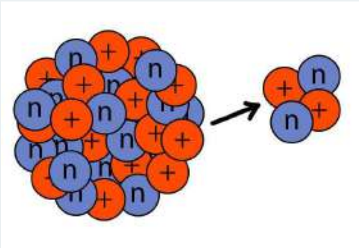
Lesson 7: Where does the energy that drives convection come from?

Previous Lesson *We developed a predictive model of the movement of the mantle. We analyzed a video of a tank containing a mixture of liquid and plastic pellets simulating the matter in the mantle to figure out what happens to the matter when heat is added. We observed convection in the tank and developed a model to represent it utilizing the M-E-F triangle.*

This Lesson

Investigation, Putting Pieces Together

2 days



We want to know where the heat comes from that drives mantle convection. We jigsaw a series of articles that answer this question from forces, matter, and energy perspectives. We develop a cause-effect model that integrates these three perspectives to explain how radioactive decay results in the release of enough heat to drive convection in the solid rock of Earth's mantle.

Next Lesson *We will analyze the radioactive element composition of rocks from Afar. We will plan and carry out an investigation using a simulation to collect data on how the amount of radioactive material in a rock crystal changes over time. We will use mathematical thinking to compare patterns in our graphs to those in an equation of exponential decay and use that equation to determine the age of rocks from Afar.*

BUILDING TOWARD NGSS

HS-PS1-8, HS-ESS1-5, HS-ESS2-1, HS-ESS2-3

What students will do

7.A Construct a cause-effect explanation for how radioactive decay provides the heat that drives mantle convection, using ideas from our previous investigations, new evidence from a set of complementary readings, and the assumption that our past observations about matter, forces, and energy hold true across contexts. (SEP: 6.2; CCC: 2.2; DCI: ESS2.B.1, PS2.B.2, PS1.C.1, PS3.A.2)

7.B Ask questions that arise from examining models for explaining how radioactive decay at the subatomic scale can cause thermal energy transfer at the macroscopic scale to clarify and seek additional information regarding the relationships between matter, energy, and forces. (SEP: 1.2; CCC: 3.3; DCI: PS1.C.1, PS2.B.2, PS3.A.2, PS3.A.4)

What students will figure out

- Nuclear energy can be modeled as being stored in the mass of the atomic nucleus itself. The conversion between mass and energy is modeled mathematically as $E=mc^2$.
- An imbalance of forces (strong and electric) in an atomic nucleus can cause protons, neutrons, and other particles to leave the atom, transferring kinetic energy into the surrounding material. This is a type of radioactive decay.
- Radioactive decay at the subatomic scale continually generates new energy, providing the primary source of the energy that drives mantle convection at the macroscopic scale.

Lesson 7 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	5 min		**NAVIGATE** Motivate the need to look at matter, energy, and forces interactions in the mantle.	A-B	
2	15 min		**OBTAIN INFORMATION FROM A READING ABOUT RADIOACTIVE DECAY** Individually read one of a series of articles about radioactive decay as part of Round 1 of a Jigsaw.	C	one of the Jigsaw handouts (*Radioactive Decay (Forces) Radioactive Decay (Matter)* or *Radioactive Decay (Energy)*), M-E-F poster developed in earlier lessons
3	20 min		**RESPOND TO CAUSE-EFFECT PROMPTS IN ROUND 1 GROUPS** Make sense of the readings by answering related cause-effect questions in Round 1 groups. Prepare for discussion in Round 2 groups in the next class.	D	one of the Jigsaw handouts (*Radioactive Decay (Forces) Radioactive Decay (Matter)* or *Radioactive Decay (Energy)*), M-E-F poster developed in earlier lessons
4	5 min		**NAVIGATE WITH AN EXIT TICKET** Complete an exit ticket about the other two corners of the M-E-F triangle.	E	loose-leaf paper
					End of day 1
5	2 min		**NAVIGATE** Turn and talk about the exit tickets from last time.	F	
6	15 min		**DEVELOP A MECHANISTIC EXPLANATION ABOUT RADIOACTIVE DECAY** Work in Round 2 groups to fill in the Cause-Effect Model handout.	G	either *Cause-Effect Model A* or *Cause-Effect Model B*, one of the Jigsaw handouts (*Radioactive Decay (Forces) Radioactive Decay (Matter)* or *Radioactive Decay (Energy)*)
7	15 min		**COME TO CONSENSUS IN A SCIENTISTS CIRCLE** Build on what we know about convection to construct a consensus cause-effect model that connects interactions at the nuclear scale to the cycling of matter in the mantle at the global scale. Update Personal Glossaries.	H-K	*Reference for Discussion Facilitators*, *Discussion Mapping Tool*, 2 clipboards (optional), Consensus Cause-Effect Model poster, chart paper marker (red), chart paper marker (green), chart paper

