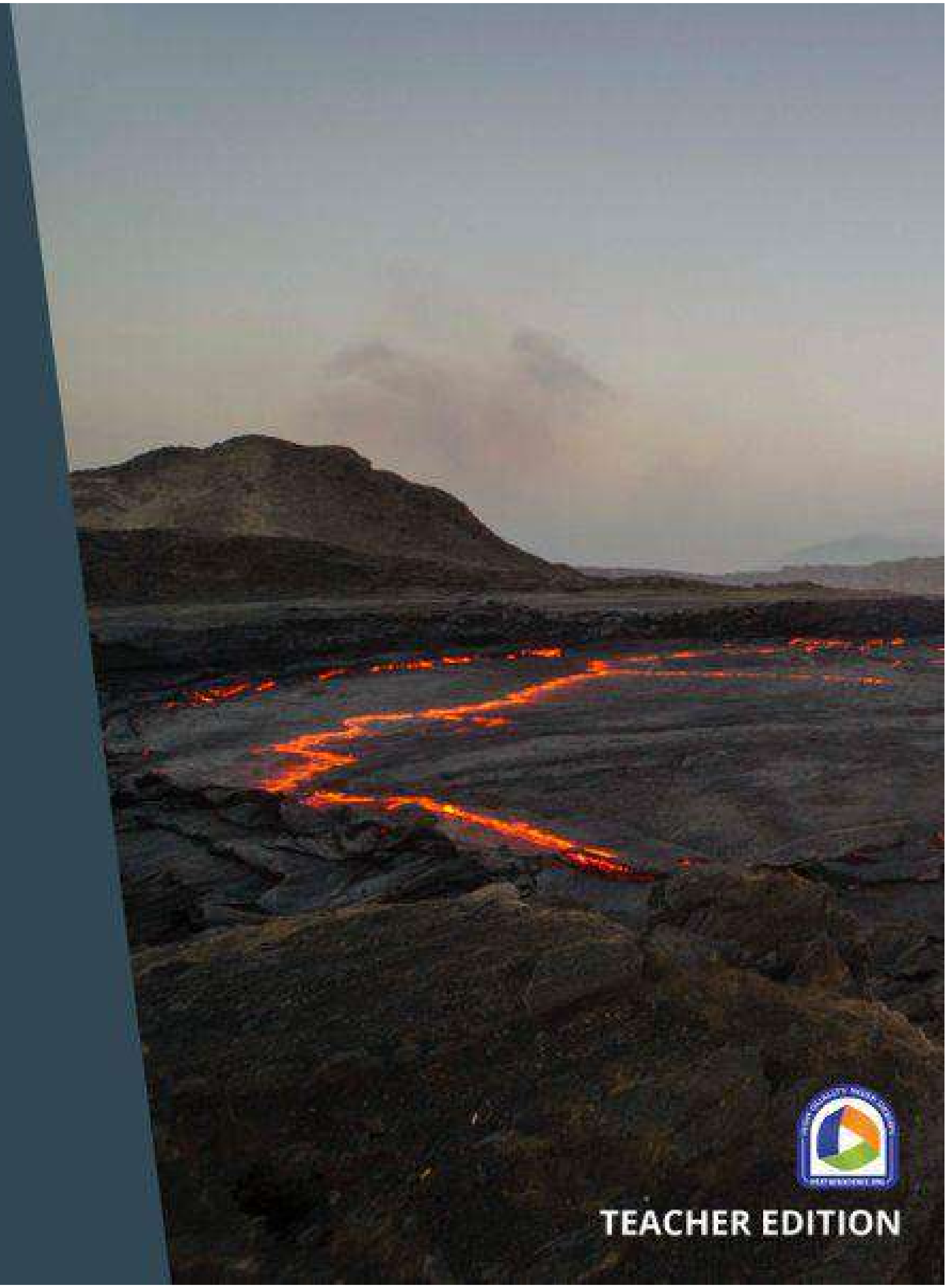
Energy, Forces, &
Earth's Crust

How do forces in Earth's interior determine what will happen to the surface we see?



OpenSciEd

HIGH SCHOOL SCIENCE

How do forces in Earth's interior determine what will happen to the surface we see?

Energy, Forces, & Earth's Crust: Afar

OpenSciEd Unit P.2

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*Special thanks to teachers who participated in the co-revision process

TABLE OF CONTENTS

UNIT P.2 How do forces in Earth's interior determine what will happen to the surface we see?

UNIT OVERVIEW

How do forces in Earth's interior determine what will happen to the surface we see?

This unit is anchored by a crack in Earth's crust that appeared in the Afar region in 2005. Earthquakes and a volcanic eruption also occurred around this time. Students read about the Afar event and about other earthquakes that occur in North America. Students look for similarities and differences in these earthquake events, prompting students to model the events that occurred before, during, and after the crack was discovered. In Lesson Set 1 (Lessons 1-8) students figure out that changes in the structure of matter involve unbalanced forces and energy transfer, using this idea to explain earthquakes and volcanoes at plate boundaries. Students then investigate the structure and dynamics of Earth's interior using tomography and modeling, including radioactivity, to explain the unbalanced forces driving changes in Earth's crust. In Lesson Set 2 (Lessons 9-13) Students investigate the ages of rocks to understand the history and future of the Afar region. Students use a simulation to figure out the interactions happening at tectonic plate boundaries, and investigate the nature of the relationship between mass and forces on the movement of tectonic plates to explain the past, present, and potential future of the Afar region. Students apply these ideas in a final transfer task to explain why the Midcontinent Rift, a rift similar to the rift in the Afar region, failed to create an ocean in the middle of North America 1.1 billion years ago.
Throughout the unit, students will do the following:
Developing and using models and **constructing explanations and designing solutions**

- Use a representation of spatial and temporal scales to investigate stability and change in Earth's systems, and the relationships between phenomena.
- Develop and use free-body diagrams to understand how unbalanced forces are related to energy transfer and matter transformations at different scales.
- Use a computer simulation to model the role of fields in matter transformations due to external forces.
- Develop and use a model of the relationships between energy, matter, and forces that will be a sensemaking tool throughout the rest of the course.
- Develop a model and analyze video to identify, model, and revise ideas about the relationship between forces, matter, and energy that drive the thermal convection cycle within the mantle.
- Construct a cause-and-effect model to explain how radioactive decay results in the release of enough heat to drive convection in the solid rock of Earth's mantle.
- Use mathematical thinking to determine the age of rocks from Afar and use that information to explain the history and future of tectonic activity around the world over large timescales.
- Use a simulation to investigate how plates interact at divergent and convergent plate boundaries.
- Model the forces of gravity and friction to explain ridge push and slab pull.

Building Toward NGSS Performance Expectations

HS-ESS1-5:
Evaluate evidence of the past and current movements of continental and oceanic crust and the theory of plate tectonics to explain the ages of crustal rocks.

HS-ESS2-1:

Develop a model to illustrate how Earth's internal and surface processes operate at different spatial and temporal scales to form continental and ocean-floor features.

HS-ESS2-3:
Develop a model based on evidence of Earth's interior to describe the cycling of matter by thermal convection.

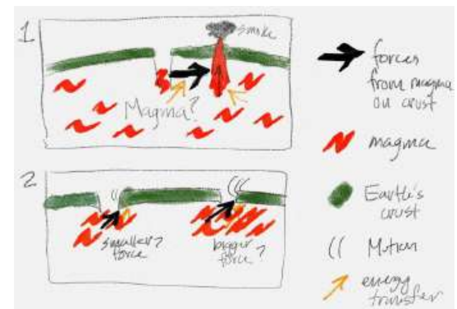
HS-PS1-8:
Develop models to illustrate the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion, and radioactive decay.

UNIT STORYLINE

How students will engage with each of the phenomena

HANDS-ON/ LAB ACTIVITIES | VIDEOS OR IMAGES | DATA SETS | READINGS | COMPUTER INTERACTIVES

Unit Question: How do forces in Earth's interior determine what will happen to the surface we see?

Lesson Set 1: How does land stretch and when/why does it break?			
Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 1 Lesson Set 1 2.5 days **What is happening in the Afar region?** Anchoring Phenomenon	 *A series of changes in Earth's crust over short and long timescales reveal puzzling patterns of earthquakes and cracks in Ethiopia, Africa, and similar patterns in North America.*	We explore a StoryMap about a series of events that left a giant crack in Earth's crust in the Afar region. We connect to prior earthquake experiences and earthquakes near us. We read about selected earthquakes and compare them with the events in Afar. We develop an initial model for before, during, and after the events. We develop questions for the Driving Question Board and ideas for investigations. We figure out: ● A crack opened up in the Afar region in 2005. A volcanic eruption and an earthquake also occurred. ● Earthquakes seem connected to faults, and most, but not all, happen along plate boundaries. ● Earthquakes happen underground and can cause cracking/moving of Earth's surface. ● There are similarities and differences between the earthquake cases and Afar events.	
⇓ **Navigation to Next Lesson:** We have explored multiple cases of earthquakes causing cracks in the ground. We wonder what could be causing the ground to shake and break.			

LESSON 2
Lesson Set 1

3 days

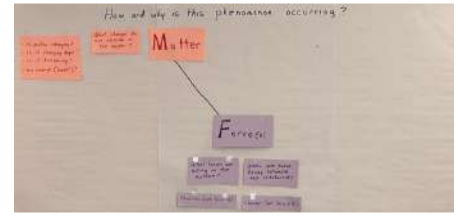
What allows a system to remain stable when forces are acting on it, and what causes it to suddenly change?

Investigation

Earth's plates show variation in their motion over the course of a year. Some combinations of contact forces on a piece of foam keep it stationary, and others do not.

We analyze plate motion data. We develop a model of force interactions between plates. We investigate the conditions that result in stability and change in motion of an object when multiple forces act on it. We use free-body diagrams to explain and predict how the magnitude of the forces applied at different scales impact the stability and changes in the matter within the system. We figure out:

- Stability is dependent on scale.
- The net force is the sum of all the forces acting on an object; it is zero when the forces are balanced along every axis.
- Forces at different scales can help explain why matter remains in a stable state and why its motion changes.



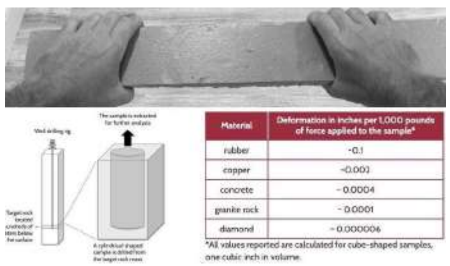
⇓ **Navigation to Next Lesson:** We have identified the net force of contact forces as a contributing factor in explaining the stability and changes within both matter and Earth' systems. We wonder about the changes in matter when external forces on an object continue to increase.

LESSON 3
Lesson Set 1

1 day

What happens to the matter and energy in a system when the magnitude of balanced forces on it increases?

Investigation



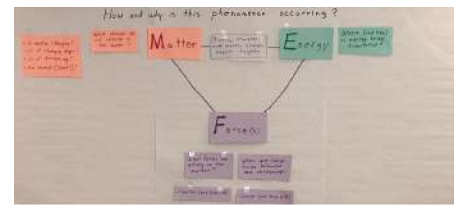
Material	Deformation in inches per 1,000 pounds of force applied to the sample*
rubber	~0.1
copper	~0.001
concrete	~0.0004
granite rock	~0.0001
diamond	~0.000006

*All values reported are calculated for cube-shaped samples, one cubic inch in volume.

Foam changes shape when we push or pull on it. Rock samples often change shape after they are extracted from the surrounding bedrock. Compression machines measure deformation as external forces are applied to a sample.

We explore changes in a piece of foam as higher-magnitude forces are applied to it. We develop a model relating how unbalanced forces cause the observed changes in matter and energy transfer. We predict whether rock would behave like the piece of foam. We gather information from a reading. We ask questions about the relationship of our new ideas to what is happening in Earth systems. We figure out:

- Changes in matter and energy transfers happen together.
- Unbalanced forces transfer energy.
- All solid materials deform elastically when force is applied to them, up to a point.
- When solids deform past their elastic limit, they permanently deform; this includes a permanent change in shape, cracks, and/or breaking into smaller pieces.



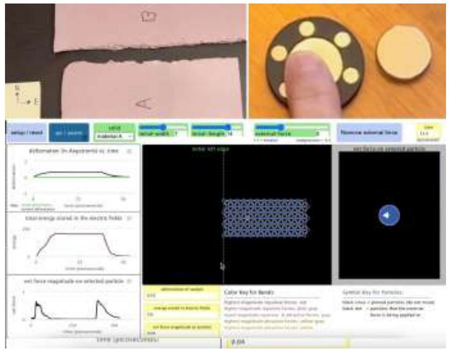
⇓ **Navigation to Next Lesson:** We raised new questions about the force interactions, elastic behavior and elastic limits, and energy transfers in solids that could help explain how earthquakes occur.

LESSON 4
Lesson Set 1

2 days

What is changing in the matter at a particle level before an earthquake, and when a solid elastically deforms or breaks?

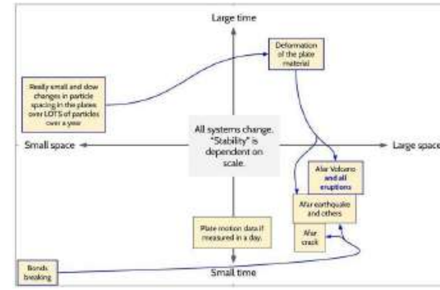
Investigation



When two pieces of foam are pushed in perpendicular directions against each other, they suddenly slip, and sometimes smaller pieces break off the larger ones.

