EQuIP RUBRIC FOR SCIENCE EVALUATION

Energy, Forces and Earth's Crust

DEVELOPER: OpenSciEd

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

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OVERALL RATING: E

TOTAL SCORE: 8

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

Click here to see the scoring guidelines.

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

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

Summary Comments

Thank you for your commitment to students and their science education. NextGenScience is glad to partner with you in this continuous improvement process. It is obvious that this unit was thoughtfully crafted, and it is strong in several areas, including:

- The focus of learning is around students making sense of a central phenomenon and related phenomena throughout all lessons.
- The unit effectively integrates both physical science and Earth science Disciplinary Core Ideas (DCIs) in making sense of the phenomena.
- The unit is coherent through the use of documents and resources such as the time/scale size chart, progress trackers, and the Driving Question Board (DQB).
- The unit thoughtfully incorporates Nature of Science ideas from the NGSS (appendix H).

During revisions, the authors and user of the materials should pay close attention to the following areas:

- Intentional reduction of scaffolding in the targeted Science and Engineering Practices (SEPs): Guidance for teachers to increase support when students first encounter an SEP and to provide less teacher support as students develop proficiency in the SEP.
- Stronger final assessment/transfer task that assesses targeted elements that have been developed throughout the unit. Better three dimensional prompts for students to show learning in all three dimensions working together.
- Opportunities are needed for students to incorporate feedback from the teacher and their peers in order to improve a subsequent performance of the same NGSS element, along with more structured self-assessment that allows students to see their progress in the targeted elements.

CATEGORY I

NGSS 3D DESIGN

I.A. EXPLAINING PHENOMENA/DESIGNING SOLUTIONS

I.B. THREE DIMENSIONS

I.C. INTEGRATING THE THREE DIMENSIONS

I.D. UNIT COHERENCE

I.E. MULTIPLE SCIENCE DOMAINS

I.F. MATH AND ELA

I.A. EXPLAINING PHENOMENA/DESIGNING SOLUTIONS

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

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

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

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

Rating for Criterion I.A. Explaining Phenomena/Designing Solutions	Extensive *(None, Inadequate, Adequate, Extensive)*

The reviewers found extensive evidence that learning is driven by students making sense of phenomena and/or designing solutions to a problem because almost all student learning is clearly linked to a central phenomenon of the crack in the ground in the Afar region or a similar phenomenon. Student questions create a need to engage in learning. However, there are a few instances in the unit when the connections to the Afar phenomenon are difficult to identify, or the questions that drive the learning come from the teacher rather than the students.

"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 volcano. This phenomenon provides the context in which to investigate the relationship between unbalanced forces and energy transfer through systems, how radioactive decay on a 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, 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" (Teacher Edition, page 11).

Student questions and prior experiences related to the phenomenon often, but not always, motivate sense-making. For example:

- Lesson 1: "Orient students to where we have been and where we are going. Say, We have been wondering about what can cause the land on Earth's surface to crack, break, or change over time. You had a chance to look at some different types of data in Afar and other locations closer to us that seem to be breaking apart and changing. We have developed initial models with our ideas about what could be happening inside the Earth to cause these kinds of changes at and below the surface. Now that you've had time to think about it, let's start building our driving question board (DQB). Write initial questions for the DQB. Present slide W. Make sure the class's Initial Consensus Model poster is located at the front of the room where students can see it. Display the 'Driving Question Board' poster. Pass out 3-4 sticky notes and a dark colored marker to each student. Say, On a sticky note, write at least one question that you have related to any of the data and phenomena we have considered so far. Write only one question per sticky please, and don't forget to add your initials so that we know who contributed a question. Remember to write your question big and bold so we can all see it clearly" (Teacher Edition, page 48).

- Lesson 2: "Develop an initial explanation. Display slide GG. Give students 5 minutes to talk with a partner and use what we figured out about matter and forces to develop a verbal explanation for why one phenomena[sic] from the larger scale earth system happened. Options include: a) Earthquakes, b) The variation in plate motion, c) The sudden crack at Afar" (Teacher Edition, page 87).
- Lesson 5: "Return to the DQB. Remind students of the DQB questions they identified earlier in the day. Ask, which of these DQB questions can we answer, or do we have ideas about? As students identify DQB questions that we have answered, put a checkmark near that sticky and move it to the side. Leave any questions that have not yet been answered on the DQB" (Teacher Edition, page 150).
- Lesson 6: "Remind students that at the end of the last lesson they revisited the DQB and determined what questions they could answer, as well as what questions were still needing answers. Ask students to look at the board and determine if the class has made progress on any new questions. Place a checkmark near the sticky notes that have been answered and move those answered questions to the side of the DQB. Ask students, Do we have any new questions based on our work in this lesson? What new lingering questions do we want to add to the Driving Question Board?" (Teacher Edition, page 170).
- Lesson 7: "Celebrate progress and wonder about radioactive material in the Afar region. Present slide N. Say, We can explain so much now about matter, energy and forces beneath the Earth's crust. Radioactivity helps us understand what might be driving some of the processes we see. I wonder if we will find radioactive material in the rock in the Afar region?[sic] Turn and Talk to a partner. Based on our ideas, do you think we will find evidence of radioactive material in the Afar region? Why or why not?" (Teacher Edition, page 184). In this transition, the teacher is asking the question, rather than supporting students to develop the next question to explore.
- Lesson 8: "Revise DQB. Present slide D. Point to the DQB and elicit students[sic] ideas with the prompt: What questions from our DQB involve reconstructing the past or predicting the future in Afar?" (Teacher Edition, page 193).
- Lesson 9: "Add new questions about plate boundaries to the DQB. Present slide X. Say, We have now thought about how new crust is created at places where plates are spreading apart, but what does that make you wonder about now? What new questions do you have about plate boundaries, crust, and forces in the Afar region? Add questions to our DQB about plate boundaries and continental versus oceanic crust" (Teacher Edition, page 224).
- Lesson 13: "Mark patterns in questions answered using the sticker dots. Facilitate the students in identifying patterns in DQB questions. Focus the discussion on identifying (1) questions we agree that we can answer, (2) questions that we have at least a partial answer to, and (3) questions we cannot answer at all. Choose one color of sticker dots to mark each of these categories. Hand out each student one set of the sticker dots and allow them to come up to the DQB and add their stickers to DQB questions" (Teacher Edition, page 301).