					marker (purple), chart paper marker (black), M-E-F poster
8	7 min		**NAVIGATE AND REFLECT ON THE DISCUSSION MAP** Discuss patterns in the discussion map, and consider what this data tells us. Identify the M-E-F connections between scales. Celebrate progress and wonder about radioactive material in Afar.	L-N	*Discussion Mapping Tool*, Community Agreements poster, Consensus Cause-Effect Model poster, Scale Chart poster, 2 3x5 sticky notes
9	6 min		**COMPLETE AN ELECTRONIC EXIT TICKET** Apply what we have figured out so far to a new phenomenon.	O	computer with access to https://docs.google.com/forms/d/149Ol8lpf1OoiwLWzLlPJNFHSnWbuFpO_vbniPllmJN8/copy, *L7 Electronic Exit Ticket Key*

End of day 2

Lesson 7 • Materials List

	per student	per group	per class
Lesson materials	- one of the Jigsaw handouts (*Radioactive Decay (Forces) Radioactive Decay (Matter)* or *Radioactive Decay (Energy)*) - loose-leaf paper - either *Cause-Effect Model A* or *Cause-Effect Model B* - science notebook - computer with access to https://docs.google.com/forms/d/1490l8lpf1OoiwLWzLlPJNFHSnWbuFpO_vbniPllmJN8/copy		- M-E-F poster developed in earlier lessons *Reference for Discussion Facilitators* *Discussion Mapping Tool* 2 clipboards (optional) - Consensus Cause-Effect Model poster - chart paper marker (red) - chart paper marker (green) - chart paper marker (purple) - chart paper marker (black) - M-E-F poster - Community Agreements poster - Scale Chart poster 2 3x5 sticky notes *L7 Electronic Exit Ticket Key*

Materials preparation (45 minutes)

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

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

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

Sign up for a free Gizmo - Explore Learning account.
Go to https://gizmos.explorelearning.com/trial and register for a free account. You will have free access to all the simulations for the first 30 days, then limited access to only the free simulations after the 30-day trial period. The Gizmo we use in this unit is a free Gizmo on their site. It will still be available after the 30-day trial period is over by logging into your account.

Prepare for the Round 2 Jigsaw on day 2 ahead of time by choosing a system for rearranging students quickly from their original reading groups into their new mixed groups of 3: 1 student who reads about forces, 1 who reads about energy, and 1 who reads about matter.

You need volunteers to be 2 facilitators and 2 discussion mappers for the Consensus Discussion on day 2. Consider reaching out ahead of time to students who may want to fulfill those roles. Putting the facilitator reference and the mapping tool on clipboards may make these easier to use.

At the end of day 2, students analyze the newly created discussion map and consider how to increase equitable participation. Be ready to share the completed discussion map with the class. You can do this by quickly taking a photo and adding it to a slide, projecting it with a document camera, uploading it to an LCMS such as Google Classroom, or making copies if a photocopier is available, but there is not a lot of turnaround time for this. As an alternative, you can move this conversation to Lesson 8 to allow yourself time to make photocopies that students can mark up and study more closely.

Make sure the M-E-F triangle poster developed in previous lessons is displayed where students can see it. Have the Scale Chart poster displayed near the front of the room, to be added to during this lesson.

Prepare chart paper for the poster you make in this lesson:

- Consensus Cause-Effect Model

Make a copy of https://docs.google.com/forms/d/149Ol8lpf1OoiwLWzLlPJNFHSnWbuFpO_vbniPllmJN8/copy . Have computers available for each student to access your copy of the Electronic Exit Ticket on day 2. Either place the link to your copy on slide O, or provide a link for students on your school's content management platform.