We evaluate different models for understanding and explaining earthquakes, elastic deformation, and breaking of solid matter. We use a computer simulation to investigate how external forces on a solid affect matter changes and energy transfers at the particle level. We revise our M-E-F poster to account for the roles of fields, and we use these ideas to explain volcanic eruptions in an Electronic Exit Ticket. We figure out:

- All changes in matter (bending, breaking, state change) are changes in motion, either macroscopic or at the particle level.
- If unbalanced forces deform a solid too much, some of the particles in it move far enough apart that their bonds break.
- Matter produces various fields (electric, magnetic, gravitational); fields exert forces that act across a distance on other particles.
- Energy can be transferred to, transferred from, and stored in fields.



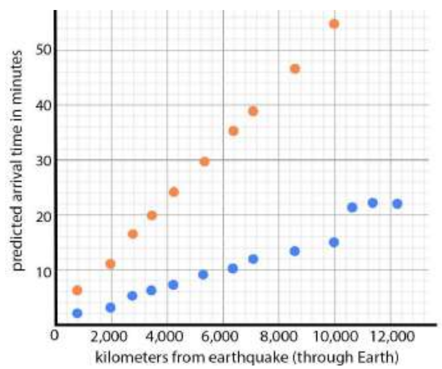
⇓ **Navigation to Next Lesson:** Though we can explain earthquakes and volcanoes at plate boundaries, Afar is not very near a plate boundary, so we need additional data to determine what is different about what is happening in the plates or below them at Afar.

LESSON 5
Lesson Set 1

3 days

How do we investigate the connection between matter in Earth's interior and surface features above?

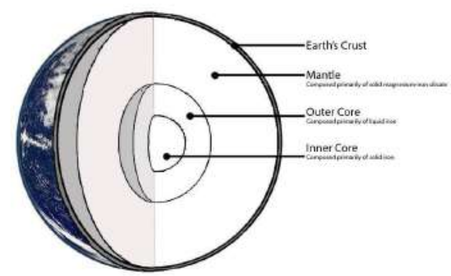
Investigation, Putting Pieces Together



Mathematical representations of earthquake data reveal anomalies in the speed at which

We wonder what could be happening in Earth's interior that could cause unbalanced forces on the crust of the Afar region. We investigate how energy transfers differently through different types of matter. We create a scale model to predict how long it should take seismic waves to reach various distances around Earth if the planet is made of solid rock. We analyze seismic data to determine how long it actually takes the waves to reach these distances. We graph the data to explore how well our model fits reality. We figure out:

- The speed of a wave through matter depends on the matter through which it is passing.
- Seismic velocity data provide evidence that Earth is composed of layers.

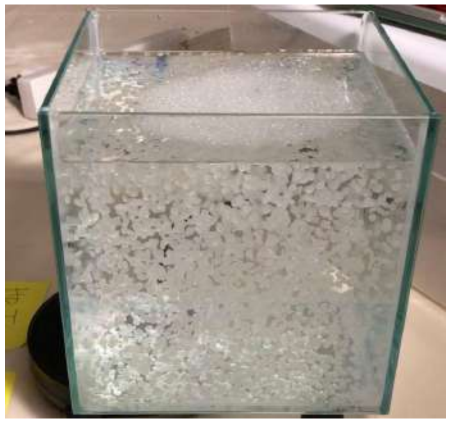
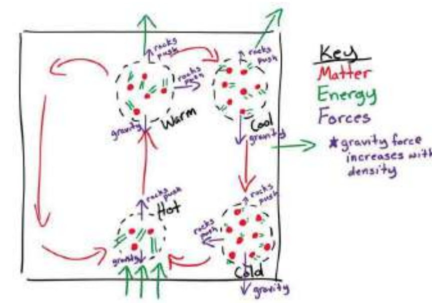


<table>
<tr><td></td><td>seismic waves travel through Earth.</td><td>Earth has a solid inner core, a liquid outer core, a mantle, and a crust.
Differences in matter in the mantle cause unbalanced forces in different locations, which is why some regions have different kinds of surface features than others.</td><td></td></tr>
<tr><td colspan="4">⇓ Navigation to Next Lesson: We wonder how temperature differences and motion in mantle matter could explain forces that cause change on Earth's surface.</td></tr>
<tr><td>LESSON 6
Lesson Set 1

2 days

How is temperature related to the behavior of the matter in the mantle?

Investigation

</td><td>
When liquid in a fish tank or a lava lamp is heated from below, the solid matter suspended in the liquid moves.</td><td>We develop a model to explain the movement of material in the mantle. We analyze a video of a tank simulating the matter in the mantle to figure out what happens to the matter when heat is added. We observe convection in the tank and revise our model to represent it. We compare this model to tomography data and revisit our DQB. We figure out:
Increasing the temperature of matter in the mantle causes particles to move faster and farther apart, occupying a larger volume that results in a lower density.
The relationship between the gravitational force and the pushing forces from beneath that act on matter in different parts of the mantle explains the cycling of matter in Earth's interior through convection.</td><td>
</td></tr>
<tr><td colspan="4">⇓ Navigation to Next Lesson: We saw that heat affected the density of parcels in the mantle tank, and we think this is also happening in the matter in the mantle. Now we wonder what might be causing this increase in energy that causes the differences in parcel density.</td></tr>
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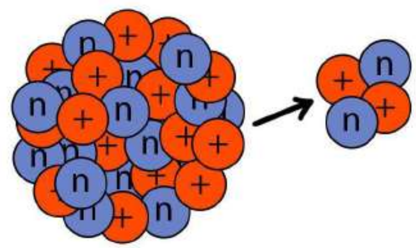
LESSON 7
Lesson Set 1

2 days

Where does the energy that drives convection come from?

Investigation, Putting Pieces Together



Scientists have used models to predict that a large portion of the heat that drives mantle convection comes from nuclear-scale processes that are unimaginably tiny in comparison.

We want to know where the heat comes from that drives mantle convection. We jigsaw a series of articles that answer this question from a forces perspective, a matter perspective, and an energy perspective. 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. We figure out:

- Nuclear energy can be modeled as being stored in the mass of the atomic nucleus itself.
- An imbalance of forces (strong and electric) in an atomic nucleus can cause 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.

⇓ **Navigation to Next Lesson:** Radioactive decay helped us understand what might be driving some of the processes we see in Earth's mantle. We wonder whether we will find radioactive material in the rock in the Afar region.

Lesson Set 2: How do forces determine what will happen on Earth's surface?

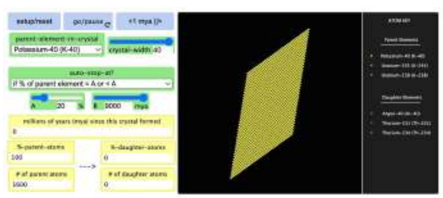
Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it

LESSON 8
Lesson Set 2

3 days

Is the rock at Afar radioactive, and what can that tell us?

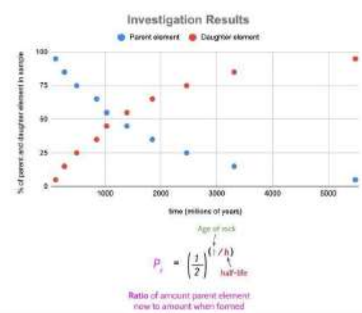
Investigation



Crystals from different rock samples around the Afar region contain different amounts of U-238 and K-40. The atoms in a simulation

We analyze the radioactive element composition of rocks from Afar. We use a simulation to collect data on how the amount of radioactive material in a rock crystal changes over time. We use mathematical thinking to compare patterns in our graphs to those in an equation of exponential decay, and we use that equation to determine the age of rocks from Afar. We figure out:

- Radioactive decay of elements follows a characteristic exponential decay law, with a specific lifetime (timescale) for each; we can



of radioactive elements within a crystal change over time from one type of atom to another.

use this to determine the ages of rocks and other materials from the ratio of parent to daughter elements present.

- Some of the rock on the western and eastern edges of Afar formed hundreds of million years ago. But most of the rock in the middle of the Afar region is very young, appearing over the last few million years.

⇓ **Navigation to Next Lesson:** Now that we have a way to determine the age of any rock, we think that comparing the ages of rocks found in other parts of the world to those found at Afar could help us figure out how long the processes going on Afar might continue, and how they might be similar or different to changes that have happened elsewhere on Earth.

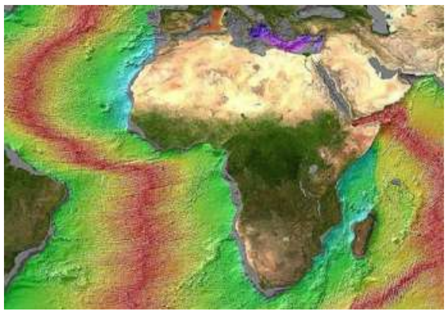
LESSON 9

Lesson Set 2

2 days

How does the rock in Afar compare to the rock around the world, and what does this tell us about the history and future of the region?

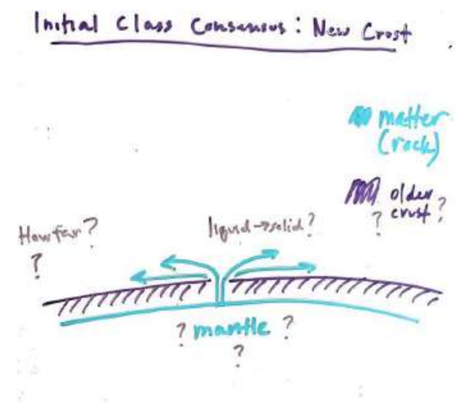
Investigation



A map of crustal ages on continents and in the ocean shows several puzzling patterns, including very young basalt in the Afar region.

We look at data on the crustal ages of rocks around the world and notice that the farther the rock is from some plate boundaries in the ocean, the older it is. We model what might be going on at these boundaries. We determine the density of basalt (oceanic crust) and granite (continental crust) and wonder about how that affects forces and energy transfer. Finally, we add questions to the DQB about plate boundaries and types of crust. We figure out:

- Continental crust is, on average, significantly older and less dense than oceanic crust.
- As you move outward from some plate boundaries in the middle of the ocean, the basalt rocks get older, suggesting that the material originated at the boundary and was pushed outward over a large timescale.
- The new rock in Afar is young basalt, suggesting that a similar process may be occurring there.



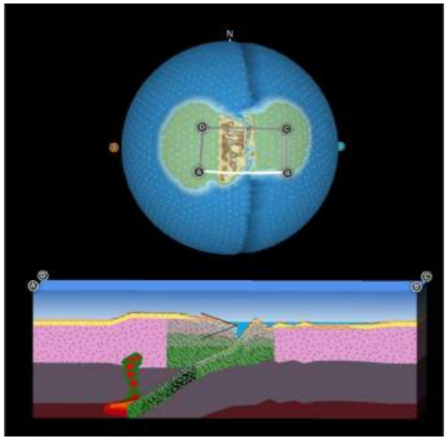
⇓ **Navigation to Next Lesson:** We want to know whether all places where plates are in contact look like these lines in the ocean where basalt is forming. We decide to look more closely at plate boundaries where continental crust meets oceanic crust.

LESSON 10
Lesson Set 2

2 days

What is happening at plate boundaries?

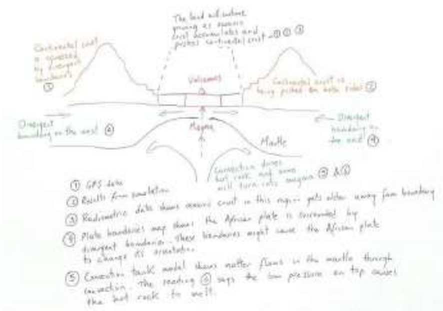
Investigation



The interactions of plates in a simulation show changes in matter in the mantle and on the surface near plate boundaries.

We use a simulation to investigate how plates interact at divergent and convergent plate boundaries. We analyze data to compare the surface features on Earth to the surface features represented in the simulation. We develop a model that explains how the interactions of plates result in the surface features we identified. We wonder which forces are acting on plates that can help us explain the patterns we identified in their motion. We figure out:

- The movement of plates and their interactions at plate boundaries shape the planet's surface features, such as mountains, islands, earthquakes, and volcanoes.



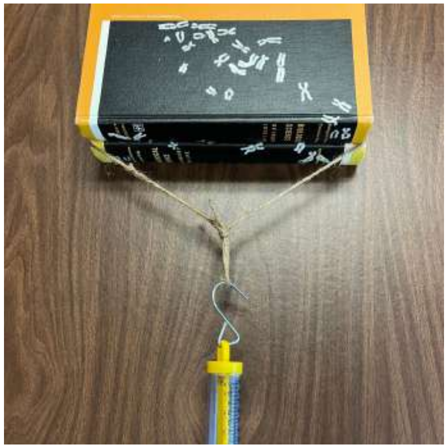
⇓ **Navigation to Next Lesson:** We are wondering which forces are acting on plates that could help us explain their motion patterns on the surface and in the mantle.

LESSON 11
Lesson Set 2

2 days

How might forces between the mantle and plates affect plate motion?