The focus of the unit is to support students in making sense of phenomena in most, but not all, lessons. Examples are listed below:

- Lesson 1: "On September 26th, 2005, at about 1:00 pm, people in the Afar region felt a very strong earthquake that shook the area. The earthquake was located at a depth of 14 km (8.7 miles). This was followed by a dark column of something that looked like smoke, which rose high into the atmosphere and spread out to form a cloud. The cloud darkened the area for 3 days and 3 nights. This cloud was the result of an eruption that occurred at a nearby volcano called Dabbahu. This was the first time that this volcano had erupted in recorded history" (A Sudden Crack in Ethiopia story map).

- Lesson 1: "Say, Let's try to develop a model to explain what might have happened before the events at Afar, and what might happen in the future. We also think that something similar might be happening in the regions of our earthquake cases. Let's try to explain that also, so we can better understand if what is happening at Afar is happening in our cases as well" (Teacher Edition, page 41).
- Lesson 3: "Scientists have been wondering about what might be happening in Afar after the earthquake occurred and the large crack in the surface appeared. The surface measurements they have collected indicate that the crack has continued to widen at a rate of about 2 centimeters per year, since its first appearance. Scientists also wondered how localized the extent of these shifts in the land were. To investigate this question they analyzed additional GPS data from a series of sensors placed in the region around where the crack occurred. One example can be found in question 3: 'If you were to extract rock samples from the plate from sites around the region before the crack appeared, what do you expect to see happen to those samples when they are brought to the surface? Why?'" (Forces Acting on Rocks Handout).
- Lesson 4: "Establish agreement that since Afar isn't happening at a plate boundary, something must be going on here different than what we think is happening for most earthquakes or the volcanoes we explained in the EET that are occurring near a plate boundary and we need some additional data/information to figure out these sort case sites that appear to be exceptions" (Teacher Edition, page 129).
- Lesson 5: "Problematize the Afar example not being at a plate boundary. Present slide B. Say, But we noticed in Lesson 1 that the earthquakes in East Africa that we thought were connected to the Afar region did not appear to be along an established boundary, right? Give students a moment to consider this gap in our current model, then point to the class consensus model and pose the question on the slide: Looking back at our consensus model, what ideas did we have that could explain where the forces come from to cause Earthquakes, volcanos, and breaking in the Afar region? Look for ideas about magma, lava, the mantle, or anything that is beneath the Earth's crust" (Teacher Edition, page 136).
- Lesson 6: "Determine how the mantle tank can be used to test our explanatory models of under Afar. Present slide H. Point out that even though there are still limitations, the mantle tank still seems like a good representation of the mantle. Ask students, How can the mantle tank be used to test the models we drew for the mantle under Afar?" (Teacher Edition, page 161).
- Lesson 7: "Present slide N. Say, We can explain so much now about matter, energy and forces beneath the Earth's crust. Radioactivity helps us understand what might be driving some of the processes we see. I wonder if we will find radioactive material in the rock in the Afar region?[sic] Turn and Talk to a partner. Based on our ideas, do you think we will find evidence of radioactive material in the Afar region? Why or why not?" (Teacher Edition, page 184).
- Lesson 8: "Discuss the presence of radioactive materials in Afar. Present slide B. Elicit 1-2 ideas with the prompt: In some regions, such as Afar, magma reaches the surface and cools, forming solid rocks. Based on our ideas, would we expect to find evidence of radioactive material in the rocks in Afar?" (Teacher Edition, page 193).
- Lesson 9: The teacher asks a series of questions related to prior experiences that motivate further exploration. "How might the young basalt rock we see in the oceans, and in the Afar region be different from older continental rock? How could that help us make progress on our questions about the Afar region?" (Teacher Edition, page 220). The lesson ends with students

revisiting the DQB which supports the introduction to the next lesson. "We have now thought about how new crust is created at places where plates are spreading apart, but what does that make you wonder about now? What new questions do you have about plate boundaries, crust, and forces in the Afar region?" (Teacher Edition, page 225).

- Lesson 10: "Motivate the development of a consensus model. It can be hard to make a prediction about what is going to happen in Africa when there are so many pieces of the system interacting with one another and multiple sources of evidence. Let's try to sort through our evidence together and create a model with all our ideas about the way plates interact. That can help us improve our predictions about the future of Africa and Afar" (Teacher Edition, page 242).
- Lesson 11: The lesson focuses on variables that affect friction forces without connecting back to Afar. The teacher reminds students, "Last time we were thinking about the forces that could be acting on the plates that could help us explain the difference in the ways plates are moving. Which forces do we think are acting on plates that could explain the motion we observed?" (Teacher Edition, page 263).
- Lesson 12: The lesson focuses on how gravity pulls along inclines without connecting back to Afar. It begins with the review of the exit question from the previous lesson — "Which other force(s) should we investigate that could help us explain why some plates change motion differently than others?) (PPT slide A)" Students decide on gravity which is the focus of this lesson.