Lesson 7 • Where We Are Going and NOT Going

Where We Are Going

The goal of this lesson is to fill in the blanks on our model of mantle convection by figuring out where the energy comes from to drive the process. Students complete a reading Jigsaw designed to help them weave together a story that combines the matter, energy, and forces perspectives. They learned about fission in *OpenSciEd Unit C.5: Which fuels should we design our next generation vehicles to use? (Fuels Unit)*, and they learn about radioactive decay in this lesson.

This lesson is designed to coherently build new ideas related to the following disciplinary core ideas (DCIs):

- **PS1.C** Nuclear processes, including ~~fusion, fission, and~~ radioactive decays of unstable nuclei, involve release or absorption of energy. The total number of neutrons plus protons does not change~~ in any nuclear process~~. (HS-PS1-8) (crossed-out bits are covered in *OpenSciEd High School Unit P.6: Why do stars shine and will they shine forever?*)
- **ESS2.B.1** The radioactive decay of unstable isotopes continually generates new energy within Earth's crust and mantle, providing the primary source of the heat that drives mantle convection.~~ Plate tectonics can be viewed as the surface expression of mantle convection.~~ (HS-ESS2-3) (crossed-out bits are covered in Lesson 10)

Students are asked to apply DCIs that they have been developing over several units, which are key to sensemaking in this lesson. These include:

- **PS2.B.2** Forces at a distance are explained by fields (~~gravitational, ~~electric~~, and magnetic~~) permeating space that can transfer energy through space. ~~Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields.~~ (HS-PS2-4, HS-PS2-5) (This DCI, including the crossed-out bits, is developed in *OpenSciEd High School Unit P.1: How can we design more reliable systems to meet our communities' energy needs?* This lesson focuses on fields in a new context to reinforce the ideas.)
- **PS3.A.2** At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. (HS-PS3-2, HS-PS3-3)
- These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as either motions of particles or energy stored in fields (which mediate interactions between particles).~~ This last concept includes radiation, a phenomenon in which energy stored in fields moves across space.~~ (HS-PS3-2)

Students encounter and/or co-construct ideas around several words during this lesson, and may decide to add the following words to their Personal Glossaries: *radioactive decay, neutrons*. **Do not** ask students to define or keep track of any words until after the class has developed a shared understanding of their meaning.

Where We Are NOT Going

Students are not asked to distinguish between different types of radioactive decay (e.g., alpha, beta, gamma). They will not learn explicitly about electromagnetic radiation until *OpenSciEd Unit P.5: How do we use radiation in our lives, and is it safe for humans? (Microwaves Unit)*. They also do not consider the potentially dangerous effects of all kinds of ionizing radiation on the human body. That will be addressed in the *Microwaves Unit* as well.

LEARNING PLAN for LESSON 7

1 · NAVIGATE

5 min

MATERIALS: None

Turn and talk about where the energy for convection might come from. Display **slide A**. Say, *We figured out that rock in the mantle is moving. As rock deep inside Earth heats up, it rises toward the surface. Then it cools and sinks back down again. This cycle depends on heat that's deep in the planet. What ideas did we have about where the heat might be coming from?* Remind students that we thought about this at the end of Lesson 6. Give them about 2 minutes to share their ideas with a partner.

Motivate the need to look at matter, energy, and forces interactions in the mantle. Present **slide B**. Use the prompt to elicit student ideas. Highlight suggestions that use science ideas to motivate the use of matter, energy, or forces, as in the examples in the table below. ✱

Suggested prompt	Sample student response
How could each of these perspectives help us figure out where the heat might be coming from, deep inside Earth?	We should look for the energy source that generates the heat, because heat is a form of energy, and energy must transfer from somewhere. We know that forces transfer energy, and heat is a form of energy, so we should look at the forces that are transferring the energy. Matter generates forces through fields, so looking at the particle changes that cause these forces will help us understand how energy is transferred as heat in the mantle.

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING ENERGY AND MATTER

This is another instance in this unit in which ideas and prompts in the M-E-F poster are used to offer multiple means of engagement with a phenomenon. By directing their attention to the relationships between these three perspectives, students can begin to identify interactions that are crucial for further investigation.