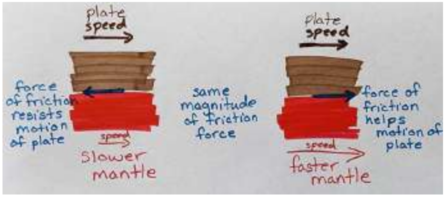
Investigation



Different objects require different amounts of

We investigate variables that we consider may affect friction forces between an object and the surface it slides over. We connect our conclusions from our investigations to properties of the plates and motion. We figure out:

- The force of friction depends on the mass of the object and the material of the surfaces rubbing together, but not on the surface area between the object and the surface.



force to drag them at a constant velocity.

⇓ **Navigation to Next Lesson:** We are still wondering how other forces, like gravity, affect plate motion.

LESSON 12

Lesson Set 2

2 days

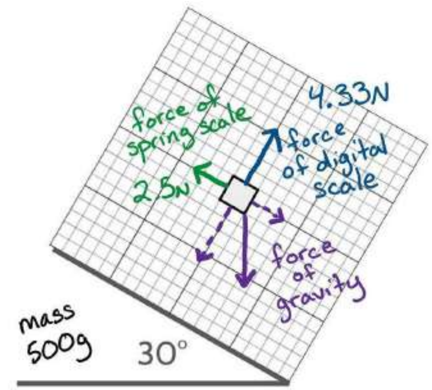
How do forces act on objects, such as the plates, when they are on inclines?

Investigation, Putting Pieces Together

Changing the incline of an object ramp changes the weight registered on a scale under the object and the magnitude of the force registered on a spring scale against the object.

We model forces acting on plates and investigate forces on an object placed on an incline. We model how the force of gravity can be split into two vector components to make sense of how gravity pulls down inclines, and we connect this to plate motion to update our plate interactions model. We figure out:

- The force of gravity can be broken into components that pull parallel and perpendicular to an incline, and as the incline gets steeper, the component of gravity parallel to the incline increases.
- The force of gravity on an object is directly proportional to the mass of the object.
- The force of gravity contributes to changes in plate motion through processes called slab pull and ridge push.



⇓ **Navigation to Next Lesson:** We have revised our consensus model of plate interactions and are wondering how it might explain other Earth events.

LESSON 13

Lesson Set 2

1 day

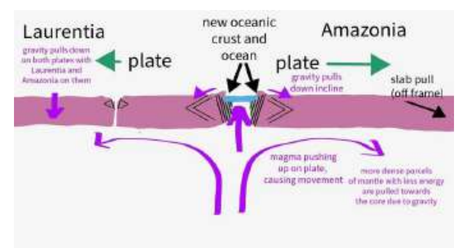
How can we use our science ideas to explain what happened at the Midcontinent Rift?

Putting Pieces Together

The Midcontinent Rift started to tear apart like the Afar rift, but failed.

We revisit our Scale Chart poster and Driving Question Board and complete a transfer task comparing the fate of the Midcontinent Ridge to the growing Afar rift.

- Many processes on the Scale Chart poster have effects on other processes at different scales.
- Processes that occurred at the Midcontinent Rift 1.1 billion years ago are similar to what is occurring at Afar today.



		• Thermal convection and the interaction of forces with plates can be used to explain how the Midcontinent Rift failed.	
⇓ **Navigation to Next Lesson:** There is no next lesson.			

LESSONS 1-13

27.5 days total

TEACHER BACKGROUND KNOWLEDGE

Lab Safety Requirements for Science Investigations

It is important to adopt and follow appropriate safety practices when conducting hands-on science investigations and demonstrations, whether in an instructional space (traditional laboratory or classroom) or in the field. To this end, teachers must be aware of any school or district safety policies, legal safety standards, and better professional safety practices that are applicable to the activities being undertaken.

Science safety practices in instructional spaces require engineering controls and personal protective equipment (e.g., sanitized safety goggles or safety glasses with side shields as appropriate, non-latex aprons and gloves, eyewash/shower station, fume hood, appropriate ventilation, and fire extinguishers). **Science investigations should always be directly supervised by qualified adults, who should review safety procedures annually, and also before initiating any hands-on activities or demonstrations.** Prior to each investigation, students should be reminded of the specific safety procedures they must follow. Each lesson within the OpenSciEd units includes teacher guidelines for applicable safety procedures for setting up and running an investigation, as well as disassembling, disposing of, and storing materials.

Prior to the first investigation of the year, a safety acknowledgement form for students and parents/guardians should be provided and signed. You can access a model safety acknowledgement form for high school activities here: https://static.nsta.org/pdfs/SafetyAcknowledgmentForm-HighSchool.pdf

Disclaimer: The safety precautions provided for each activity are based in part on use of the specifically recommended materials and instructions, as well as legal safety standards and better professional safety practices. Be aware that selecting alternative materials or procedures for these activities may affect the activity's level of safety, and is therefore at the user's own risk.

Please follow these lab safety recommendations for any science investigation:

1. Wear sanitized safety goggles (specifically, indirectly vented chemical splash goggles) or safety glasses with side shields, as appropriate, a non-latex apron, and non-latex gloves during the set-up, hands-on investigation, and take-down segments of the activity.
2. Safety goggles are required when working with liquid biological or chemical hazards (e.g., microbes, acids, bases, etc.). Safety glasses with side shields or safety goggles may be used when working with physical hazards (sharps, springs, glass, projectiles, etc.).
3. Immediately wipe up any spilled liquid (e.g., water) and/or granules on the floor, as this is a slip-and-fall hazard.
4. Follow your *Teacher Guide* for instructions on disassembling and storing materials and disposing of waste materials.
5. Secure loose clothing, remove loose jewelry, wear closed-toe shoes, and tie back long hair.
6. Wash your hands with soap and water immediately after completing the activity.
7. Never eat any food items used in a lab activity.
8. Never taste any substance or chemical in the lab.
9. Use only GFCI-protected circuits when using electrical equipment, and keep away from water sources to prevent shock.
10. Use caution when working with glassware, which can shatter if dropped and cut skin.

11. Use caution when using sharp [tools/materials], which can cut or puncture skin.
12. Never pour chemicals, either used or unused, back into their original container. Dispose of chemicals according to your teacher's instructions.
13. If you get a hazardous chemical on your clothing or have a clothing fire, use the emergency shower.
14. If you get a chemical in your eye, use an eyewash station immediately.
15. Point the test tubes, beakers, or other vessels away from yourself and other people when the vessels contain reactants or other substances.
16. When diluting acids or bases, the acid or base should be added to water and not water to the acid or base.
17. Projective trajectory zones must be well defined and free of any obstacles. No participant is to be in the zone during operation of the projectile.
18. Make sure the ventilation system meets the needs relative to removal of flammable vapors produced. Also make sure there are no active flames or sparks in the work zone.

Specific safety precautions are called out within the lesson using this icon and a callout box.

Where does this unit fall within the OpenSciEd Scope and Sequence?

This unit is the second in the OpenSciEd High School Physics course sequence. It is designed to build on student ideas about energy transfer and matter interactions from the course's first unit, *OpenSciEd Unit P.1: How can we design more reliable systems to meet our communities' energy needs? (Electricity Unit)*. In that first unit, students developed ideas around energy transfer and conservation in the context of charged particles (electrons) colliding with other electrons (electricity) to transfer energy across great distances. In this unit, Earth science phenomena that transfer energy differently across scales of time and space will motivate the need for forces to explain observations. Students establish conventions for modeling forces using free-body diagrams and think deeply about the connection between unbalanced forces, energy transfer, and motion. Although they do not quantify the relationship between forces and acceleration in this unit, they develop a robust intuitive understanding of forces, which will be fundamental to deriving and applying Newton's second law (F=ma), which will form the basis for the way forces are applied over the next several units.

In the course's third unit, *OpenSciEd Unit P.3: What can we do to make driving safer for everyone? (Vehicle Collisions Unit)*, students develop a more robust understanding of forces as vectors and use conservation of momentum to make predictions about the outcomes of collisions. In the fourth unit, *OpenSciEd Unit P.4: Meteors, Orbits, and Gravity (Meteors Unit)*, they expand their model of forces to include the force of gravity at great distances, using ideas about fields developed in the first unit to understand the relationships between gravity and energy transfer. In the fifth unit, *OpenSciEd Unit P.5: How do we use radiation in our lives and is it safe for humans? (Microwave Unit)*, they use energy transfer, electromagnetism, wave mechanics, and forces at a distance to explain how food heats up in a microwave and how this technology might be dangerous for humans. In the final unit, *OpenSciEd Unit P.6: Earth's History and the Big Bang (Cosmology Unit)*, students explore cosmology and the Big Bang, applying ideas about forces and energy from all five previous units on the largest scale.

What is the anchoring phenomenon and why was it chosen?

This unit is anchored by a puzzling Earth science phenomenon: the land in East Africa appears to be ripping apart. In 2005, a crack opened up very suddenly in a region called Afar in Ethiopia, accompanied by earthquakes and a volcanic eruption. This phenomenon provides the context in which to investigate the relationship between unbalanced forces and energy transfer through systems, how radioactive decay on the particle scale drives global-scale convection, and the role of plate tectonics in explaining Earth's surface features. This unit uses fundamental physics ideas about how unbalanced forces transfer energy through systems, causing motion. The unit then uses these ideas to describe and explain fundamental Earth science ideas about how the hidden processes playing out in Earth's interior over short and long temporal/spatial scales shape the surface patterns we see.

The Afar anchoring phenomenon was chosen from a group of phenomena aligned with the target performance expectations based on the results of a survey administered to almost 1000 students from across the country, and in consultation with external advisory panels that include teachers, subject matter experts, and state science administrators. The phenomena in units 1, 3, 4, and 5 were chosen because they have high relevance to students' everyday experiences and communities. The phenomenon in this unit is playing out on a timescale at which it can be difficult to see the relevance to human lives. This more abstract and Earth-scale phenomenon was chosen with a purpose. The full physics course is designed to purposefully highlight a variety of different types of phenomena, some of which overlap: from justice-oriented (P1, P3), to everyday (P3, P5), to culturally embedded (P4), to more abstract (P2, P6). Though we design to privilege the interests of students to whom we owe an educational debt, we must not essentialize minoritized groups by assuming that a trend in the data equates to homogeneous interests and experiences. Providing a diverse suite of entry points into content and practices creates more opportunities for every student to connect with the content.

The Afar phenomenon was chosen for the following reasons:

- Students showed high interest in explaining unique and puzzling surface features in survey data.
- To provide a diverse suite of entry points across the course, we were seeking an event that allowed students to consider a global-scale phenomenon.
- Teachers and administrators saw the phenomenon as interesting and on grade band.
- Explaining the mechanisms of Earth's interior using physics concepts grounds abstract ideas about forces.
- Explaining the phenomenon addresses all the disciplinary core ideas in the bundle at a high school level.
- Explaining the phenomenon requires the use of both forces and energy in order to understand sudden and long-timescale change.

How is the unit structured?

The unit is organized into two main lesson sets. **Lesson Set 1** (Lessons 1-8) focuses on answering the question: *How does land stretch and when/why does it break?* In the first lesson set, students make observations of a series of changes in Earth's crust over short and long timescales that reveal patterns at a local scale in a region called the Afar Triangle in Ethiopia, and at a larger scale along the eastern half of the African continent. This leads them to wonder about the nature of stretching and breaking in matter. They work with manipulatives and simulations to establish the role of unbalanced forces in natural processes, which helps them figure out why some energy transfer processes in Earth's crust are slow and stable but others are sudden and unpredictable. Their investigations lead them to explore seismography and tomography data, which allows them to model the structure of Earth's interior and notice dynamic patterns in the mantle. To explain these patterns, students observe a model of mantle convection and read about radioactivity, which gives them the tools to describe mantle processes from a forces, matter, and energy transfer perspective.

Lesson Set 2 (Lessons 9-13) focuses on answering the question: *How do forces determine what will happen to Earth's surface?* In the second lesson set, students apply their new ideas about radioactivity to understand radiometric dating, and discover that many of the rocks in the Afar region are very young compared to the surrounding area. They explore the differences in density between oceanic and continental rocks (basalt and granite) and figure out that just as density differences can cause an unbalance of forces in the mantle, they can also cause an unbalance of forces in the crust due to an emergent relationship between mass and gravitational force, which can contribute to the movement of tectonic plates. Finally, students put the pieces together to predict what will happen to the Afar region in the geological future and apply their understanding to explain why the Midcontinent Rift failed 1.1 billion years ago.

LS1: How does land stretch and when/why does it break?

Lesson 1

Students observe changes in Earth's crust in East Africa and North America. They wonder about the nature of stretching and breaking in matter.

Lessons 2-4

Students figure out that changes in the structure of matter involve unbalanced forces and energy transfer.

Lessons 5-8

Students investigate the structure and dynamics of Earth's interior using tomography and modeling, including radioactivity, to explain the unbalanced forces driving changes in Earth's crust.

LS2: How do forces determine what will happen to Earth's surface?

Lesson 9

Students investigate the ages of rocks in the Afar region and across Earth's surface to understand the history and future of the region.

Lesson 10-13

Students use a simulation to figure out the interactions happening at tectonic plate boundaries, and investigate the nature of the relationship between mass and forces to put the pieces together.

Transfer Task

Students use science ideas to explain why the Midcontinent Rift, a rift similar to the rift in the Afar region, failed to create an ocean 1.1 billion years ago.

What elements of the NGSS three dimensions are developed in this unit?

This unit is designed to introduce students to the concept of force in an intuitive and grounded context, allowing them to make strong connections between forces, energy transfer, and matter changes that they can carry forward into the rest of the course and beyond. In addition, this unit supports students in understanding fundamental Earth science ideas related to plate tectonics, radioactivity, convection, and rock formation at a high school level.