Suggestions for Improvement

- Currently, students return to the DQB five times throughout the course of the unit. Consider providing more opportunities for students to revisit the DQB to draw out student questions to ensure learning is driven by student questions throughout the unit.
- The unit has numerous opportunities for students to connect their learning in service of the Afar phenomenon. Consider making this explicit in the last two lessons to further support students' sense-making of phenomena.

I.B. THREE DIMENSIONS

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

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

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

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

Rating for Criterion I.B. Three Dimensions	Adequate *(None, Inadequate, Adequate, Extensive)*

The reviewers found adequate evidence that the materials give students opportunities to build understanding of grade-appropriate elements of the three dimensions because the materials provide students with opportunities to develop and use DCI elements at the high school level. However, some claimed Crosscutting Concept (CCC) and SEP elements are fully developed and used in the unit.

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

The reviewers found adequate evidence that students have the opportunity to use or develop the SEPs in this unit because students have frequent opportunities to engage with science and engineering practices. Students engage with elements of **Developing and Using Models** in particular depth and frequency. However, elements of the focal SEP, **Constructing Explanations and Designing Solutions,** is under-developed, with only one individual performance of the key element. There are some mismatches between the SEP elements claimed and used, with some claimed elements missing or not fully used, and other instances of fully used elements that are not claimed.

Constructing Explanations and Designing Solutions

- *Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.*
    - Lesson 7: Students construct an explanation using the "cause and effect model A/B" worksheet. Students use notes that they took from their readings to summarize cause and effect relationships to explain where the energy for convection comes from. However, without explicit guidance, students may not revise their explanation over the course of the whole class discussion. Students do not discuss the assumption that theories operate the same in the past and will continue to do in the future.
    - Lesson 10: "1. Make a prediction about how the surface of East Africa will look in the future. Use drawings and/or words to describe your prediction. 2. Use drawings and/or words to explain how the interactions between the plates and the mantle will cause the surface changes in Afar and Africa that you are predicting. Include any relevant source(s) of evidence from our investigations and your progress trackers to support your prediction" (Predicting the Future of Afar Handout). "Present slide O. Say, We can use models to explain data, and we can use models to make predictions about events in the future. We have used so many different types of evidence during this work. Let's see if we can use this evidence, and the model we made, to improve our predictions and explanations about what will happen to Afar in the future. You can change or add on to the predictions and explanations you developed at the beginning of the class. Give students the rest of the class period to complete this task. They should revise their responses to questions 1 and 2 on Predicting the Future of Africa and Afar, and then respond to all parts of question 3 on the back" (Teacher Edition, page 255).
    - Lesson 13: "Discuss the questions the class can now answer. Present slide C. Have them gather in a Scientists Circle to discuss the answers to those questions as a whole group. Display the Takeaways poster to record the class' answers. Revisiting the DQB at the end of the unit helps students see the progress they have made toward answering questions that were important to them at the onset of the unit. As students share, put an emphasis on any questions that students have previously

constructed an answer for, but can now fully explain. When this occurs, ask students to explain what evidence they collected that helped them revise their answer" (Teacher Edition, page 301). Laws and theories regarding the processes that drive radioactive decay and convection operated the same way in the past are not explicitly used.

- In the final Midcontinent Rift assessment students answer questions about a new phenomenon in a transfer task. They are asked to pull from specific things they learned throughout the unit. However, students do not revise their explanations and their explanations are not based on a variety of sources. This task better fits the middle school element: *Apply scientific ideas, principles, and/or evidence to construct, revise and/or use an explanation for real-world phenomena, examples, or events.*

- *Make a quantitative and/or qualitative claim regarding the relationship between dependent and independent variables.*
  - Although claimed as a focal element, students are not provided with the opportunity to develop this element in multiple instances in the unit and only use it in one lesson.
  - Lesson 3: "Question 1) If an engineer tested similar sized samples of two different materials from the data table shown here, which one of those materials would require application of higher magnitude forces on it, to produce the same amount of elastic deformation as the other material? Write an evidence-based claim that answers this question. Make sure your claim references the variables in question and two materials in the data table: Question 2) How would doubling the external force applied to elastically deform a solid, affect the amount of energy that could be transferred back out of it when the force is removed? Write an evidence-based claim to answer this question. Make sure your claim references the variables in question and two materials in the data table. Use the ideas in the M-E-F poster your class developed, to support your claim" (Forces Acting on Rocks Handout). Students make claims regarding the relationship between external force and deformation of a solid. Students may not realize they are making claims regarding independent or dependent variables as this language is not used in the prompts.