2 · OBTAIN INFORMATION FROM A READING ABOUT RADIOACTIVE DECAY

15 min

MATERIALS: one of the Jigsaw handouts (*Radioactive Decay (Forces) Radioactive Decay (Matter)* or *Radioactive Decay (Energy)*), M-E-F poster developed in earlier lessons

Motivate the readings. Point to the M-E-F poster. Say, *It sounds like it might help to obtain information about matter, energy,* ***and*** *forces, rather than just focus on one, and see whether we can make sense of what is going on here. I have three readings to help us answer our questions. One reading takes an energy perspective, one takes a forces perspective, and one takes a matter perspective.*

Organize Round 1 groups. Present **slide C**. Break the classroom into three reading groups: Forces, Matter, and Energy. Within each reading group, organize students into smaller groups of 3-4. Distribute *Radioactive Decay (Forces)*, *Radioactive Decay (Matter)*, and *Radioactive Decay (Energy)* to the three respective reading groups.

Give students 10 minutes to read their articles and respond to the first two questions on their handouts independently. ✱

✱ ATTENDING TO EQUITY

Differentiation opportunity/Support for emergent multilingual learners: Although all three readings are leveled between grades 8 and 9, Matter is the longest (over 1,000 words) and Forces is the shortest (under 800 words). Consider assigning students who may need additional support for literacy to the Forces group, so they have less text to read. We **do not** recommend homogenous groupings, but rather, creating mixed-ability groupings, with a higher proportion of students who need more support in the Forces group.

3 · RESPOND TO CAUSE-EFFECT PROMPTS IN ROUND 1 GROUPS

20 min

MATERIALS: one of the Jigsaw handouts (*Radioactive Decay (Forces) Radioactive Decay (Matter)* or *Radioactive Decay (Energy)*), M-E-F poster developed in earlier lessons

Make sense of the readings in Round 1 groups. Present **slide D**. Have students work for 20 minutes with their small reading groups to answer the cause-effect questions on the last page of their handouts. Tell them that next time, they will each share their responses with a new group in Round 2, so they may want to take additional notes on this first conversation to prepare.

Collect students' handouts to review after class (see the Assessment Callout), but be ready to return them at the next class, as students will need them. ✱

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment:

- Students distill ideas from the readings to explain that radioactive decay provides the heat that drives mantle convection. (SEP: 6.2)
- Students link cause at the particle scale to effect at the macroscopic scale using mechanistic reasoning. (CCC: 2.2)
- Students accurately describe radioactive decay according to the subject of the article they read

✱ ATTENDING TO EQUITY

Supporting emergent multilingual students: Encourage students to record their ideas using linguistic modes (e.g., written words) and nonlinguistic modes (e.g., drawings) in the space provided in the readings. This is especially important for emerging multilingual students, because making connections between written words and nonlinguistic representations helps students generate richer explanations of scientific phenomena.

(forces, energy, or matter). See the accompanying *Cause-Effect Model Key* for examples at various levels of proficiency. (DCI: ESS2.B.1, PS1.C.1, PS2.B.2, PS3.A.2)

What to do: Provide feedback using the suggestions in the key. This will be useful for students in Round 2, as they join their Jigsaw groups to compare and integrate their ideas with those of their peers.

Building toward: 7.A.1 Construct a cause-effect explanation for how radioactive decay provides the heat that drives mantle convection, using ideas from our previous investigations, new evidence from a set of complementary readings, and the assumption that our past observations about matter, forces, and energy hold true across contexts. (SEP: 6.2; CCC: 2.2; DCI: ESS2.B.1, PS2.B.2, PS1.C.1, PS3.A.2)

4 · NAVIGATE WITH AN EXIT TICKET

5 min

MATERIALS: loose-leaf paper

Respond to the exit ticket. Present **slide E**. Say, *Today, each of you has been thinking deeply about only one corner of the M-E-F triangle.* Read the slide's question aloud:

- *What questions do you have about the other two corners of the M-E-F triangle that would help to explain how a process at the subatomic scale can produce enough heat to drive convection?*

Distribute a sheet of loose-leaf paper to each student. Have them respond to the prompt as an exit ticket, and then hand the paper in as they leave class.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment:
Accept all ideas, but across the class, look for the following:

- Students apply what they know about matter, energy, and forces in articulating their questions. For example, a student who reads about forces might ask, "What energy transfers when the forces are imbalanced?" A student who reads about energy might ask, "What changes can you detect in the matter when energy is released from atomic nuclei?" A student who reads about matter might ask, "What unbalanced forces cause the motion of the particles?" (DCI: PS1.C.1, PS2.B.2, PS3.A.2, PS3.A.4)
- Students ask questions that seek to clarify an understanding or provide additional information about

nuclear processes to explain macroscopic thermal energy. Look for sentence stems like “How does _____ cause _____?” or “Why does _____ happen when _____?” (SEP: 1.2; CCC: 3.3)

What to do: Accept all student ideas. Consider using the exit tickets for strategic grouping in Round 2 of the Jigsaw, by distributing students who are asking questions that meet the above criteria across the new small groups, if possible.