The crosscutting concept of scale, proportion, and quantity is **intentionally developed** across this unit. Students add to a Scale Chart that they use to track important mechanisms and structures across scales of time and space, beginning with the spatial scale of the events in Lesson 1, and progressing to both spatial and temporal processes through the end of the unit. Throughout this unit, students apply cause-and-effect reasoning to build complex mechanistic explanations that span across scales; for example, how nuclear processes at the scale of an atomic nucleus can be part of a cause-and-effect chain that helps to explain plate tectonics, and thus Earth's changing surface. They use the Scale Chart (and their Progress Trackers) to keep track of new cause-effect connections across scales.

Students also use the Scale Chart to consider how stability and change manifest differently at different scales (i.e., a system that appears stable at a macro scale might be unstable at an atomic scale). In this way, the crosscutting concept of stability and change is also **intentionally developed across the unit.** To support this sensemaking, the crosscutting concepts of cause and effect and scale proportion and quantity, and the science and engineering practice of constructing explanations, are **intentionally developed** in this unit.

This unit **intentionally develops** students' engagement in developing and using models by providing opportunities for students to model tectonic processes across scales and to move flexibly between different types of models, including manipulative models, diagrammatic models, cause-effect models, descriptive models, cross-sectional models, and mathematical models. Students use evidence from a variety of sources to inform the development and revision of these models. Students apply the *Matter-Energy-Forces triangle framework* that they have developed to model key interactions within a system.

This unit **intentionally develops** the crosscutting concept of energy and matter using a tool called the *Matter-Energy-Forces triangle*. Students model the transfer of energy through subsystems in Earth's geosphere, such as through convection and volcanic eruptions, and keep track of how energy transfer impacts matter change and cycling. They add forces to their understanding of energy and matter, and develop an intuitive understanding of how forces transfer energy and deform matter. They also develop conventions for free-body diagrams, a type of modeling that is key to building explanations in classical mechanics and will be important in *OpenSciEd Unit P.3: What can we do to make driving safer for everyone? (Vehicle Collisions Unit)*, as students figure out Newton's second law.

This unit builds toward these performance expectations:
HS-ESS1-5 Evaluate evidence of the past and current movements of continental and oceanic crust and the theory of plate tectonics to explain the ages of crustal rocks. **HS-ESS2-1†** Develop a model to illustrate how Earth's internal and surface processes operate at different spatial and temporal scales to form continental and ocean-floor features. **HS-ESS2-3** Develop a model based on evidence of Earth's interior to describe the cycling of matter by thermal convection. **HS-PS1-8†** Develop models to illustrate the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion, and radioactive decay.

*This performance expectation is developed across multiple units. This unit reinforces these NGSS PEs in a physics context.

†This performance expectation is developed across multiple courses. This unit reinforces or works toward these NGSS PEs that students will have previously developed in the OpenSciEd Chemistry and/or Biology courses.

Science and Engineering Practices	Disciplinary Core Ideas*	Crosscutting Concepts
Developing and using models in 9–12 builds on K–8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds. The following elements of this practice are intentionally developed across this unit: ● Evaluate merits and limitations of two different models of the same proposed tool, process, mechanism, or system in order to select or revise a model that best fits the evidence or design criteria. ● 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. ● Develop and/or use multiple types of models to provide mechanistic accounts and/or predict phenomena, and move flexibly between model types based on 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. **Constructing explanations and designing solutions** in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories. The following elements of this practice are intentionally developed across this unit: ● Make a quantitative and/or qualitative claim regarding the relationship between dependent and independent variables. ● 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	**PS2.B: Types of Interactions** ● 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 is associated with a performance expectation that is not included in the bundle for this unit, and is covered in the first unit in this course. Applying this idea is key to building the ideas necessary to explain breaking in Earth's crust.) ● Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter~~, as well as the contact forces between material objects~~. (HS-PS2-6, secondary to HS-PS1-1, secondary to HS-PS1-3) (This DCI is associated with a performance expectation that is not included in the bundle for this unit, and is covered in the OpenSciEd HS Chemistry course. Applying this idea is key to building the ideas necessary to explain breaking in Earth's crust.) **PS3.A: Definitions of Energy** ● At the macroscopic scale, energy manifests itself in multiple ways, such as in motion~~, sound, light,~~ and thermal energy. (HS-PS3-2, HS-PS3-3) (This DCI is associated with a performance expectation that is not included in the bundle for this unit, and is covered in the first unit in this course. Applying this idea is key to building the ideas necessary to explain breaking in Earth's crust.) ● 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) (This DCI is associated with a performance expectation that is not included in the bundle for this unit, and is covered in the first unit in this course. Applying this idea is key to building the ideas necessary to explain breaking in Earth's crust.)	**Energy and Matter.** Tracking energy and matter flows, into, out of, and within systems helps in understanding their system's behavior. The following elements of this crosscutting concept are intentionally developed across this unit: ● 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. ● Energy cannot be created or destroyed—it only moves between one place and another place, between objects and/or fields, or between systems. **Cause and Effect.** Events have causes, sometimes simple, sometimes multifaceted. A major activity of science is investigating and explaining causal relationships and the mechanisms by which they are mediated. The following elements of this crosscutting concept are intentionally developed across this unit: ● 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. **Patterns.** Observed patterns in nature guide organization and classification and prompt questions about relationships and underlying causes. The following elements of this crosscutting concept are intentionally developed across this unit: ● Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena. ● Classifications or explanations used at one scale may fail or need revision when information from smaller or larger scales is introduced, thus requiring

natural world operate today as they did in the past and will continue to do so in the future. Elements from the following practices are also **key to the sensemaking** in this unit: ● Asking Questions ● Obtaining, Evaluating, and Communicating Information ● Planning and Carrying Out Investigations ● Using Mathematics and Computational Thinking	**PS3.B: Conservation of Energy and Energy Transfer** ● Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. (HS-PS3-2) (This DCI is associated with a performance expectation that is not included in the bundle for this unit, and is covered in the first unit in this course. Applying this idea is key to building the ideas necessary to explain breaking in Earth's crust.) **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. (HS-PS4-1) (This DCI is associated with a performance expectation that is not included in the bundle for this unit, and the parts that are crossed out here are covered in the fifth unit in this course, when students investigate electromagnetic waves.) ● Geologists use seismic waves and their reflection at interfaces between layers to probe structures deep in the planet. (secondary to HS-ESS2-3) **PS1.C: Nuclear Processes** ● 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) ● Spontaneous radioactive decays follow a characteristic exponential decay law. Nuclear lifetimes allow radiometric dating to be used to determine the ages of rocks and other materials. (secondary to HS-ESS1-5, secondary to HS-ESS1-6) **ESS1.C: The History of Planet Earth** ● Continental rocks, which can be older than 4 billion years, are generally much older than the rocks of the ocean floor, which are less than 200 million years old. (HS-ESS1-5) **ESS2.A: Earth Materials and Systems** ● Earth's systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes. (HS-ESS2-1, HS-ESS2-2) ● Evidence from deep probes and seismic waves, ~~reconstructions of historical changes in Earth's surface and~~	improved investigations and experiments. ● Mathematical representations are needed to identify some patterns. ● Empirical evidence is needed to identify patterns. The following crosscutting concepts are also **key to the sensemaking** in this unit: ● Structure and Function ● Systems and Systems Models

	~~its magnetic field,~~ and an understanding of physical and chemical processes lead to a model of Earth with a hot but solid inner core, a liquid outer core, a solid mantle and crust. Motions of the mantle and its plates occur primarily through thermal convection, which involves the cycling of matter due to the outward flow of energy from Earth's interior and gravitational movement of denser materials toward the interior. (HS-ESS2-3) **ESS2.B: Plate Tectonics and Large-Scale System Interactions** ● 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) ● Plate tectonics is the unifying theory that explains the past and current movements of the rocks at Earth's surface and provides a framework for understanding its geologic history. (ESS2.B Grade 8 GBE) (secondary to HS-ESS1-5) ● Plate tectonics is the unifying theory that explains the past and current movements of the rocks at Earth's surface and provides a framework for understanding its geologic history. ● Plate movements are responsible for most continental and ocean-floor features and for the distribution of most rocks and minerals within Earth's crust. (HS-ESS2-1)	

*"Disciplinary Core Ideas" are reproduced verbatim from *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. DOI: https://doi.org/10.17226/13165. National Research Council; Division of Behavioral and Social Sciences and Education; Board on Science Education; Committee on a Conceptual Framework for New K-12 Science Education Standards. National Academies Press, Washington, DC. This material may be reproduced and used by other parties with this attribution. If the original material is altered in any way, the attribution must state that the material is adapted from the original.

Connections to the Nature of Science (NOS)

Connections to the Nature of Science (NOS)	
Which elements of NOS are developed in the unit?	How are they developed?
Scientific Knowledge Is Based on Empirical Evidence. Science includes the process of coordinating patterns of evidence with current theory.	In Lesson 5, students coordinate patterns of evidence with a model of Earth's interior. They respond to a reflection question during the navigation into day 2 on how empirical evidence helped them identify patterns and anomalies in seismic velocities to support their reasoning about the plausibility of the layers model.

Scientific Investigations Use a Variety of Methods. Scientific inquiry is characterized by a common set of values that include: logical thinking, precision, open-mindedness, objectivity, skepticism, replicability of results, and honest and ethical reporting of findings.	In Lesson 2, students are asked to consider whether they need to collect more trials in light of their empirical results. The class discusses data accuracy, the number of trials needed, potential causes of errors, outliers, and uncertainty in an investigation. In Lesson 8, students assess the accuracy and replicability of their results as they investigate radioactive decay using a simulation. Working in groups and as a class, they discuss the importance of accuracy and replicability in scientific investigations.
Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena. Models, mechanisms, and explanations collectively serve as tools in the development of a scientific theory.	In Lesson 13, the Scale Chart is revisited to determine that the models, mechanisms identified, and explanations used in the unit up to Lesson 13 represent the Theory of Plate Tectonics. The items on the Scale Chart are grouped and labeled the Theory of Plate Tectonics.
Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena. Scientists often use hypotheses to develop and test theories and explanations.	In Lesson 11, students use sentence stems to develop explanatory hypotheses that describe how they predict independent variables are related to the dependent variable of the amount of friction force acting on an object.

How does the unit build three-dimensional progressions across the course and the program?

OpenSciEd units support students in integrated development and use of the three dimensions. No single dimension can be developed in isolation from the others, as reflected in three-dimensional lesson-level performance expectations (LLPEs), which detail the specific dimensions and elements used and assessed in each lesson. However, some practices and crosscutting concepts are more productive for investigating particular anchoring phenomena, so focal practices and crosscutting concepts are articulated in each unit. All 46 SEP and 29 CCC elements are developed at some point in the high school OpenSciEd program, so all elements of a given SEP or CCC may not be present even in a unit that emphasizes developing that SEP or CCC.

This unit uses and builds upon the following **disciplinary core ideas (DCIs)** and other science ideas that students should have previously developed in the **OpenSciEd High School Biology and Chemistry courses**:

- We can trace energy flow in systems using computational models because energy is conserved. (*Serengeti Unit* and *Fuels Unit*)
- Thermal energy transfer through particle collisions may result in phase change of matter as the average kinetic energy (temperature) of the matter rises or falls. It is easier to raise the temperature of a substance with less mass. (*Polar Ice Unit*)
- Atoms have nuclei with protons and neutrons--the number of nuclear particles is conserved in nuclear processes. (*Electrostatics Unit* and *Fuels Unit*)

This unit uses and builds upon **DCIs** and other science ideas that students should have previously developed in this course:

- Energy transfers through systems and is conserved. (*Electricity Unit*)
- Energy can be transformed into less useful forms. (*Electricity Unit*)
- Matter and energy can flow together. (*Electricity Unit*)

This unit also reinforces and builds from the following **DCI elements** from the **OpenSciEd Middle School sequence**:

- Thermal energy describes the average kinetic energy of particles in a system, and can be transferred through particle collisions. (*Cup Design Unit*)

- Mechanical waves transfer energy through space by changing the position of particles in a medium such as water or air. (*Sound Unit*)
- Earth's crust is broken into plates that move and change surface features as they interact. (*Everest Unit*)
- Forces cause matter changes, and energy transfer (*Collisions Unit*)

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:

	Questions	Models	Investigations	Data	Math	Explanation	Argument	Obtaining
Biology	*Genetics Unit*	*Serengeti Unit, Fires Unit*	*Fires Unit, Natural Selection Unit*	*Natural Selection Unit, Genetics Unit*	*Serengeti Unit*	*Fires Unit, Genetics Unit, Natural Selection Unit*	*Speciation Unit*	*Genetics Unit, Speciation Unit*
Chemistry	*Polar Ice Unit, Oysters Unit*	*Electrostatics Unit, Space Survival Unit*	*Polar Ice Unit*	*Fuels Unit*	*Polar Ice Unit, Oysters Unit*	*Fuels Unit*	*Fuels Unit*	*Electrostatics Unit, Space Survival Unit*
Physics	*Electricity Unit, Cosmology Unit*	*Electricity Unit, Microwave Unit*	*Microwave Unit*	*Electricity Unit, Earth's Interior Unit, Vehicle Collisions Unit, Meteors Unit*	*Vehicle Collisions Unit, Meteors Unit*	*Electricity Unit, Earth's Interior Unit, Vehicle Collisions Unit*	*Vehicle Collisions Unit*	*Cosmology Unit, Microwave Unit*

	Patterns	Cause/Effect	Scale	Systems/Models	Energy/Matter	Structure/Function	Stability/Change
Biology	*Natural Selection Unit, Speciation Unit*	*Genetics Unit, Natural Selection Unit, Speciation Unit, Serengeti Unit*	*Serengeti Unit*	*Fires Unit, Genetics Unit, Serengeti Unit*	*Fires Unit, Serengeti Unit*	*Genetics Unit*	*Speciation Unit, Serengeti Unit*
Chemistry	*Electrostatics Unit, Space Survival Unit*	*Oysters Unit, Fuels Unit*	*Electrostatics Unit, Oysters Unit*	*Polar Ice Unit*	*Polar Ice Unit, Fuels Unit*	*Space Survival Unit*	*Oysters Unit*
Physics	*Cosmology Unit, Vehicle Collisions Unit, Earth's Interior Unit*	*Vehicle Collisions Unit, Earth's Interior Unit*	*Meteors Unit, Earth's Interior Unit*	*Electricity Unit, Vehicle Collisions Unit, Microwave Unit*	*Electricity Unit, Earth's Interior Unit*	*Earth's Interior Unit, Vehicle Collisions Unit*	*Electricity Unit, Cosmology Unit*

What are some common ideas that students might have?