Developing and Using Models

- *Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system.*
  - Lesson 1: Students use this element in the "Initial Afar Models" handout. One question asks, "What mechanisms might be causing changes and what interactions might be happening between those mechanisms?"
  - Lesson 4: The handout "Particle Investigations" directs students to explore how different variables affect relationships between the magnitude of external forces acting on a solid, the changes in matter across different scales, and the energy changes in the system. They use a computer model in order to make these relationship predictions.
  - Lesson 6: Students create a predictive model on the role of temperature and matter (Lesson 6 slide C). In the handout "Model tank" question #2 asks students to "create a model to describe and explain why the matter in the tank is moving in the way we observed." Students create a consensus model in order to explain the roles of matter, energy and force in the pellet model. They then compare this to the Afar model and are asked to reflect. "Ask students to use the newly formed consensus model that was developed using the video evidence to check if their initial models to explain how and

why the mantle is moving under the Afar region still holds. Refer to the instructions on the slide: Using our consensus model for the mantle tank, revise your model of the mantle movement under Afar on your handout. Make note of any lingering questions or uncertainties" (Teacher Edition, page 169).
    - Lesson 11: "Draw an initial model that shows your ideas about how these forces act on the plates to cause their motion. What would happen to a plate's motion if multiple forces were acting on it at the same time?" (Lesson 11 slide C). Then students discuss changing variables and revisit their models to show this prediction: "revise your model on a separate piece of paper in order to predict what would happen to the forces acting on the plates if one of these properties is changed" (Lesson 11 slide E). Finally, students are asked to add in the roles of friction, mass, surface area, and tension to convert predictive models to explanatory models (Lesson 11 slide X).
    - Lesson 12: "Section 4: Connecting Gravity and Plate Motion What do our lab results tell us about the more complex plate systems? Use free body diagrams, words, and/or drawings to connect our lab findings with the stability and change of plate motion over long time[sic] scales" (P.2 Lesson 12 Handout Measuring Forces on, page 4).
- *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.*
    - This element is listed as a focal element in the unit overview materials (Teacher Edition, page 14), but there are no claims of this element being used or developed within the unit itself.
    - Lesson 5: There is potential for students to develop this element within this lesson. Students use a pellet model, a lava lamp, class consensus model, and then also discuss merits and limitations of the pellet model.
    - Lesson 10: There is potential for students to develop this element in the Handout: "Predicting the future of Africa and Afar" question #3b: "What are the limitations and assumptions of the models of the Earth and plate tectonics that we have been working with that could affect the accuracy of your prediction? How would these limitations or assumptions influence your prediction?"
- *Develop and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems.*
    - Lesson 2: "Explore with the manipulatives. Distribute one copy of Free-Body Placemat and one bag of cutouts from Free-body Manipulatives to each pair of students. Cue students to use a calculator and work with a partner with these manipulatives for about 5 minutes to see what they can figure out. Ask students to share their findings. Listen for the following: The magnitude of the horizontal force squared added to the magnitude of the vertical force squared equals the magnitude of the force that is at an angle. You can form a right triangle, using the smaller two force vectors as the legs and the larger force as the hypotenuse" (Teacher Edition, page 78). Students do not engage with the second part of this element "*support explanations, predict phenomena, analyze systems, and/or solve problems.*"
    - Lesson 10: "1. Make a prediction about how the surface of East Africa will look in the future. Use drawings and/or words to describe your prediction. 2. Use drawings and/or words to explain how the interactions between the plates and the mantle will cause the surface changes in Afar and Africa that you are predicting. Include any relevant source(s) of evidence from our investigations and your progress trackers to support your prediction" (Handout Predicting the Future, page 1).

- *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.*
    - Lesson 4: "Display slide D. Read aloud the text at the top of the slide, Every model has advantages and limitations. Understanding these can help us move more flexibly between different types of models for explaining of how and why phenomena occur. SUPPORTING STUDENTS IN ENGAGING IN DEVELOPING AND USING MODELS This text is also on the top of Evaluating Models. It is being emphasized here and on slide D to make these elements of the modeling practice explicit to students. You could start using the word merits as a synonym for advantages. You may however want to continue using world advantages too going forward, as a synonym, as it tends to be the word that is used in more everyday language by more students" (Teacher Edition, page 114). Students subsequently evaluate two different models of fault lines, one with smooth edges and one with rough edges.
    - Lesson 4: "Emphasize that option d is included on the slide, because the models of bonds listed here are all analogies, which are each useful in some ways but limited in others, and they may have a different model that they think would be more useful for explaining what bonds are analogous to the properties of a solids" (Teacher Edition, page 117).
    - Lesson 4: "Lesson 4: "Identify advantages and limitations of model 2. Present slide N. Use the first prompt to give students a half a minute to consider how this first model helped them explain how/why any of the phenomena listed on the top of our sheet occur. Then cue them to record the advantages (merits) and limitations of the model in their handout using and the lens they are using to evaluate model 2" (Teacher Edition, page 118). Students do not select or revise a model to fit the evidence or design criteria.
    - Lesson 6: The element is not claimed in this lesson, but students are provided with the opportunity to use it. "Discuss advantages and limitations of the mantle tank. Present slide G. Read the prompt on the slide: What advantages and limitations does this model have for testing our models? SUPPORTING STUDENTS IN ENGAGING IN DEVELOPING AND USING MODELS In lesson 4, students evaluated the merits and limitations of different models using three lenses: 1) Stability or change over time or space; 2) Thinking across different scales; and 3) Cause and effect in M-E-F relationships. Encourage students to continue using these lenses to assess whether and how a model can help explain the phenomenon under investigation" (Teacher Edition, page 161).

Asking Questions and Defining Problems

- *Ask questions that arise from careful observation of phenomena, or unexpected results, to clarity and/or seek additional information.*
    - Lesson 1: "On a sticky note, write at least one question that you have related to any of the data and phenomena we have considered so far. Write only one question per sticky please, and don't forget to add your initials so that we know who contributed a question. Remember to write your question big and bold so we can all see it clearly" (Teacher edition, page 48).
    - Lesson 9: "Present slide X. Say, We have now thought about how new crust is created at places where plates are spreading apart, but what does that make you wonder about now? What new questions do you have about plate boundaries, crust, and forces in the Afar region? Add questions to our DQB about plate boundaries and continental versus oceanic crust" (Teacher edition, page 224). After observing different types of rock and

measuring their density, students return to their Afar region data and models to add questions for additional information about the phenomenon.