Building toward: 7.B Ask questions that arise from examining models for explaining how radioactive decay at the subatomic scale can cause thermal energy transfer at the macroscopic scale to clarify and seek additional information regarding the relationships between matter, energy, and forces. (SEP: 1.2; CCC: 3.3; DCI: PS1.C.1, PS2.B.2, PS3.A.2, PS3.A.4)

End of day 1

5 · NAVIGATE

2 min

MATERIALS: None

Turn and talk about the exit tickets. Present **slide F**. Return students’ exit tickets, and ask them to consider the slide’s prompt:

- *How would answering these questions help us understand how radioactivity causes mantle convection?*

Have students take a moment to bounce their ideas off a partner, and add any other questions to their exit tickets before Round 2 of the Jigsaw.

6 · DEVELOP A MECHANISTIC EXPLANATION ABOUT RADIOACTIVE DECAY

15 min

MATERIALS: either *Cause-Effect Model A* or *Cause-Effect Model B*, one of the Jigsaw handouts (*Radioactive Decay (Forces) Radioactive Decay (Matter)* or *Radioactive Decay (Energy)*)

Reshuffle students into Round 2 groups. Quickly arrange students into new groups of 3: one student with the Energy reading, one with the Matter reading, and one with the Forces reading.

Present **slide G**. Each group member should get up to 3 minutes to summarize the article they read in Round 1, read the three questions at the end aloud, and share their answers. Consider asking one student in each group to keep time, or use a timer at the front of the classroom.

✱ **ATTENDING TO EQUITY**

Supporting emergent multilingual learners: There are two versions of the same cause-

Fill in the cause-effect handout. Tell students to work in their Round 2 groups, using the answers to all the cause-effect questions to fill in the Cause-Effect Model handout (whichever version you choose) to explain where the energy to drive convection comes from. ✱

effect modeling handout, which vary in the level of scaffolding they provide. *Cause-Effect Model A* is a more scaffolded version with suggestions for building the causal chain, whereas *Cause-Effect Model B* only provides sentence frames. We recommend starting with the less-scaffolded version but having the other on hand. If a student needs extra support, offer them the more-scaffolded version in the moment as needed. However, if you have a class with many students who are multilingual, or who need additional literacy support, consider starting with the more scaffolded version for all students.

7 · COME TO CONSENSUS IN A SCIENTISTS CIRCLE

15 min

MATERIALS: *Reference for Discussion Facilitators*, *Discussion Mapping Tool*, 2 clipboards (optional), Consensus Cause-Effect Model poster, chart paper marker (red), chart paper marker (green), chart paper marker (purple), chart paper marker (black), M-E-F poster

Introduce the *Discussion Mapping Tool*. Display s**lide H**. Say, *We're going to use a tool today to map our discussion. This will help us think about how we can all work together when we're discussing new ideas to move our thinking forward.* If you used this tool in Lesson 1, suggest to students that we might look for a shift in the focus of our discussion.

Establish student volunteers. You need 4 student volunteers for this discussion: 2 facilitators and 2 mappers. Consider reaching out ahead of time to students who may want to fulfill these roles.

ADDITIONAL GUIDANCE

The *Discussion Mapping Tool* provides a visual representation of the conversation patterns happening within the class. Use lines to track how the discussion moves between speakers. After you track the first few moves, pause to show the class what the map looks like. Ask for a volunteer to map the rest of the discussion. This can be a way to involve a student who is less comfortable speaking publicly. Each time you use the discussion tool in this unit, have a new volunteer record the map.

Though the *Discussion Mapping Tool* includes codes to mark various types of contributions, you may want to simply track discussion patterns the first few times you use the tool. As students become more comfortable with discussion mapping, you can add the contribution codes.

