explicitly stated in the lessons.

Suggestions for Improvement

- Consider providing self-assessment supports for students to monitor their own progress toward the unit's learning goals.
- It would be helpful to provide specific guidance for teachers about when to use the self-assessment discussion rubric that is directly embedded within the Teacher Edition for those particular lessons. To support student growth, consider indicating where the rubric might be used at a specific point in a lesson and how teachers might support students in developing actionable goals based upon their own self-assessment.
- Consider adding pre-assessment guidance related to all learning goals in the unit.

III.F. OPPORTUNITY TO LEARN

Provides multiple opportunities for students to demonstrate performance of practices connected with their understanding of disciplinary core ideas and crosscutting concepts and receive feedback.	
Rating for Criterion III.F. Opportunity to Learn	Adequate

The reviewers found adequate evidence that the materials provide multiple opportunities for students to demonstrate performance of practices connected with their understanding of DCIs and CCCs because, for most key learning claimed in the unit, there are multiple student performances that provide students with iterative opportunities to demonstrate their growth. However, there is not a clear opportunity for students to iteratively demonstrate their growth in **Planning and Carrying Out Investigations**.

Students receive feedback from peers and the teacher. This feedback focuses on improving student performance in claimed learning in all three dimensions. Related evidence includes:

- Lesson 1: Students exchange peer feedback on their initial models of how MICROWAVE OVENs work to heat food. "Use the handout to evaluate a partner's models. Distribute a copy of the Initial Modeling Peer Feedback handout, colored pens, and sticky notes to each student. Direct them to switch models with a partner to provide peer feedback. Point out the M-E-F poster as a reference" (Teacher Edition, page 35).
- Lesson 1: Students use the peer feedback they've received to revise their initial models. "Give, receive, and incorporate feedback. Present slide M. In partners, have students take turns discussing the feedback they gave, and listening carefully to their partner's feedback, for about 5 minutes. Then, have students work individually to incorporate the feedback into their own models" (Teacher Edition, page 35).
- Lesson 4: The modeling exercise requires students to make sense of energy transfer from the electron in the first antennae to the electron on the second antennae using **Cause and Effect** as a CCC. The Teacher Edition states, "Discuss revisions of the energy transfer model. Present slide S. Ask students to use evidence and their new ideas to discuss how we would need to change the model in the Energy Transfer from an Antenna poster in order to show: How do changes at one place cause changes at other places in the system. How does the vibrating electron at A cause energy to transfer? What do we call this system of changing electric and magnetic fields?" (Teacher Edition, page 98)
- Lesson 5: Students plan and carry out an investigation regarding the doors and walls of the microwave. However, the use of this SEP is teacher-led and would not ensure that all students have the opportunity to demonstrate learning and growth. Students share ideas after a Turn and Talk about potential EM interactions in the microwave. They identify areas of uncertainty (Teacher Edition, page 112), but not every student would be able to contribute to this discussion or demonstrate their understanding. Students individually come up with investigation questions before coming together for a consensus investigation. "Consider asking students to rephrase or revoice this question once it has been written to reinforce the

joint goal of the classroom community" (Teacher Edition, page 113), but repeating the discussion question is not enough to allow students to demonstrate or develop their proficiency within planning and designing an investigation. In small groups, they outline an investigation plan. "Develop the control condition investigation plan. Use the prompts on slide Q to engage in a discussion. As a class, converge on a consensus investigation plan for the control condition. Establish the setup given in the Key Ideas box below" (Teacher Edition, page 117). They argue for the design of the investigation. "Emphasize that our goal is to come to agreement on a single plan, but that we are going to engage in argument first to make sure that the plan we agree on represents the ideas we all determine have the most merit" (Teacher Edition, page 118). However, there is not clear guidance for teachers to gather data in individual student performance on this or ensure that each student shows proficiency. The consensus investigation is teacher-led.

- Lesson 8: Students give feedback on peers' models that explain hot and cold spots in MICROWAVE OVENs. "Compare and give feedback on models. Present slide H. Describe the activity using the prompts: Add check marks in places of the model that agree with your understanding. Add questions on sticky notes to places where the model does not yet explain the patterns we observed" (Teacher Edition, page 161).
- Lesson 9: Students present their arguments about EM radiation applications and give feedback to peers. "Once all pairs have been formed, provide them with a set of Electromagnetic Radiation Cards and read the prompts on the slide to describe the task: 1. Each student will have 1 minute to present their argument. 2. The other person will have 1 minute asking questions and giving feedback about the ideas presented." There is a missed explicit opportunity to have students revise the argument based on teacher feedback between Day 1 and Day 2. The guidance says to "review the argument" but it is not explicit to incorporate teacher feedback. "Instruct students to revise their argument by reading the prompt: Based on the discussion you had with your peer, revise your argument in Part 4 of the handout. Give them a few minutes to complete this task. Collect EM Radiation Applications" (Teacher Edition, page 185).
- Lesson 10: Students work in pairs to provide one another with feedback on their ionization analogies. "Ask pairs to join with another pair and give feedback. Display slide T. Circulate around the room as students share. Allow students to ask questions first, but if they are hesitant to contribute, model use of the question starters in your own questioning: What represents ionization in your analogy? What objects absorb and emit photons? How is that similar or different from the water wave analogy? What represents changes in frequency and amplitude? How is that similar or different from the water wave analogy?" (Teacher Edition, page 204).