- *Ask questions that arise from examining models or a theory, to clarify and/or seek additional information and relationships.*
    - Lesson 3: "Question 4) What new question(s) does this raise for you about what interactions might be happening below Earth's surface?" (P.2 Lesson 3 Handout Forces Acting on, page 4). After analyzing new data and information about rock elasticity and deformation, students ask questions about the overarching phenomenon of the Afar crack.
    - Lesson 7: "Present slide E. Say, Today, each of you has been thinking deeply about only one corner of the M-E-F triangle. What questions do you have about the other two corners of the M-E-F triangle that would help you explain how a process at a subatomic scale can produce enough heat to drive convection? Have students respond to the prompt on the slide as an exit ticket." (Teacher edition, page 179)
    - Lesson 9: "Add new questions about plate boundaries to the DQB. Present slide X. Say, We have now thought about how new crust is created at places where plates are spreading apart, but what does that make you wonder about now? What new questions do you have about plate boundaries, crust, and forces in the Afar region?" (Teacher Edition, page 224).

Planning and Carrying Out Investigations

- *Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly.*
    - Lesson 2: "1) For each investigation, place the four spring scales provided to your group pushing on the foam at the locations indicated by the arrows. 2) For each condition, increase or decrease the magnitude of the forces pushing on the foam, and record the force measurements when the system is stable (the foam is not moving and nobody is touching the foam)" (P.2 Lesson 2 Handout Investigation A&B, page 1). And "You may also want to suggest the following to support students in future use of this practice: • Since knowing the certainty of results will be based on the variation in the data, it is not something they can necessarily know with any large degree of certainty until the data they are collecting starts coming in. It is considered best practice to be ready to change their data collection plan as they go, particularly when they uncover unexpected results or possible sources of error. When they do this, making note of what uncertainty in their data is leading them to make this change is also best practice."
    - Lesson 2: "6. Repeat steps 2-5 for each condition you test, ensuring that the magnitude of the initial forces is different for each condition 7. Keep an eye out for whether you think you need to modify your investigation plan as results come in. 8. Answer the questions on the back of this handout" (P2 Lesson 2 Handout Investigation C&D).
    - Lesson 8: "SUPPORTING STUDENTS IN ENGAGING IN PLANNING AND CARRYING OUT INVESTIGATIONS In Lesson 2, students had the opportunity to consider whether they had collected enough data when measuring the force combinations acting on an object. This prompt engages students in the same practice. Scan the room to decide whether students seem confident about how to answer this type of question. Knowing when they have collected enough data is key for engaging in other practices, such as

developing arguments and counterarguments based on data and evidence. If you see fit, display a sample spreadsheet that shows a limited number of trials, and conduct a few more tests using the simulation in front of the class to show that new values are either higher or lower than the ones currently collected, which suggests the need for more trials" (Teacher Edition, page 198). This element is not claimed for this lesson.

Analyzing and Interpreting Data

- *Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution.*
    - Lesson 5: Students use a digital tool to analyze data about the interior earth layers beneath the Afar region to make claims about the composition of these layers.
    - Lesson 8: "Analyze and Interpret data individually. Display slide U. Distribute Analyzing decay trends. Have students individually record their analysis of their graphs on the first two questions of this sheet: How do the patterns across your graphs compare? How do these patterns compare to your predictions?" (Teacher Edition, page 199). Students take the data they collected from the radioactive decay simulation and analyze the data to look for patterns in their graphs.
- *Evaluate the impact of new data on a working explanation and/or model of a proposed process or system.*
    - Lesson 5: "Revise our model to include local differences in the matter in the mantle. Pose the first two questions on the slide: What have we figured out that can help explain the plate motions we observed? How should we revise our Earth's Interior Model to reflect our new understandings about the mantle?" (Teacher Edition, page 149). Students revise their model based on new data, but they do not evaluate the impact of that data on their model data to determine what that implies about their model of the earth's interior.
    - Lesson 6: "Test/revise Afar mantle models using mantle tank understanding. Present slide R. Ask students to use the newly formed consensus model that was developed using the video evidence to check if their initial models to explain how and why the mantle is moving under the Afar region still holds. Refer to the instructions on the slide: Using our consensus model for the mantle tank, revise your model of the mantle movement under Afar on your handout. Make note of any lingering questions or uncertainties" (Teacher Edition, page 169). This element is not claimed for this lesson, but students are engaged with this element.

Using Mathematics and Computational Thinking

- *Decide if qualitative or quantitative data are best to determine whether a proposed object or tool meets criteria for success.*
    - Lesson 2: "SUPPORTING STUDENTS IN ENGAGING IN USING MATHEMATICS AND COMPUTATIONAL THINKING Encourage students to manipulate attributes of the model, both geometrically or[sic] algebraically. The former could include translating the vector representation to see if they make three sides of the right triangle. The latter could include performing calculations and recording results on scratch paper" (Teacher Edition, page 78). This element and its use in Lesson 2 are not claimed.
- *Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations.*
    - Lesson 5: "Test data points to quantify the anomaly. Present slide K. Say, One way we can test to see if this is really an anomaly is by checking to see what speed each of these

waves were traveling. Remember that speed is just distance over time. Miles per hour. Kilometers per second. Speed is just a measure of how far something goes in a certain amount of time. Model the calculation first with the dot at 2,000 km. The P-wave appears to arrive at about 3 minutes, and the S-wave appears to arrive at about 11 minutes.2000km/(3*60 seconds) = 11.1 km/s 2000km/(11*60 seconds) = 3 km/s. Ask students to look back to the reading to confirm that these speeds are accurate. Then ask students to choose a data point to test on their own. Split the class down the middle and ask one half of the class to test another data point from Part 1 of the graph. The rest of the class should test the anomalous data. Give students time to work out the math, and then ask them to share their findings with a show of hands" (Teacher Edition, page 140).