After framing the questions, be ready to keep track of student ideas on chart paper.

Come to consensus in a Scientists Circle. Present **slide I**. Convene a Scientists Circle. Gather around the Consensus Cause-Effect Model poster to construct a class consensus version of the model students have been working on. See the preparation section for more. Alternatively, you can facilitate this by projecting a digital version of the handout, or using a document camera, and filling it in together.

Have the first volunteer facilitator initiate the discussion by following the instructions in *Reference for Discussion Facilitators*:

- *To begin, ask one group to get us started by sharing their responses in the first row.*
- *When this group has finished speaking, ask the other groups to raise their hands if they have something similar. Give groups that raised their hands time to share.*
- *Ask whether any groups disagreed, or had something to add. Ask students who disagree to share their ideas.*
- *Repeat this process for each row. If there is disagreement, ask the class which ideas best explain the patterns we see at the macroscopic scale.*

As students suggest phenomena, use the *Discussion Mapping Tool* to record the first few who offer ideas. Take a moment to show the tool to the class, then ask the first volunteer mapper to take over. This allows you to focus on listening to student ideas (see the Key Ideas callout and the Assessment callout below) and recording them on the Consensus Cause-Effect Model poster. After a few minutes, pause the discussion and ask the second volunteer mapper to continue the mapping.

As students share ideas and you record these in the class consensus model, ask students to clarify the framing of the mechanisms they suggest (point to the M-E-F poster). Use black to underline key phrases and annotate them with “matter”, “energy”, or “forces” (or M, E, F).

Discuss the interconnectedness of M-E-F perspectives. Present **slide J**. Pose the slide’s questions:

- *Where did you integrate ideas about the interactions between matter and energy?*
- *Between matter and forces?*
- *Between energy and forces?*

Listen for ideas about unbalanced forces transferring energy (for example, when electrostatic forces and strong forces are no longer in balance, transferring energy out of the atomic nucleus). Point to the M-E-F poster to remind students that this is a principle we have previously identified.

Listen for ideas about energy transfer happening with changes to the motion of matter (for example, when heat from radioactivity transfers into the surrounding matter, causing changes to the density of the matter, which then causes it to float upward toward Earth's surface). Point to the M-E-F poster to remind students that this is another principle we have previously identified.

Students might also point out how fields between particles in the nucleus cause forces that can be either balanced or unbalanced, or how moving matter transfers thermal energy from Earth's core to the surface.

KEY IDEAS	**Purpose of this discussion**: The purpose of this discussion is to build on what we know about convection to construct a cause-effect model that connects interactions at the nuclear scale to the cycling of matter in the mantle at the global scale. The model should integrate forces, matter, and energy perspectives to explain how radioactive decay results in heat. This model motivates the need to understand how convection can be causing the surface features observed in Afar. **Listen for these ideas:** ● Atomic nuclei are made of particles. ● Changing the number of protons in an atomic nucleus results in a new element. ● Unbalanced forces (electrostatic and strong) can result in a process called radioactive decay, which results in the transfer of energy and sometimes matter out of the nucleus. ● The energy transferred out of the nucleus becomes the heat that drives convection. ● Through convection, material from the mantle moves upward into the crust, and material from the crust moves down into the mantle (connect to Lesson 6).

ASSESSMENT OPPORTUNITY	**What to look for/listen for in the moment:** ● Listen for the key ideas listed in the Key Ideas callout, all of which rely on evidence from a variety of sources (our previous investigations, new evidence from the readings, and the assumption that our past observations about the relationships between matter, forces, and energy hold true across contexts). (SEP: 6.2; DCI: ESS2.B.1, PS1.C.1, PS2.B.2, PS3.A.2) ● Use the *Cause-Effect Model Key* (cause-effect chain) as an example of what a class consensus model explaining mantle convection at multiple scales might look like. (SEP: 6.2; CCC: 2.2)

- Listen for students to be able to explicitly identify how matter, energy, and forces interact as part of the class consensus model. (DCI: ESS2.B.1, PS1.C.1)

What to do: Press students for evidence from their small-group conversations and/or the readings. Use the sources listed in gray in the key to point students back to the places in their readings where they might find more information about gaps in their understanding.