Students will come into the unit with many ideas about forces and Earth dynamics derived from previous classroom experiences, intuitive understandings of the way the world works, everyday experiences with movement, and conversations they have had with parents, friends, and family members.

Some relevant ideas that students may come into the unit with include the following:

1. A continuous force is needed for continuous motion.
2. Direction of motion implies direction of force.
3. The mantle is liquid, and convection can only occur in a liquid.
4. Only continents move, floating on top of oceans.
5. Most crust motions (especially those associated with processes of mountain building or deep sea trench formation) are due to vertical motions, not lateral.
6. The only place magma reaches the surface is at volcanoes.
7. Plate movement is imperceptible on a human time frame.
8. Plate motion is rapid enough that continent collision can injure animals and plants.
9. The weight of oceans is responsible for the higher density of oceanic crust.
10. The edge of a continent is the same thing as a plate boundary.
11. A plate boundary type is the same thing as a plate. For example, a plate has to be divergent or convergent.

It is valuable to think of ideas like these not as misconceptions that need to be erased but as productive ideas that we can use to build understanding. Not only does this help some students feel more comfortable talking about science and build a scientific identity, it improves science learning across the board. For example, in Lesson 5, students explore the idea that Earth might be solid rock all the way through. In fact, Earth most likely has a liquid outer core, in addition to small pockets of magma throughout the mantle. 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 convection.

How will I need to modify the unit if taught out of sequence?

This is the second unit of the High School Physics Course in the OpenSciEd Scope and Sequence. Given this placement, several modifications would need to be made if teaching Physics first, or teaching this unit earlier in the Physics course. These include the following adjustments:

- If taught before OpenSciEd High School Chemistry, supplemental teaching of the particle model of matter will be required, including a conceptual understanding of the nature of electrons, nuclei, and atoms. You will also need to review the nature of thermal energy and thermal energy transfer.
- If taught earlier in the school year, supplemental teaching around the nature of energy transfer through systems and how to represent it may be required.
- If taught as part of an AP physics course, be prepared to provide students with additional support around equations that are not treated in depth.

How do I shorten or condense the unit if needed? How can I extend the unit if needed?

The following are example options to shorten or condense parts of the unit without eliminating important sensemaking:

- Lesson 8: Shorten the investigation time within the lesson.
- Lesson 9: Instead of conducting the Rock Sample Density Lab, give students the data from this investigation to work with instead.
- Lessons 11-12: You could give students the data, instead of having them conduct the investigation, or give them the investigation design to collect their own data.
- The first half of the unit attends more heavily to DCIs related to physics, whereas the second lesson set attends more heavily to the interdisciplinary connections between physics and Earth science. Though it is not recommended, there are two other options for condensing. To focus on primarily a physics perspective, you could teach Lessons 1-6, 11-12, and modify the assessment in Lesson 13. To focus primarily on an Earth science perspective, you could teach Lessons 1, 4-10, add in ideas of slab push and ridge pull to 10, and modify the assessment in Lesson 13.

To extend or enhance the unit, consider the following:

- Lesson 1: Use the guidance given in Lesson 1 about collaborating with the English Language Arts department to create expository texts.
- Lesson 4: There is an information tab in the simulation that describes the model rules further and a code tab that lets students inspect, modify, and recompile the code for the model, for students who are interested.
- Lesson 10: This lesson utilizes specific features of the simulation. Consider allowing students to further explore the features of the simulator, and build in class time for them to come to consensus around their findings.
- Lesson 12: Discussions could be led around how increasing the incline made the perpendicular component of gravity read by the digital scale decrease, and how this means that friction would decrease as the angle increased, among other discussions.
- All lessons: Remove scaffolds provided with science and engineering practices (SEPs) as a way to give students more independent work with the elements of these practices.

What mathematics concepts will students engage with in the unit?

This unit requires knowledge of how to solve algebraic equations but is not math-intensive. Students apply the Pythagorean theorem to understand how forces function as vectors. Students need to gather and represent data in ways that can help them identify patterns in investigation results, tomography, seismic data, and maps.

The unit does not assume fluency with the mathematical practices listed below; rather, students develop these practices as part of the sensemaking. Thus, these standards are not so much prerequisites as co-requisites. If students are simultaneously developing the skills and vocabulary in math class, you can help by making explicit connections to the mathematical standards listed below:

Category	Code	Domain and Heading	Standard	Relevant Lessons
Number and Quantity	CCSS.MATH.CONTENT.HS.N-VM.1	**Vector and Matrix Quantities:** Represent and model with vector quantities.	Recognize vector quantities as having both magnitude and direction.	2, 11, 12, 13
Number and Quantity	CCSS.MATH.CONTENT.HS.N-VM.3	**Vector and Matrix Quantities:** Represent and model with vector quantities.	Solve problems involving velocity and other quantities that can be represented by vectors.	2, 11, 12

Algebra	CCSS.MATH.CONTENT.HS.A-SSE.1b	**Seeing Structure in Expressions:** Interpret the structure of expressions.	Interpret complicated expressions by viewing one or more of their parts as a single entity. For example, interpret P(1+r)n as the product of P and a factor not depending on P.	8
Algebra	CCSS.MATH.CONTENT.HS.A-CED.2	**Creating Equations:** Create equations that describe numbers or relationships.	Create equations in two or more variables to represent relationships between quantities; graph equations on coordinate axes with labels and scales.	5
Geometry	CCSS.MATH.CONTENT.HSG.SRT.C.8	**Similarity, Right Triangles, and Trigonometry:** Define trigonometric ratios and solve problems involving right triangles.	Use trigonometric ratios and the Pythagorean theorem to solve right triangles in applied problems.	12

See individual lessons referenced above for details.

What strategies are available to support equitable science learning in this unit?

OpenSciEd units are designed to promote equitable access to high-quality science learning experiences for all students. Each unit includes strategies that are integrated throughout the OpenSciEd routines and are intended to increase relevance and provide access to science learning for all students. These equity goals are supported through several specific strategies, such as: (1) integrating Universal Design for Learning (UDL) Principles during the unit design process to reduce potential barriers and increase accessibility for students to engage in learning experiences; (2) developing and supporting classroom agreements that encourage a safe learning culture; (3) supporting classroom discourse to promote students in developing, sharing, and revising their ideas; and (4) offering specific strategies for supporting emerging multilingual students in science classrooms.

Many of these strategies are highlighted in the *Teacher Guide* in sidebar callout boxes with these headings:

- Attending to Equity
- Supporting Emerging Multilingual Learners
- Supporting Universal Design for Learning
- Additional Guidance
- Alternate Activity
- Key Ideas
- Discussion

What are recommended adult-level learning resources for the science concepts in this unit?

The OpenSciEd instructional model focuses on the teacher being a member of the classroom community, supporting students to figure out scientific ideas motivated by their questions about phenomena. Students iteratively build their understanding of phenomena as the unit unfolds. To match the incremental build of a full scientific explanation across the unit, the science content background necessary for you to teach individual lessons incrementally builds, too. Throughout the unit, we provide just-in-time science content background for you that is specific to the DCIs that will be figured out in a lesson. Places to look for this guidance include the “Where we are going” and “Where we are not going” sections for each lesson. Also, the expected student responses, keys, and rubrics illustrate important science ideas that should be developed in each lesson. The K-12 Science Framework is another great resource to learn more about the DCIs in this unit (**PS2.B: Types of Interactions, PS3.A: Definitions of Energy, PS3.B: Conservation of Energy and Energy Transfer, PS4.A: Wave Properties, PS1.C: Nuclear Processes, ESS1.C: The History of Planet Earth, ESS2.A: Earth Materials and Systems, ESS2.B: Plate Tectonics and Large-Scale System Interactions**), including what students have learned previously and where they are headed in high school. In addition to the science content background information embedded in the lesson resources, below are recommended resources that can help build your understanding of the phenomena and performance expectations bundle for this unit:

- To learn more about the culture and history of the Afar region, and the events in 2005:
  - https://www.nationalgeographic.com/magazine/article/africas-afar-depression
  - https://www.newscientist.com/article/dn18114-giant-crack-in-africa-formed-in-just-days/
  - https://www.esa.int/Applications/Observing_the_Earth/Envisat/ESA_s_Envisat_satellite_witnesses_Earth_s_largest_crack
- To learn more about what geologists believe might be happening beneath the surface in East Africa, and the future of the continent:
  - https://www.nbcnews.com/science/environment/african-continent-very-slowly-peeling-apart-scientists-say-new-ocean-n1234128
  - https://www.livescience.com/10592-giant-crack-africa-create-ocean.html
  - https://www.discovermagazine.com/planet-earth/africas-big-break
  - https://www.scientificamerican.com/article/a-superplume-is-the-reason-africa-is-splitting-apart/
  - https://www.nature.com/articles/s41467-019-13181-7

How do I support students' emotional needs?

In this unit, students analyze data on earthquakes and volcanoes. It is important to keep in mind throughout this unit that these events can be traumatic, and recalling past experiences or learning about others’ experiences can be triggering. Adolescents may develop symptoms following a geologic hazard, such as difficult behaviors or emotions shown at home or school. According to the CDC, “Adopting a trauma-informed approach is not accomplished through any single particular technique or checklist. It requires constant attention, caring awareness, [and] sensitivity.”

Before beginning this unit, make sure to reach out to the counselor at your school for student-specific support and strategies that might be needed in regard to the students in your classroom, and consider asking the counselor to join you on the first day of instruction. Also consider planning follow-up check-ins with the counselor in regard to any students who may need additional emotional support.

Reach out to students’ support systems at home before the unit, using *Afar Unit Home Communication*. This letter is a way to communicate with trusted adults and make them aware of the unit’s content. The letter also provides an opportunity for trusted adults to share important context with you about students’ experiences and background that might be relevant. This topic can be sensitive for those who have experienced injury, trauma, or loss due to a geologic hazard. Please be mindful of this and provide safety and support by sharing awareness. If there is time, consider beginning the class with a brief mindfulness activity (see *Afar SEL Supports* for suggestions).

Be aware that students who are struggling may demonstrate a variety of behaviors including but not limited to: fidgeting, withdrawal, disruption or distraction, rapid breathing, holding their breath, change in body language or tonation. If you notice a student might be struggling, share what you are observing and ask if they need some help.

Often in science classrooms, we are focused on evidence and data. When addressing a phenomenon or design solution that straddles the nature-cultural divide, like this one, supporting students in using an empathy or socio-emotional lens will also be important. Make space for students to process, and validate their feelings and reactions
For more support around Social and Emotional Learning, visit https://casel.org. For more trauma-informed strategies to support your students' emotional needs, please visit https://transformingeducation.org/.

Guidance for Developing Your Personal Glossaries

This unit refers to two categories of academic language (i.e., vocabulary). Most often in this unit, students will have experiences with and discussions about science ideas before they know the specific vocabulary word that names that idea. After students have developed a deep understanding of a science idea through these experiences, and sometimes because they are looking for a more efficient way to express that idea, they have co-developed that definition and can add the specific term to a Personal Glossary at the back of their notebooks. These "definitions we co-develop" should be recorded using the students' own words whenever possible. On the other hand, "definitions we encounter" are "given" to students in the course of a reading, video, or other activity, often with a definition clearly stated in the text. Sometimes, definitions we encounter are helpful only in that lesson and need not be recorded in students' Personal Glossaries. However, if a word we encounter will be frequently referred to throughout the unit, it should be added.

It is best for students if you create consensus definitions in the moment, using phrases and pictorial representations that the class develops together as they discuss their experiences in the lesson. When they co-create the meaning of the word, students "own" the word—it honors their use of language and connects their specific experiences to the vocabulary of science beyond their classroom. It is especially important for emergent multilingual students to have a reference for this important vocabulary, which includes an accessible definition and visual support. Sometimes defining a word is a challenge. The *Teacher Guide* provides a suggested definition for each term to support you in helping your class develop a student-friendly definition that is also scientifically accurate.

The definitions we co-develop and encounter in this unit are listed in this document and in each lesson to help prepare and to avoid introducing a word before students have earned it. These are not intended as a vocabulary list for students to study before a lesson, as that would undermine the authentic and lasting connection they can make with these words when they are allowed to experience them first as ideas they're trying to figure out.