- Lesson 8: "Prediction 1: • Draw a solid line below to show the predicted trend for the % of parent element found in a crystal over time. • Draw a dotted line below to show the predicted trend for the % daughter element(s) found in a crystal over time" (P.2 Lesson 8 Handout Predicting composition trends, page 1).
- Lesson 8: "Have students work in a group to analyze their graphs to approximate the times (on average) when there was 50% and 25% of parent element left. Space is provided on Analyzing decay trends for recording such averages from up to 6 conditions. Some groups may only get to completing this table for a smaller sub-set of conditions (e.g.[sic] 2 or 3), which is fine. This should take about 4 minutes" (Teacher Edition, page 199). And "Argue from evidence. Display slide X. Distribute Analyzing decay trends. Discuss the question on the slide as the class. Does crystal size affect the time at which there is a certain fraction (e.g.[sic] ½ or ¼) of the parent material left? Which of these two claims shown on the slide did the data support? • No, regardless of the crystal size, the time is similar. • Yes, the larger the crystal size, the longer the time" (Teacher Edition, page 200).
- Lesson 12: "Let's use our findings to write a mathematical model for the force of gravity based on mass. We can start by substituting variables in for the values we read according to the units. Ask students what variable the newtons should become and write Force of Gravity on the board out in words. Then write the 'x 100 =' and ask what variable the grams should become, adding 'mass' to the end of the equation when prompted by students. On the board this should look like 'Force of Gravity x100 = Mass'. Continue, Now let's figure out what the units of this 100 are. Look for students to rearrange the equation to get 100 on its own, guide them to show that the units of 100 are g/N. Say, Since we are developing a model for the force of gravity, we should solve for that. How should we rearrange the equation to solve for the force of gravity?" (Teacher Edition, page 287). Students use data from their investigations to develop a mathematical model of gravity in order to support their explanation of how forces on the tectonic plates affect their motion.

Disciplinary Core Ideas (DCIs) | **Rating: Extensive**

The reviewers found extensive evidence that students have the opportunity to use or develop the DCIs in this unit because students regularly develop and use targeted high school DCI elements in both the Earth science and physical science domains to make sense of phenomena. There is a close match between DCI elements claimed in the "Elements of NGSS Dimensions" document and student activities found in the lessons.

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~~.*
    - Lesson 7: "Because strong force is so affected by distance, if two protons move apart far enough the strong force between them will get weaker very quickly. This will cause the balance between the electric forces pushing them apart and the strong forces pulling them together to shift. The electric forces will be stronger than the strong force. If this happens, some of the particles that are furthest away from the center of the nucleus will be pushed away from the nucleus. We call an atom that reaches this state unstable" (Radioactive Decay (Forces) Handout).
- *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~~.*
    - Lesson 4: "Which interactions at the particle scale do we need in order to explain why the crust above the magma will break, allowing magma to reach the surface? The repulsion due to electric forces (bonds) between the particles of rock will weaken when the particles are forced apart by the upward forces; The attraction due to electric forces (bonds) between the particles of rock will get stronger when the particles are forced apart by the upward forces; The attraction due to gravity between the particles of rock and the Earth will get stronger when the particles are forced apart by the upward forces; The repulsion due to gravity between the particles of rock and the Earth will weaken when the particles are forced apart by the upward forces" (Lesson 4 Exit Ticket).

PS3.A: Definitions of Energy

- *At the macroscopic scale, energy manifests itself in multiple ways, such as in motion~~, sound, light~~, and thermal energy.*
    - Lesson 4: "Update the M-E-F poster as you prompt students for examples for how we knew there was energy in the system or not for the electricity powered devices in our prior unit, Electricity Unit. Students will say heat and light and maybe sound coming from those devices. Validate that these were ways of knowing there was electricity transferring energy through the system…Point out that this new way we are considering how energy is stored in systems, related to elastic deformation, involves thinking about the motion of the particles in the matter and the energy stored in the field based on their position in space relative to each other. Emphasize that in our prior unit (Electricity Unit) we also thought about electricity in terms of particle motion and fields transferring energy, though we didn't focus on how fields can store energy" (Teacher Edition, pages 127–128).
    - Lesson 6: "Use your knowledge about the particle nature of matter at different temperatures to create a model for why the parcels in the mantle move on the tomography data below. Use a combination of words and drawings to explain the mechanisms behind the movement in the mantle" (Afar Mantle Model Handout).
    - Lesson 7: "How is energy transferred away from an atomic nucleus? The protons and neutrons released by the nuclei in this kind of radioactive decay will transfer most of the energy that was stored in the mass away from the atomic nucleus as kinetic energy. Some small fraction of that energy will also end up in the recoil of the nucleus itself as the particles leave. As those particles collide with nearby atoms, they will transfer energy to them, because collisions transfer energy. This will make the average kinetic

energy of the atoms in the surrounding matter go up (they will vibrate more), causing that matter to heat up (temperature to rise). This energy transfer process from radioactive decay in the mantle is one of the primary causes of convection in the Earth's interior" (Radioactive Decay [Energy] Handout).