Building toward: 7.A.2 Construct a cause-effect explanation for how radioactive decay provides the heat that drives mantle convection, using ideas from our previous investigations, new evidence from a set of complementary readings, and the assumption that our past observations about matter, forces, and energy hold true across contexts. (SEP: 6.2; CCC: 2.2; DCI: ESS2.B.1, PS2.B.2, PS1.C.1, PS3.A.2)

Add new terms to our Personal Glossaries. Present **slide K**. Ask students to identify 2-3 important new terms that we think we have developed definitions for and want to add to our Personal Glossaries. Make sure that *radioactivity* and/or *radioactive decay* is one of these terms. *Nucleus, isotopes, protons*, and *neutrons* may also be terms that students decide to define.

8 · NAVIGATE AND REFLECT ON THE DISCUSSION MAP

7 min

MATERIALS: science notebook, *Discussion Mapping Tool*, Community Agreements poster, Consensus Cause-Effect Model poster, Scale Chart poster, 2 3x5 sticky notes

Reflect on the discussion map. Display the discussion map by passing it around, putting it under a document camera, or snapping a photo and projecting it on **slide L**. Give students a few minutes to individually observe the map and document any patterns they notice in their notebook.

Then point to the Community Agreements and say, *After looking at this map, what are some things we should consider during our discussions to make sure that everybody plays a role in moving our thinking forward?* ✱ Listen for responses such as:

- We should ask questions and respond to each other instead of directing our responses to the teacher.
- We should invite people into the discussion who have not had chances to contribute.
- We should monitor our airtime and give other people time to talk.

Identify the M-E-F connections between scales. Present **slide M**. Pose the slide's first question:

- *Where do the cause-effect mechanisms we identified today belong on our Scale Chart poster?*

✱ ATTENDING TO EQUITY

Building classroom culture: The goal of this reflection is to notice whole-class patterns and decide how all students can move discussions forward as a community, which is a part of our Community Agreements. Avoid addressing the contributions or behaviors of specific students. If these are brought up, prompt students to return to the class-level patterns, saying, *Let's look at the whole map. What suggestions can we make that would support our whole class community?*

Move through the rows of the Consensus Cause-Effect Model poster and identify the spatial and temporal scales of each mechanism relative to what we have on the Scale Chart poster. For example, radioactive decay occurs on a very tiny spatial scale. The decay itself happens on a very short timescale, but convection occurs over millions of years. Decide as a class where it belongs along the temporal axis.

Ask students to look back at the Consensus Cause-Effect Model poster to see that we figured out that the radioactive decay causes increased particle movement in the mantle. Move over to the Scale Chart poster, add “particle movement in the mantle”, and draw an arrow to it from “radioactive decay.”

Work with the class to determine that mantle convection happens on a very large timescale and over a very large spatial scale. It should be near the top right corner of the Scale Chart poster.

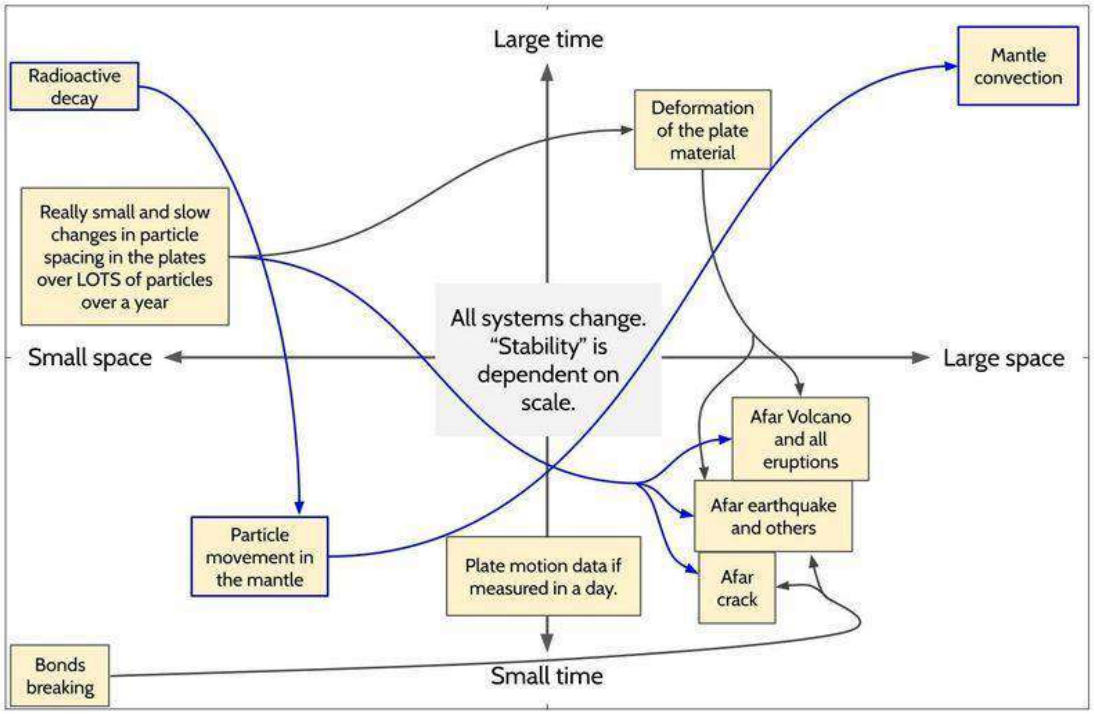
Finally, ask what mechanisms cause the mantle convection. Students should say that particle movement at the micro-scale causes this macro-scale change. If they decide to add more mechanisms to the Scale Chart poster, follow their lead. An example of this is shown below.