Multiple iterative student performances allow students to show growth in proficiency in the SEP element: *Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system*.

- Lesson 1: Students develop initial models of how the oven system heats and blocks signals and then receive peer feedback. Time is given for the students to incorporate the feedback into their initial models.
- Lesson 4: Students develop an energy transfer model of how the antennae work. Then in Lesson 5, after learning about EM radiation and light, students update their models from Lesson 4. "If there is time, allow students to quickly share their models with a partner and provide feedback on the potential interactions" (Teacher Edition, page 112).
- Lesson 8: Students develop models to explain the heating pattern seen in the cheese and the lightbulbs in small groups. Later in the same lesson, the students learn about wave interference and after receiving feedback from peers on their group models, they revise the group models to include the new learning and the feedback.

Multiple iterative student performances allow students to show growth in proficiency in the SEP element: *Compare, integrate and evaluate sources of information presented in different media or formats (e.g., visually, quantitatively) as well as in words in order to address a scientific question or solve a problem*. However, feedback provided to students and their opportunities for growth relate more to the middle school level element: *Integrate qualitative and/or quantitative scientific and/or technical information in written text with that contained in media and visual displays to clarify claims and findings*.

- Lesson 6 – Summative Assessment: Students use visual models, graphs, data tables, and text to integrate information to address a scientific question about rising temperatures on Earth. After the assessment, students receive feedback from the teacher based on the scoring rubric provided.
- Lesson 9: Students read about EM radiation applications from several "EM Radiation cards" with diagrams, charts, and text. Students integrate this information into an explanation in the "Radiation Applications" handout. Students then present to each other, ask each other questions about their responses and give feedback. Students then revise their arguments based on the feedback.
- Lesson 12 – Stations Activity: Students read several articles that also contain data tables, charts, graphs, and diagrams. Students then summarize the information they learned in their written response. No feedback is given on this performance.
- Lesson 13: In the final summative assessment, students integrate information from text, images, tables, and diagrams to write an argument about the safety of 5G technology. While this is a summative assessment, feedback from the teacher is still recommended by the Teacher Edition (Teacher Edition, page 238).

Suggestions for Improvement

- With many of the targeted elements of the three dimensions, students only engage with them once or twice and do not receive and integrate feedback. More opportunities for students to show growth in all of the targeted learning would strengthen the evidence for this criterion.
- Consider providing guidance to teachers on what assignments would be most beneficial to have students with "foundational understanding" revise after receiving teacher feedback and when that revision could happen.

- Consider including guidance in Lesson 9 to prompt students to incorporate both peer and teacher feedback into their revised arguments.
- Consider including iterative opportunities for students to show growth in **Planning and Carrying Out Investigations**, since it is claimed as a focal SEP.

OVERALL CATEGORY III SCORE: **3** (0, 1, 2, 3)	
Unit Scoring Guide – Category III	
Criteria A-F	
3	At least adequate evidence for all criteria in the category; extensive evidence for at least one criterion
2	Some evidence for all criteria in the category and adequate evidence for at least five criteria, including A
1	Adequate evidence for at least three criteria in the category
0	Adequate evidence for no more than two criteria in the category

SCORING GUIDES

SCORING GUIDES FOR EACH CATEGORY

UNIT SCORING GUIDE – CATEGORY I (CRITERIA A-F)

UNIT SCORING GUIDE – CATEGORY II (CRITERIA A-G)

UNIT SCORING GUIDE – CATEGORY III (CRITERIA A-F)

OVERALL SCORING GUIDE

Scoring Guides for Each Category

Unit Scoring Guide – Category I (Criteria A-F)	
3	At least adequate evidence for all of the unit criteria in the category; extensive evidence for criteria A–C
2	At least some evidence for all unit criteria in Category I (A–F); adequate evidence for criteria A–C
1	Adequate evidence for some criteria in Category I, but inadequate/no evidence for at least one criterion A–C
0	Inadequate (or no) evidence to meet any criteria in Category I (A–F)

Unit Scoring Guide – Category II (Criteria A-G)	
3	At least adequate evidence for all criteria in the category; extensive evidence for at least two criteria
2	Some evidence for all criteria in the category and adequate evidence for at least five criteria, including A
1	Adequate evidence for at least three criteria in the category
0	Adequate evidence for no more than two criteria in the category

Unit Scoring Guide – Category III (Criteria A-F)	
3	At least adequate evidence for all criteria in the category; extensive evidence for at least one criterion
2	Some evidence for all criteria in the category and adequate evidence for at least five criteria, including A
1	Adequate evidence for at least three criteria in the category
0	Adequate evidence for no more than two criteria in the category

OVERALL SCORING GUIDE	
E	**Example of high quality NGSS design—**High quality design for the NGSS across all three categories of the rubric; a lesson or unit with this rating will still need adjustments for a specific classroom, but the support is there to make this possible; exemplifies most criteria across Categories I, II, & III of the rubric. (total score ~8–9)
E/I	**Example of high quality NGSS design if Improved—**Adequate design for the NGSS, but would benefit from some improvement in one or more categories; most criteria have at least adequate evidence (total score ~6–7)
R	**Revision needed—**Partially designed for the NGSS, but needs significant revision in one or more categories (total ~3–5)
N	**Not ready to review**—Not designed for the NGSS; does not meet criteria (total 0–2)