- *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.~~*
    - Lesson 4: "Point out that this new way we are considering how energy is stored in systems, related to elastic deformation, involves thinking about the motion of the particles in the matter and the energy stored in the field based on their position in space relative to each other…Point out that it is not just elastic deformation and electricity that can be broken down into just some combination of one or two things that describe where the energy is in the system and how it is being transferred - either the kinetic energy OF objects (generators, magnetics, plates) or particles (electrons, atoms, molecules) and/or energy IN fields (electric, magnetic). Challenge students to keep this lens in mind going forward - that we can, if needed, account for all changes in energy as some combination of changes in kinetic energy and changes energy stored in fields, even if the everyday name we give to the way in which that energy is transfer is something like 'sound' or 'heat'" (Teacher Edition, page 128).

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.*
    - Lesson 3: "Display slide G. Give students 1 minute to Turn and Talk with the first prompt: How are matter changes related to energy transfers we observed in this system? When did we see evidence of energy transferred in or out of the system? After 1 minute, have students share their ideas about the first prompt" (Teacher Edition, page 100). Students discuss energy transferring in and out of a system but do not discuss how energy cannot be created or destroyed and that it transfers to other systems.
    - Lesson 4: "Identify the following connections to prior discussions. Continue, When the foam is being held in this stable bent shape, there is no measurable energy increase in the system, like an increase in kinetic energy or an increase in temperature. We need to find a way to describe where exactly the energy is being stored, otherwise we will not be able to account for conservation of energy – something we know should occur in every process. When changing distance between objects or particles acting on each other through a field affects the amount of energy stored in the system, scientists say that the energy is getting transferred into, out of or stored in the field(s)" (Teacher Edition, page 125).

PS4.A: Wave Properties

- *Geologists use seismic waves and their reflection at interfaces between layers to probe structures deep in the planet.*
    - Lesson 5: "Pictured above is the currently accepted model of Earth's interior. Earthquakes create seismic waves that travel through the Earth. By analyzing these seismic waves, seismologists can make inferences about the matter in the Earth's interior. The difference between the crust and the mantle is determined by the composition of the layers. The mantle and crust are both made up of silicon and oxygen.

But the mantle contains significantly more iron and magnesium than the crust. This difference in composition affects the structure and state of matter of the material, and thus the speed of seismic waves through the material" (Earth's Interior Model Handout).

- *~~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.*
    - The part of the element that has strikethrough text is only present in the unit overview (Unit Overview Materials, page 14) but not in the dimensions document (Elements of NGSS Dimensions, page 11).
    - Lesson 5: "This is an opportunity to help students see that '…the speed of travel of [a] wave…depends on the…medium through which it is passing.' This is part of the DCI element associated with the performance expectation HS-PS4-1: 'Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media.' This performance expectation and the associated DCI are addressed primarily in [material: pr], where students derive the relationship between frequency, wavelength, and wave speed. But the important idea that wave speed is affected by the medium is established first in this unit" (Teacher Edition, page 140).

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.~~*
    - Lesson 7: "Forces Q1: How does the size of the atom cause the forces to be either balanced or unbalanced? Forces Q2: What is the effect on the protons and neutrons in the nucleus when the forces become unbalanced, and why? Forces Q3: Annotate the diagram below to show the forces on the particles that make up an atomic nucleus during radioactive decay" (Radioactive Decay (Forces) Handout).
- *Spontaneous radioactive decays follows a characteristic exponential decay law. Nuclear lifetimes allow radiometric dating to be used to determine the ages of rocks and other materials.*
    - Lesson 8: "Identify the half-lives. Say, Scientists have found this pattern as well and it is an important part of the mathematical model they developed to predict how any element decays over time. Every radioactive isotope takes a certain amount of time to decay to 50% of its initial amount, regardless of how much of it you start out with, and the time it takes to decay 25% is twice as long as it takes to reach 50%. They also noticed that to get from 100% to 50% is the same as it takes to get from 50% to 25%. They call this time the element's half life. Circle the half life on the class half life table for each of the elements and label it as the half-life for that element" (Teacher Edition, page 201). After looking at mathematical patterns in their data, students learn about the idea of half-lives to determine the age of a sample.

ESS1.C: The History of Planet Earth

- *Continental rocks, which can be older than four billion years, are generally much older than the rocks of the ocean floor, which are less than 200 million years old.*
    - Lesson 9: "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 need empirical evidence to answer. (CCC: 1.5; DCI: ESS1.C.1)" (Teacher Edition, page 316).