This is also an opportunity to remind students that the *Discussion Mapping Tool* captures only spoken contributions, and to explicitly state that nonverbal participation and listening closely are also valued. If this idea resonates with students, make sure it is reflected in the Community Agreements.

Radioactive decay was placed in the bottom left, indicating very small space and very small time, but this sticky note could go anywhere on the small space quadrant. In Lesson 8, it might move to the top left when we learn about half-lives.

Mantle convection was added in the top right corner.

Connections were made between **radioactive decay** and **particle movement,** and between **particle movement** and **mantle convection.**



Celebrate progress and wonder about radioactive material in Afar. Present **slide N**. Say, *We can explain so much now about matter, energy, and forces beneath Earth's crust! Radioactivity helps us understand what might be driving some of the processes we see. I wonder whether we'll find radioactive material in the rock in the Afar region. Quickly turn and talk with a partner. Based on our ideas, do you think we'll find evidence of radioactive material in Afar? Why or why not?*

9 · COMPLETE AN ELECTRONIC EXIT TICKET

6 min

MATERIALS: computer with access to https://docs.google.com/forms/d/149Ol8lpf1OoiwLWzLlPJNFHSnWbuFpO_vbniPllmJN8/copy, *L7 Electronic Exit Ticket Key*

Assign the Electronic Exit Ticket. Before class, make a copy of https://docs.google.com/forms/d/149Ol8lpf1OoiwLWzLlPJNFHSnWbuFpO_vbniPllmJN8/copy . Share the link to the copy with students (**do not** share the original link provided here, as that will create a new copy for each student, and you will not have access to their responses). Present **slide O**. Give students 5-10 minutes to complete the Electronic Exit Ticket.

ASSESSMENT OPPORTUNITY	**What to look for/listen for in the moment:** Use the *L7 Electronic Exit Ticket Key* to assess student work. **What to do:** This assessment is designed to make it easy to gather information about where students are still struggling to put the pieces together. It assesses one of the lesson-level performance expectations (LLPEs) from this lesson (Lesson 7), which brings together DCIs, CCCs, and SEPs from the previous three lessons. **Building toward: 7.A** Construct a cause-effect explanation for how radioactive decay provides the heat that drives mantle convection using ideas from our previous investigations, new evidence from a set of complementary readings, and the assumption that our past observations about matter, forces, and energy hold true across contexts. (SEP: 6.2; CCC: 2.2, 3.3; DCI: ESS2.B.1, PS3.A.2, PS2.B.2, PS1.C.1)

Additional Lesson 7 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA	**CCSS.ELA-LITERACY.11-12.RST.9** Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible. This standard is claimed because students synthesize information from several readings to develop a coherent understanding of how radioactivity drives convection in Earth's interior. Each reading alone is not sufficient to describe the phenomenon. The class works together to create this coherent understanding. **CCSS.ELA-LITERACY.11-12.RST.2** Determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.

	This standard is claimed because students determine the central ideas from the readings. They must paraphrase these important ideas to distill the cause-and-effect mechanisms required to create a consensus causal chain model.