Lesson	Words and equations with meanings we co-construct	Words and equations with meanings we encounter
L1		
L2	vector, magnitude, force, balanced forces, unbalanced forces, net force, contact forces, plate	vector component
L3	elastic behavior, deformation, elastic limit	
L4	bond, electric field, pressure	compression, tension, nucleus, protons, electrons, magnetic field

L5	heterogeneous, seismic waves, anomaly	homogeneous, seismic waves, Moho, tectonic plates
L6	convection	
L7	radioactive decay	neutron
L8		crystal, spectrometer, parent element, daughter element
L9	plate boundary, continental crust, oceanic crust	
L10	convergent boundary, divergent boundary, transform boundary	
L11	friction	
L12	slab pull, ridge push	
L13		

ASSESSMENT SYSTEM OVERVIEW

Each OpenSciEd unit includes an assessment system that offers many opportunities for different types of assessments throughout the lessons, including pre-assessment, formative assessment, summative assessment, and student self assessment. Formative assessments are embedded and called out directly in the lesson plans. Please look for the “Assessment Icon” in the teacher support boxes to identify places for assessments. In addition, the table below outlines where each type of assessment can be found in the unit.

Overall Unit Assessment

When	Assessment and Scoring Guidance	Purpose of Assessment
Lesson 1	*Initial Afar Models* Driving Question Board	**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 developed on day 2 of Lesson 1 is a good opportunity to pre-assess student understanding of the relationships between Earth systems to explain what causes land to crack, break, and move. The Driving Question Board is another opportunity for pre-assessment. Reinforce for students to generate open-ended questions, such as how and why questions, to post to the board. However, any questions they share, even if they are close-ended questions, can be valuable. Make note of any close-ended questions and use navigation time throughout the unit to have students practice turning these questions into open-ended questions when they relate to the investigations underway.
Lesson 2	*Investigations A&B* *Free-Body Placemat Key* *Investigations A&B Key*	**Formative** In Lesson 2, students carry out an investigation to explore the relationship between the magnitude of the forces acting on a system and the observed stability and change in motion. They use these results to develop a free-body diagram to predict the changes in an object‘s motion due to the forces acting on it. They use this model to evaluate whether the plate motion data presented in *GPS Plate Map* helps explain the apparent stability of the Caribbean plate.
Lesson 3	*Analyzing Rock Behavior*	**Formative**

	Unknown material with identifier: pf.l3.key1 *Unknown material with identifier: pf.l3.key2*	In Lesson 3, students are asked to read about how scientists measure the forces acting on rocks, and respond to some questions. They then work collaboratively to explore the relationship between the magnitude of external forces acting on an object, its deformation, and the energy transferred into it. A key is provided to support the scoring of both tasks.
Lesson 4	*Evaluating Models* *Evaluating Models Key* *Particle Investigations* *Particle Investigations Key* L4 Electronic Exit Ticket *L4 EET Key*	**Formative** In Lesson 4, students complete a handout in which they evaluate the merits and limitations of two physical models to help explain matter, energy, and force interactions at the particle level. They also use a computer simulation to further investigate these interactions. A key is provided to support the scoring of this task. **Summative** This Electronic Exit Ticket addresses 3-D elements associated with the lesson-level performance expectations (LLPEs) for Lesson 4, which is a problematize/putting-the-pieces-together routine for the first lesson set of the unit. This assessment is designed to make it easy for you to gather information about where students are still struggling to put the pieces together.
Lesson 5	*How Do Scientists Explore Earth's Interior?*	**Formative** In Lesson 5, students read about S and P waves, and compare their calculated S and P wave arrival times at stations with the times from the graph in the reading. They then compare the patterns with what they have learned about wave speeds and how these are affected by the media through which they pass.
Lesson 6	*Afar Mantle Model*	**Formative** In Lesson 6, students create an initial model of the mantle under Afar. They then investigate a mantle tank model and create an explanatory model of the mantle tank, using a matter, energy, and/or forces perspective. They compare the model of the mantle tank to the mantle under Afar and use the mantle tank to test and revise their initial models of the mantle under Afar.
Lesson 7	*Radioactive Decay (Forces)* *Radioactive Decay (Matter)* and *Radioactive Decay (Energy)* *Cause-Effect Model Key* L7 Electronic Exit Ticket	**Formative** In Lesson 7, students put the pieces together to create a cause-effect model of how particle-scale interactions in Earth's mantle manifest as global-scale phenomena. A key is provided to support the scoring of this task. **Summative** This Electronic Exit Ticket addresses 3-D elements associated with the lesson-level performance expectations (LLPEs) for Lesson 7, which is a problematize/putting-the-pieces-together routine for the first lesson set of the unit. This assessment is designed to make it easy for you to gather information about where students are still struggling to put the pieces together.

	L7 Electronic Exit Ticket Key	
Lesson 10	*Investigating Plate Interactions* *Investigating Plate Interactions Key* *Predicting the Future of Africa and Afar* *Predicting the Future of Africa and Afar Key*	**Formative** In Lesson 10, students investigate plate interactions. They also get a chance to apply what they have learned to predict the future of the land that makes up the African continent, and the Afar region in particular. A key is provided to support the scoring of this task.
Lesson 12	*Measuring Forces on Inclines Investigation*	**Formative** In Lesson 12, students create free-body diagrams to make sense of how the forces change with the angle, connect that to mass, and consider what would happen if the forces become unbalanced. Students apply this idea to the context of divergent and convergent plate boundaries.
Lesson 13	*Midcontinent Rift Transfer Task* *Failed Midcontinent Rift Key*	**Summative End-of-Unit Transfer Task** At the end of this final lesson, students will have the opportunity to demonstrate their competence with a transfer task, in which they will explain how the Midcontinent Rift failed to create a new ocean 1.1 billion years ago. This task is robust and will take approximately 30 minutes. The ideas, crosscutting concepts, and practices students engage with as part of completing this assessment can be found at the top of the Scoring Guidance (key). The scoring on this assessment represents our recommendation for how to weigh questions. Please use scoring that works for your class and your requirements. We strongly recommend that you encourage students to use their notebooks as a resource for completing all assessments.
Embedded in each lesson	Lesson-by-Lesson Assessment Opportunities (below)	**Formative Assessment** Use this document to see which parts of lessons or can be used as embedded formative assessments.
Occurs in several	*Progress Tracker*	**Formative and Self-Assessment**

lessons	*Progress Tracker Examples*	Progress Trackers are thinking tools designed to help students (1) keep track of important discoveries that the class makes while investigating phenomena and (2) figure out how to prioritize and use those discoveries to develop a model to explain phenomena. It is important that what students write in their Progress Trackers reflects their own thinking at that particular moment. In this way, the tracker can be used throughout the unit to formatively assess individual student progress or for students to assess their own understanding. Because a tracker is meant to be a thinking tool, we strongly suggest that it not be collected for a summative "grade" other than to note its completion. In this unit, students add to their *Progress Tracker* in Lessons 2, 5, 6, 9, and 12. Examples of models and ideas that students may include in this tracker are embedded in these lessons, and an example of potential responses can also be found in *Progress Tracker Examples*.
Occurs in several lessons	Student Self-Assessment Rubrics	**Self-Assessment** Student self-assessment rubrics for giving and receiving feedback can be used throughout the unit. Opportunities include, after a discussion or at the end of a class period. The rubric helps students reflect on their participation in the class that day. Choose to 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 for the next time, such as sentence starters for discussions. As they gain practice and proficiency with discussions, ask for their ideas about how the whole-class and small-group discussions can be more productive. Additional support can be found in the *OpenSciEd Teacher Handbook: High School Science.*
Occurs in several lessons	Routines and Tools to Support Peer Assessment	**Peer Assessment** There will be times in your classroom when facilitating students to give each other feedback will be very valuable for their three-dimensional learning and for learning to give and receive feedback. We suggest that peer feedback happen at least two times per unit. Peer feedback is most useful when there are complex and diverse ideas visible in student work and not all work is the same. Student models or explanations are good opportunities to use a peer feedback protocol. They do not need to be final pieces of student work; rather, peer feedback will be more valuable to students if they have time to revise after receiving it. This should be a formative rather than summative type of assessment. It is also necessary for students to have experience with past investigations, observations, and activities in which they can use these experiences as evidence for the feedback they give. Additional support can be found in the *OpenSciEd Teacher Handbook: High School Science.*

For more information about the OpenSciEd approach to assessment and general program rubrics, visit the OpenSciEd Teacher Handbook.

Lesson-by-Lesson Assessment Opportunities

Every OpenSciEd lesson includes one or more lesson-level performance expectations (LLPEs). The structure of every LLPE is designed to be a three-dimensional learning, combining elements of science and engineering practices, disciplinary core ideas and cross cutting concepts. The font used in the LLPE indicates the source/alignment of each piece of the text used in the statement as it relates to the NGSS dimensions: alignment to Science and Engineering Practice(s), alignment to Cross-Cutting Concept(s), and alignment to the Disciplinary Core Ideas.

The table below summarizes opportunities in each lesson for assessing every lesson-level performance expectation (LLPE). Examples of these opportunities include student handouts, home learning assignments, progress trackers, or student discussions. Most LLPEs are recommended as potential formative assessments. Assessing every LLPE listed can be logistically difficult. Strategically picking which LLPEs to assess and how to provide timely and informative feedback to students on their progress toward meeting these is left to the teacher's discretion.

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 1	**1.A** Develop a diagrammatic model of relationships between Earth systems to explain what causes land to crack, break, and move, and to predict what will happen to the land in the Afar region in the future. (SEP: 2.3; CCC: 2.2; DCI: ESS2.B) **1.B** Ask questions about the mechanisms driving changes in Earth's crust that arise from careful observation of patterns in the Afar region, in order to seek additional information from indirect evidence because aspects of the phenomenon are too slow and too large to study directly. (SEP: 1.1; CCC: 3.2, 3.3; DCI: ESS2.B)	**1.A When to check for understanding:** On day 2, when students develop initial models for change before, during, and after the events in Afar. **What to look for/listen for in the moment:** ● Indication of movement, force, and/or energy transfer (e.g., arrows) between components of the model. (SEP: 2.3) ● Modeling changes in the shape or composition of the matter that makes up material at and/or below the surface, related to the changes at the surface. (SEP: 2.3) ● Discussion of different timescales and/or gradual versus sudden change, either in models or in written responses. (DCI: ESS2.B) ● A cause-and-effect relationship between something happening inside Earth and something happening at the surface. (CCC: 2.2) **1.B When to check for understanding:** On day 3, during the development of the Driving Question Board (DQB). **What to look for/listen for in the moment:** ● Questions that arise from our work together about things that are too large, too slow, or too inaccessible to observe directly (e.g., properties and motion deep inside Earth). (SEP: 1.1; CCC: 3.2, 3.3) ● Questions that arise from our work together at a variety of timescales (e.g., short-term effects versus long-term geologic change). (SEP: 1.1; CCC: 3.2, 3.3) ● Questions that arise from our work together that connect observations of the Afar region to larger-scale tectonic phenomena. (SEP: 1.1; DCI: ESS2.B)

Lesson 2	**2.A** Plan and conduct an investigation to determine the contact force interactions that result in the observed stability and change in the motion of an object. (SEP: 3.2; CCC: 4.2, 7.1; DCI: ESS2.A.1) **2.B** Develop and use free-body diagrams (models) to explain and predict how the magnitude of the force interactions applied to matter at different scales would impact the stability and changes within a system. (SEP: 2.6; CCC: 7.1; DCI: ESS2.A.1)	**2.A.1 When to check for understanding:** On day 1, while displaying **slides P** and **Q**, as students discuss calibration protocols and then carry out their investigation and record their results on the *Investigations A&B* handout. **What to look for/listen for in the moment:** ● A record of the direction and magnitude of force interactions from four spring scales labeled in newtons. (SEP: 3.2; DCI: ESS2.A.1) ● A description of how the group decided they had carried out enough tests to determine what keeps the system stable in every condition. (SEP: 3.2; CCC: 7.1) **2.A.2 When to check for understanding:** On day 3, with **slides AA** and **BB**, as students record the changes that result from removing or adding a force, and the new stable state of the system, on the *Investigations A&B* handout. **What to look for/listen for in the moment:** ● Recording data using a free-body diagram for each condition, including the initial force conditions acting on the stable system, and labeling which force interaction was added or removed. (SEP: 3.2; CCC: 4.2; DCI: ESS2.A.1) ● Recording the dynamic changes in the system (e.g., how much the object moved, in what direction, and for how long). (SEP: 3.2, CCC: 4.2; DCI: ESS2.A.1) ● Repeated trials or measurements yielding consistent results for several contact force combinations to support the reliability of the results. (SEP: 3.2; DCI: ESS2.A.1) ● Following the calibration protocols for gathering accurate results using the spring scales. (SEP: 3.2) ● Recording the new stable state of the system (where the foam rectangle is in the end and/or the new interactions on each spring scale) for each measurement. (SEP: 3.2, CCC: 7.1; DCI: ESS2.A.1) **2.B.1 When to check for understanding:** On day 2, with **slide U**, as students draw their first free-body diagram at the bottom of the *Investigations A&B* handout. **What to look for/listen for in the moment:** ● Two arrows pointed in one direction and one arrow pointed in the other, each with the magnitude labeled in newtons. (SEP: 2.6; DCI: ESS2.A.1) ● Negative values for any vector(s) pointed to the left and positive values for any vector(s) pointed to the right. (CCC: 7.1) ● Each arrow length proportionally scaled to its magnitude. (SEP: 2.6; CCC: 7.1, DCI: ESS2.A.1)

		2.B.2 When to check for understanding: On day 3, with **slide AA**, as students record a free-body diagram for each condition they test on the graph paper on the back of *Investigations A&B*. **What to look for/listen for in the moment:** ● Using the results collected as free-body diagrams to explain how force interactions applied to matter would impact stability and changes within a system. (SEP: 2.6; CCC: 7.1; DCI: ESS2.A.1) ● Using the free-body diagrams to suggest that this model does not help to explain the apparent stability of the Caribbean plate. (SEP: 2.6; CCC: 7.1; DCI: ESS2.A.1)
Lesson 3	**3.A** Make qualitative claims about how differences in the magnitude of forces (1) acting on different materials (cause) would produce similar effects in their structure (elastic deformation) and (2) acting on a single material would affect the amount of energy transferred into and out of it. (SEP: 6.1; CCC: 2.2, 5.2, 6.2; DCI: PS3.B.2) **3.B** Ask questions arising from development of the M-E-F model to clarify (1) additional relationships related to energy transfer and storage in deformed matter and (2) the model's application to various dynamics and interactions occurring in Earth systems. (SEP: 1.2; CCC: 5.2, 7.1; DCI: PS3.B.2, ESS2.A.1)	**3.A When to check for understanding:** When students complete Questions 1-3 on the *Analyzing Rock Behavior* handout (**slide J**). **What to look for/listen for in the moment:** See the *Analyzing Rock Behavior Key*. (SEP: 6.1; CCC: 2.2, 5.2, 6.2; DCI: PS3.B.2) **3.B.1 When to check for understanding:** When students complete Question 4 on the *Analyzing Rock Behavior* handout (**slide J**). **What to look for/listen for in the moment:** See the *Analyzing Rock Behavior Key*. (SEP: 1.2; CCC: 5.2, 7.1; DCI: PS3.B.2, ESS2.A.1) **3.B.2 When to check for understanding:** When students add new questions to their sticky note(s) for the exit ticket/home learning (**slide L**). **What to look for/listen for in the moment:** ● Questions that clarify differences in the relationship between changes in matter, forces acting on the system, and energy transfer occurring along plate boundaries and in other plate locations. (SEP: 1.2; CCC: 5.2, 7.1; DCI: PS3.B.2, ESS2.A.1)
Lesson 4	**4.A** Evaluate the merits and limitations of different models using a crosscutting lens (*stability and change*, *thinking across scales*, and/or *cause and effect*) for understanding and explaining different phenomena (earthquakes) and mechanisms (elastic deformation, cracking/breaking). (SEP: 2.1;	**4.A. When to check for understanding:** Toward the end of day 1, when you collect the *Evaluating Models* handout. **What to look for/listen for:** ● Use evidence generated by the model to discuss the mechanism(s) the model helps explain in terms of matter changes and/or M-E-F interactions. (SEP: 2.1; CCC: 2.2, 3.2, 7.1; DCI: PS3.A.4, PS2.B.3, ESS2.B.2) ● Use a crosscutting lens (*stability and change*, *thinking across scales*, and/or *cause and effect*) to discuss the

	CCC: 2.2, 3.2, 7.1; DCI: PS3.A.4, PS2.B.3, ESS2.B.2) **4.B** Use a computational model to explore stability and change and cause-and-effect relationships between the magnitude of external forces acting on a solid, the changes in matter given its mass (number of particles), and the changes in energy in the system across different scales. (SEP: 2.3; CCC: 2.2, 3.2, 7.1; DCI: PS3.A.4, PS3.B.2, PS2.B.3, ESS2.B.2)	advantages and limitations of the model to further explain or test plate changes, breaking, and elastic deformation. (SEP: 2.1; CCC: 2.2, 3.2, 7.1; DCI: PS3.A.4, PS2.B.3, ESS2.B.2) See the *Evaluating Models Key* for sample responses. **4.B.1 When to check for understanding:** ● On day 2, after the simulation investigation, in student responses on the *Particle Investigations* handout. **What to look for/listen for:** ● See the *Particle Investigations Key*. It includes a brief explanation of the goal of each investigation (1-4) and what to look for in student responses. **4.B.2 When to check for understanding:** ● At the end of day 3, with **slide BB**, when students complete the Electronic Exit Ticket. **What to look for/listen for:** This Electronic Exit Ticket addresses 3D elements associated with a lesson-level performance expectation (LLPE) for Lesson 4. This assessment is designed to make it easy to gather information about where students are still struggling to put the pieces together.
Lesson 5	**5.A** Analyze mathematical representations of indirect data to reveal anomalies in the pattern of arrival times for seismic waves to support a claim about the relationship between wave speed and the medium through which the wave is passing in Earth's interior. (SEP: 4.1, 5.2; CCC: 1.4, 3.2; DCI: PS4.A.1, ESS2.A.2) **5.B** Analyze seismic velocity anomaly data at multiple scales and evaluate the impact of this data on our working model of Earth's interior to provide evidence for a causal link between local matter variation in Earth's mantle and surface features, such as	**5.A.1 When to check for understanding:** On day 1, on the *How Do Scientists Explore Earth's Interior?* handout and as a class, when students consider connections across disciplines by discussing other systems they have learned about that cannot be studied directly because they are too small, too large, too fast, or too slow. **What to look for/listen for in the moment:** ● Students should list examples of systems at various scales, such as the solar system, the electrical grid, tectonic motion, or an atom. ● Students should recognize and explain that scale affects our ability to collect empirical evidence. If something is too large, too small, or on too long a timescale, it is very difficult to observe directly. (CCC: 3.2) **5.A.2 When to check for understanding:** When students work through *How Do Scientists Explore Earth's Interior?* in pairs and as a class, analyzing empirical data to reveal an anomaly in the pattern of seismic wave arrival times when the chord the waves follow through the globe is approximately 10,000 km or more. **What to look for/listen for in the moment:**

	mountains, volcanoes, and cracks. (SEP: 4.1, 4.5; CCC: 1.1, 1.2; DCI: ESS2.A.2, PS4.A.4)	• Students should recognize that the data points representing observed arrival times depart significantly from the expected times, with arrivals later than expected for P-waves and none at all for S-waves. (SEP: 4.1; CCC: 1.4) • Through discussion, students should make a connection between this pattern and the reading, which explains that wave speed is affected by the media through which the wave passes. (DCI: PS4.A.1) • Students should make and defend the claim that in Part 2 of the image on **slide K**, the pattern of speed anomalies indicates that the seismic waves have encountered matter that is not a solid. S-waves do not travel through liquid, which is why they disappear. P-waves slow down in a liquid, which is why they arrive later than expected. (SEP: 5.2; CCC: 1.4) **5.A.3 When to check for understanding:** On day 1, in the exit ticket, when students use the working model of Earth's interior to make a claim about which layers cause P-waves to slow down and S-waves to disappear, supporting their claim with evidence from mathematical representations. **What to look for/listen for in the moment:** • Students should make the claim that the liquid outer core causes P-waves to slow down and S-waves to disappear. (DCI: ESS2.A.2) • Students may use the speed provided on the slide (9 km/s) to test at least one anomalous data point from the graph in the *How Do Scientists Explore Earth's Interior?* handout. For example, to test the dot at about 12,200 km, they should divide this number by the given speed to get 1,356 seconds, then divide by 60 to get 22.6 minutes. They can also divide the x-value (12,200 km) by the y-value (22 minutes = 1,320 seconds) to get 9.2 km/sec. They then compare that number to either the y-value of the tested point on the graph or the speed on the slide, and find that it is roughly equal; it should be a little off, because the waves are not passing exclusively through liquid iron. Students should use this test to support their claim that the liquid core causes the slow-down pattern in the P-wave data. (SEP: 4.1, 5.2; DCI: PS4.A.1) • Alternatively, students may choose to support their explanation without doing the calculations but still applying mathematical reasoning. For example, they may argue that because 9 km/s is slower than 11 km/s, it makes sense that the P-waves arrive later than expected. They may also point out that these data points move in an odd pattern, going up and then back down. This implies that at some point, the waves are no longer moving through as much liquid iron and may be moving through a more solid inner core, reducing the lag. (SEP: 4.1, 5.2; DCI: PS4.A.1) **5.A.4 When to check for understanding:** At the end of day 1, during navigation into day 2, when students respond to a reflection question on how indirect empirical evidence and mathematical representations helped them identify patterns and anomalies in seismic velocities to support their reasoning.

		What to look for/listen for in the moment: Use this as a quick check-in to make explicit that by organizing the data as a graph, we could see patterns that might not have been clear, and by applying mathematical reasoning, we could quantify how anomalous certain patterns were and highlight patterns that helped us figure out what might be going on deep inside our planet. (CCC: 1.4) **5.B.1 When to check for understanding:** On day 3, after the Building Understandings Discussion, when students add to their models. Collect the *Earth's Interior Model* handout to provide feedback before the next class. **What to look for/listen for in the moment:** ● Look for students to add images or words to their models to indicate that the mantle layer is not all the same; rather, it varies on a relatively local scale. (SEP: 4.5; CCC: 1.2; DCI: ESS2.A.2, PS4.A.4) ● Students may include information about temperature or seismic wave velocities. They may add surface features corresponding to heterogeneity in the mantle below (e.g., volcanoes above a warmer mantle location). They may also show that these differences create different unbalanced forces in different locations, which is why some regions have different kinds of surface features than others. (DCI: ESS2.A.2, PS4.A.4) **5.B.2 When to check for understanding:** On day 3, when students return to the Driving Question Board and fill out their Progress Trackers. **What to look for/listen for in the moment:** ● Listen for students to start answering questions about specific surface features (such as volcanoes) and events (such as earthquakes) by describing seismic anomalies in the mantle at a regional scale that were added to our working model of Earth's interior. (SEP: 4.5; CCC: 1.1; DCI: ESS2.A.2, PS4.A.4) ● Look for students to describe in their Progress Trackers how scaling down from a global to a regional grain size allowed us to see patterns of differences in mantle matter that were important for understanding surface features. (CCC: 1.2) ● Students still have a significant gap in the causal chain connecting surface features to mantle matter, because they have not yet connected temperature variation to convection, and thus to plate movement. This will be developed over the next several lessons. Do not look for students to be able to make that connection here.
Lesson 6	**6.A** Develop a model to explain the relationship between energy transfer and the motion of matter in a solid material via thermal convection and the motion of	**6.A.1 When to check for understanding:** At the beginning of day 1, when students complete their individual models on the *Afar Mantle Model* handout, predicting the interactions of the different temperature parcels in the mantle. **What to look for/listen for in the moment:** ● Look for all models to predict the relationship between the particle nature of parcels of different temperatures and

	particles. (SEP: 2.3; CCC: 5.4; DCI: ESS2.A.2, PS3.A.4)	their movement in the mantle. (SEP: 2.3; DCI: PS3.A.4) ● Models should include particle-level interactions at various locations in the mantle system. (DCI: PS3.A.4) ● Models should include changes in the mantle's matter related to the energy transferred into and out of the mantle parcels. (CCC: 5.4) **6.A.2 When to check for understanding:** At the end of day 1, when students complete their models on the *Mantle Tank Model* handout, explaining the movement of matter in the mantle tank. **What to look for/listen for in the moment:** ● Look for all models to reference the observed motion of matter and the temperature readings in the mantle tank video as evidence about energy transfer and matter changes. (SEP: 2.3) ● Models using the matter perspective should include particle-level interactions at various locations in the mantle tank system. (DCI: PS3.A.4) ● Models using the energy perspective should include changes in the matter related to the energy transferred into and out of the mantle tank system. (CCC: 5.4) ● Models using the forces perspective should include the forces acting on matter at various locations in the mantle tank system that could explain the convective motion of matter or energy transfer in the model. (DCI: ESS2.A.2; CCC: 5.4) **6.A.3 When to check for understanding:** On day 2, when students revise their models on the *Afar Mantle Model* handout. **What to look for/listen for in the moment:** ● Look for revised models to include density differences in the particle-level modeling of the matter based on thermal energy tomography data and evidence from the mantle tank and lava lamps. (SEP: 2.3; DCI: ESS2.A.2, PS3.A.4) ● Models should include energy being transferred into and out of the system to heat/cool the matter in the mantle, causing motion in the mantle. (SEP: 2.3; CCC: 5.4; DCI: ESS2.A.2) ● Models should reference balanced and unbalanced forces to explain the convective motion of matter in the mantle due to density differences. (SEP: 2.3; DCI: ESS2.A.2, PS3.A.4)
Lesson 7	**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	**7.A.1 When to check for understanding:** At the end of day 1, when you read students' responses to the cause-effect questions in their handouts (*Radioactive Decay (Forces)*, material:PF.L7.HO2], or *Radioactive Decay (Energy)*). **What to look for/listen for in the moment:**

	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)	• 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 (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) **7.A.2 When to check for understanding:** On day 2, as you listen to students' ideas during the Building Understandings Discussion. **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 explicitly identify how matter, energy, and forces interact as part of the class consensus model. (DCI: ESS2.B.1, PS1.C.1) **7.B When to check for understanding:** At the end of day 1, when you collect the exit tickets. Remember to have these ready to return for students' use at the start of day 2. **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 to clarify an understanding or seek 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)

		Electronic Exit Ticket: The Electronic Exit Ticket addresses the lesson-level performance expectation (LLPE) for Lesson 7. This assessment is designed to make it easy to gather information about where students are still struggling to put the pieces together.
Lesson 8	**8.A** Sketch and describe graphs for percent of parent and daughter elements versus time; use a spreadsheet to graph and compare patterns across different crystal sizes and different parent elements and compare these to patterns predicted by an exponential decay law. (SEP: 5.2; CCC: 1.4; DCI: PS1.C.2) **8.B** Analyze data using a spreadsheet and an exponential decay law to find the age of various rock samples using relationships (half-lives) discovered in prior investigations; interpret the patterns across the ages of these samples and the sites where these are located to reconstruct the geologic history of Afar over the last 700 million years. (SEP: 4.1; CCC: 1.5; DCI: PS1.C.2)	**8.A.1 When to check for understanding:** At the end of day 1, when you collect student predictions on the *Predicting Composition Trends* handout. **What to look for/listen for in the moment:** ● A graph that shows a trend (linear or nonlinear) with a solid line of decreasing y-values as x-values increase for the percentage of parent element found in a crystal over time, and a dotted line of increasing y-values as x-values increase for the percentage of daughter element found in a crystal. (SEP: 5.2; CCC: 1.4, DCI: PS1.C.2) **8.A.2 When to check for understanding:** At the end of day 2, when you collect student analysis on the *Analyzing Decay Trends* handout. **What to look for/listen for in the moment:** A summary of the following: ● The patterns in the trends of the data and how they compare to the predictions. ● That the estimated time for at least one parent element to reach 25% is approximately twice the time it took to reach 50%. (SEP: 5.2; CCC: 1.4) ● How quickly or slowly various radioactive elements change into daughter elements. (SEP: 5.2; CCC: 1.4; DCI: PS1.C.2) **8.B.1 When to check for understanding:** At the end of day 2, when students individually calculate and record the age of rocks in Afar on the *Analyzing Decay Trends* handout. **What to look for/listen for in the moment:** ● Using the mathematical model of radioactive decay to calculate the age of the assigned group of rock samples. (SEP: 4.1; DCI: PS1.C.2) ● **A** is 0.12–0.33 mya, **B** is 0.49–4.0 mya, **C** is 1.9–3.2 mya, **D** is 4.5–8.2 mya, **E** is 23–25 mya, **F** is 29–31 mya, **G** is 583-659 mya. **8.B.2 When to check for understanding:** At the end of day 3, when students use evidence they recorded on the *Transcript: Plate Interaction and Earthquake Demonstration* handout to identify patterns in the age distribution of rocks in Afar. **What to look for/listen for in the moment:**

		● Using evidence from the group data recorded on the *Age of Rocks* handout and the map in the *Rock Sample Site Map* to interpret the geologic history of Afar. (SEP: 4.1; CCC: 1.5; DCI: PS1.C.2)
Lesson 9	**9.A** Ask questions that arise from careful observations of patterns across multiple empirical sources to refine our model of how new oceanic crust is formed at plate boundaries. (SEP: 1.1, 1.2; CCC: 1.5; DCI: ESS1.C.1)	**9.A When to check for understanding:** At the end of day 2, when students add their questions to the Driving Question Board. **What to look for/listen for in the moment:** ● Assess whether students are asking questions intended to refine our model by looking for alignment with the question marks on the Initial Class Consensus Model: New Crust poster. (SEP: 1.1, 1.2) ● Assess student understanding of the DCI by looking for questions about plate boundaries, oceanic versus continental crust, and the ages of rocks in the Afar region and elsewhere that require empirical evidence to answer. (CCC: 1.5; DCI: ESS1.C.1)
Lesson 10	**10.A** Use a computer model that simulates the movement of tectonic plates to produce data to serve as the basis for evidence that can support an explanation of how plate interactions at plate boundaries shape the planet's surface features. (SEP: 2.6; CCC: 4.3; DCI: ESS2.B.3) **10.B** Construct an explanation about the patterns in radiometric data using a consensus model of plate interactions at convergent and divergent boundaries. (SEP: 6.2; CCC: 1.5; DCI: ESS2.B.1, ESS2.B.3) **10.C** Construct and revise an explanation about the future of Afar and Africa based on valid and reliable evidence obtained from a variety of sources and the assumption that plate tectonics is the unifying theory that explains the past and current movements of the rocks at Earth's	**10.A When to check for understanding:** On day 1, when students complete the *Investigating Plate Interactions* handout. **What to look for/listen for:** Using the *Investigating Plate Interactions Key*, look for students to: ● Rows 2 and 3: Use a model to generate data to serve as the basis for evidence that can support an explanation. In row 3 specifically, look for a description of plates' vertical and horizontal motion. This evidence will be central to the investigation in Lesson 11. (SEP: 2.6) ● Row 4: Use ideas about density to explain how plate interactions at plate boundaries shape the planet's surface features. (DCI: ESS2.B.3) ● Row 5: Use the simulation to describe the interactions between these components of the system's matter: moving plates, mantle material, magma, and surface features. (CCC: 4.3) **10.B When to check for understanding:** On day 2, when students develop an explanation about the patterns in the radiometric data explored in Lesson 9. **What to look for/listen for:** Look for students to: ● Explicitly use the consensus model of plate interactions to explain the patterns in radiometric data. (SEP: 6.2; CCC: 1.5; DCI: ESS2.B.1, ESS2.B.3) ● Include the flow of magma through the system as a mechanism that influences the movement of rocks and explains the patterns in the ages of crustal rocks. (CCC: 1.5; DCI: ESS2.B.1, ESS2.B.3) ● Include divergent and convergent plate boundary interactions to explain the differences in composition of the crust. (SEP: 6.2; DCI: ESS2.B.1, ESS2.B.3)

	surface. (SEP: 6.2; CCC: 4.4; DCI: ESS2.B.2, ESS2.B.3)	**10.C When to check for understanding:** At the end of day 2, when students complete the handout *Predicting the Future of Africa and Afar*. **What to look for/listen for:** Use the *Predicting the Future of Africa and Afar Key* to assess students' engagement with each of the three dimensions: ● Question 1: Make a prediction about the future of Afar and Africa focused on surface features changes. (CCC: 4.4) ● Question 2: Use multiple sources of evidence and the consensus model to construct and revise an explanation of how the plate interactions occurring under Africa will cause the predicted surface changes. (SEP: 6.2; CCC: 4.4; DCI: ESS2.B.2, ESS2.B.3)
Lesson 11	**11.A** Develop and revise models that predict the relationship between mass, surface area, or texture and the force of friction acting on Earth's plates due to mantle convection, which is a process that is too large and too slow to observe directly. (SEP: 2.3; CCC: 3.2; DCI: ESS2.A.2)	**11.A.1 When to check for understanding:** On day 1, when students create initial predictive models in small groups. **What to look for/listen for in the moment:** Models should include: ● Interactions between the plates and other systems, such as the mantle (via friction) or Earth (via gravity). (SEP: 2.3; DCI: ESS2.A.2) ● Mantle movement affecting the plates through system interactions. (SEP: 2.3; DCI: ESS2.A.2) ● Earth-sized systems of plates and the mantle interacting and representing change that occurs over large timescales. (CCC: 3.2; DCI: ESS2.A.2) **11.A.2 When to check for understanding:** On day 2, when students revise their initial predictive models into explanatory models. **What to look for/listen for in the moment:** Models should include: ● Interactions between the plates and other systems, including the mantle (via friction) or other plates, influencing the motion of the plates. (SEP: 2.3; DCI: ESS2.A.2) ● Mantle movement affecting the plates through friction force interactions between systems. (SEP: 2.3; DCI: ESS2.A.2) ● Earth-sized systems of plates and the mantle interacting and representing change that occurs over large timescales. (CCC: 3.2; DCI: ESS2.A.2) ● The relationship between mass (more mass, more friction), surface area (no relationship), or texture (rougher texture, more friction) and the force of friction between the plates and the moving mantle. (SEP: 2.3; DCI: ESS2.A.2)

Lesson 12	**12.A** Use mathematical models to illustrate the force interactions (including gravity) between a plate and other systems to explain stability and change of plate motion that is too large and too slow to observe directly. (SEP: 2.3, 5.2; CCC: 3.2; DCI: ESS2.A.2)	**12.A.1 When to check for understanding:** On day 1, when students draw free-body diagrams for gravity acting on plates. **What to look for/listen for in the moment:** Students to talk about: ● Use their free-body diagram models to support their claims or explanations about plates. (SEP: 2.3, 5.2; DCI: ESS2.A.2) ● The force of gravity pulling on plate systems and affecting plate motion. (SEP: 2.3; DCI: ESS2.A.2) ● That we cannot directly measure the force of gravity on plates or their motion because they are too large and too slow. (CCC: 3.2; DCI: ESS2.A.2) ● Talk about how the mantle and plates interact and how this changes based on how they are configured at plate boundaries (e.g., how tilted the plate is on the mantle). (SEP: 2.3; DCI: ESS2.A.2) **12.A.2 When to check for understanding:** On day 2, when you collect the *Measuring Forces on Inclines Investigation* handout and review student responses. **What to look for/listen for in the moment:** Look for student models and explanations to show (SEP: 2.3): ● The force of gravity pulls plates toward Earth's center/down, but a component of it also pulls things down inclines. (SEP: 2.3, 5.2; DCI: ESS2.A.2) ● Component forces are mathematically related to the force they make up according to the Pythagorean theorem. (SEP: 5.2) ● Relationships between the systems of the plates, mantle, and gravity can be balanced or unbalanced to keep plates stable or cause changes in plate motion. (SEP: 2.3; DCI: ESS2.A.2) ● Plate motion and changes in motion are too big and happen on timescales that cannot be directly observed, but forces on plates can be modeled at different scales. (CCC: 3.2; DCI: ESS2.A.2)
Lesson 13	**13.A** Revise an explanation based on valid and reliable evidence to answer Driving Question Board questions that involve explaining the change over time in stability of the interactions between motions of the mantle and the plates. (SEP: 6.2; CCC: 7.1; DCI: ESS2.A.2, ESS2.B.2, ESS2.B.3)	**13.A When to check for understanding:** At the beginning of the lesson, when students revise the Driving Question Board. **What to look for/listen for in the moment:** ● Look for students to use multiple sources of evidence to explain a surface feature, or the motion of the mantle and the plates and their stability and change over time, using matter changes and interactions, forces acting on matter, and/or energy flow. (SEP: 6.2; CCC: 7.1; DCI: ESS2.A.2, ESS2.B.3) ● Listen for students to use multiple sources of evidence to explain that changes that occur over a long time through the process of plate tectonics may appear stable over short time periods. (SEP: 6.2; CCC: 7.1; ESS2.B.2)

		Transfer Task PE: HS-ESS2-1 Develop a model to illustrate how Earth's internal ~~and surface~~ processes operate at different spatial and temporal scales to form continental and ocean-floor features. (SEP: 2.3; CCC: 7.2; DCI: ESS2.A.1, ESS2.B.2)

HOME COMMUNICATION

Dear Guardian,

Your child's high school physics class is starting a unit called, *How do forces in Earth's interior determine what will happen to the surface we see?* as part of the OpenSciEd high school science curriculum. This unit establishes fundamental physics ideas about how unbalanced forces transfer energy through systems, causing motion. Those ideas are then used to describe and explain fundamental Earth science ideas about how the hidden processes playing out in Earth's interior over short and long temporal/spatial scales shape the surface patterns we see.

This unit is anchored by a puzzling Earth science phenomenon: an area of land in East Africa appears to be ripping apart. In 2005, a crack opened up very suddenly in a region called Afar in Ethiopia, accompanied by earthquakes and a volcanic eruption. This phenomenon provides the context in which to investigate the relationship between unbalanced forces and energy transfer in systems, how radioactive decay on the particle scale drives global-scale convection, and the role of plate tectonics in explaining Earth's surface features.

Students may come home with questions about earthquakes, volcanoes, and other Earth science phenomena. Share your experiences, ideas, and questions with them.

Geologic hazards can be traumatic, and recalling past experiences or learning about other people's experiences can be triggering. If your child or someone close to your child has sustained an injury, lost a loved one, or experienced any trauma due to an earthquake or a volcanic event, please contact me at ____________________, if you are comfortable doing so. You can also contact the school counselor at _________________. By knowing about these experiences in advance, we can be sensitive to students' needs and provide support if they experience any strong emotions during this unit.

Adolescents will sometimes develop difficult behaviors after a geologic hazard. It is important for trusted adults to understand that these behaviors and emotions are common when children experience trauma. Students may be more aggressive or withdrawn, and go through periods of sadness or anger or emotional "numbing." Contact a counselor if you see any of the following behaviors in your child:

- problems sleeping, nightmares
- changes in school performance
- truancy
- risk-taking behavior
- conflicts with peers
- new or increasing psychosomatic complaints, including stomachaches and headaches
- depression or suicidal thoughts

Being able to talk to someone who is removed from the situation is often helpful to both adults and children after a traumatic event. After experiencing trauma, children are best supported when their parents or trusted caregivers accept their feelings and are open to listen and talk. Let your child come to you. Do not overwhelm them if they are not ready to talk. Respect their need to take breaks.

Reach out to a counselor or support center if you are concerned about trauma your child may have due to experiences related to a geologic hazard.

If you have any questions about the content of this unit or would like to discuss anything further, I encourage you to reach out to me at _________________.

Best,