ESS2.A: Earth Materials and Systems

- *Evidence from deep probes and seismic waves~~, reconstructions of historical changes in Earth's surface and 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.*
    - Lesson 5: "Pose the question on the slide: What can we infer about the states of matter that make up Earth's structure from each part of the graph?" (Teacher Edition, page 141).
    - Lesson 5: "Pictured above is the currently accepted model of Earth's interior. Earthquakes create seismic waves that travel through the Earth. By analyzing these seismic waves, seismologists can make inferences about the matter in the Earth's interior. The difference between the crust and the mantle is determined by the composition of the layers. The mantle and crust are both made up of silicon and oxygen. But the mantle contains significantly more iron and magnesium than the crust. This difference in composition affects the structure and state of matter of the material, and thus the speed of seismic waves through the material" (Earth's Interior Model Handout).
    - Lesson 6: "Use your knowledge about the particle nature of matter at different temperatures to create a model for why the parcels in the mantle move on the tomography data below. Use a combination of words and drawings to explain the mechanisms behind the movement in the mantle" (Afar Mantle Model).
    - Lesson 11: "Say, It seems like we still have a lot of questions about forces on the plates. Two themes that seem to be common are rubbing forces between the mantle and crust and where the plates seem to be sliding down inclines pulled by Earth's gravity. Maybe we need to investigate how these types of forces work more in order to build our understanding. Hand thought experiment. Present slide H. Say, Let's think for a minute about the interaction between the mantle and the plates. Let's use our hand and a book to model how we think these two layers are interacting. Demonstrate putting a book on top of your hand and sliding it across your hand" (Teacher Edition, page 266).
    - Lesson 12: "Present slide Y. Repeat the process for convergent boundaries. Look for students to say things such as gravity is pulling the plate under the other, into the mantle and it would pull more as it becomes more slanted. They may also mention something about density of the plates and that the plate going into the mantle must be denser" (Teacher Edition, page 292).
    - Lesson 13: "Q1a: The four cross-sections below model modern-day seismic velocity anomalies in the Earth's mantle. Which cross-section do you think is the most similar to what was happening in the mantle under the Midcontinent Rift 1.1 billion years ago? Q1b: Explain how the energy in the mantle cross-section you chose would result in rifting at the surface using your understanding of convection and unbalanced forces. Q2: How do you think the mantle under this region might have changed over time? How would this change over time affect the transfer of energy from the Earth's interior to the surface?" (Midcontinent Ridge Assessment).
- *Earth's systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes.*

- Lesson 2: Students do not engage with feedback effects increasing or decreasing changes. Students instead engage with the **PS2.A** element, *Newton's second law accurately predicts changes in the motion of macroscopic objects.*
- Lesson 3: Students do not engage with feedback effects increasing or decreasing changes. Students instead engage with the **PS2.A** element, *Newton's second law accurately predicts changes in the motion of macroscopic objects.*

ESS2.B: Plate Tectonics and Large-Scale System Interactions

- *Plate movements are responsible for most continental and ocean-floor features and for the distribution of most rocks and minerals within Earth's crust.*
  - Lesson 10: "1. Which specific plates on the map interact at this kind of boundary? 2. What surface changes did you observe as a result of this interaction? 4. In the simulation we have to define the density of the plates we are investigating. What role, if any, could the density of the plates play in their motion or their interactions? 5. What do the cross sections tell us about the relationship between the movement of the plates and the observed changes in the crust?" (Investigating Plate Interactions Handout).
  - Lesson 13: "Q6: The process of rifting has many components, listed below: Volcanic activity Earthquakes Formation of new plate material (basalt) Mantle convection Plate movement Breaking of plate material Based on your knowledge of changes to Earth's systems, do you think this process of the rift failing happened over a long period of time or a short period of time? Use the class Scale Chart to explain the spatial and temporal scales over which the events would occur, as well as any connections between those changes" (Midcontinent Ridge Assessment).
- *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.*
  - Lesson 4: "How would the scale of a plate, and the number of particles that make up the matter in it, affect the amount of energy that can be stored in the electric fields between the particles before part of it reaches an elastic limit? We know the motion of the plates is relatively slow. What does that tell us about why there are periods of apparent stability between one earthquake and the next one in any specific region?" (PPT slide Z). Students are prompted to think about how changes at the particle level can be seen over time at the macroscopic level of rock formation.
  - Lesson 4: "Anak Krakatau is a volcano off the coast of Indonesia. It lies near the boundary between the Indo-Australian Plate, and the Eurasian Plate. Interactions between these two plates transfer energy into the rock near the boundary. This causes pockets of rock to melt and become magma. Gases in the hot magma put pressure on the solid rock above as a result of particle collisions. The upward force from this pressure can cause the crust to deform over time, and eventually break, allowing magma to reach the surface" (Lesson 4 Exit Ticket). Students use an Exit Ticket to show their learning about how interactions at a plate boundary can cause geologic phenomena.
  - Lesson 10: "To turn a solid rock into lava, we need to raise the temperature high enough to cause the material in the rock to melt. On Earth's surface, we refer to the temperature at which this happens as the melting point of a substance. The interior of the Earth is very hot, warmed by radioactive decay. This led scientists hundreds of years ago to predict that the interior of the Earth must all be liquid. But think back to

the model we developed in Lesson 5. The Earth's interior is mostly solid!" (Magma's Origins Handout).

- *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.*
  - Lesson 7: "With your Round 1 Group , answer the following questions: Energy Q1: When mass is converted into energy in the atomic nucleus, where does energy transfer, and why? Energy Q2: What happens to the surrounding atoms when particles leaving the nucleus collide with them? Energy Q3: Complete and annotate the diagram below to show how energy transfers between systems and system components during radioactive decay…" (Radioactive Decay (Energy) Handout).
  - Lesson 10: "To turn a solid rock into lava, we need to raise the temperature high enough to cause the material in the rock to melt. On Earth's surface, we refer to the temperature at which this happens as the melting point of a substance. The interior of the Earth is very hot, warmed by radioactive decay. This led scientists hundreds of years ago to predict that the interior of the Earth must all be liquid. But think back to the model we developed in Lesson 5. The Earth's interior is mostly solid!" (Magma's Origins Handout).

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

The reviewers found adequate evidence that students have the opportunity to use or develop the CCCs in this unit because there are numerous CCC elements used, with some focal CCC elements practiced multiple times over the course of the unit. For some focal CCC elements, teachers are provided guidance on how to make the use of the CCC explicit to students. Over the course of the unit, a successful student will use at least one element from six out of seven CCCs, which may be too many for the CCCs to be a framework to support student thinking about phenomena. There are numerous examples of CCC use that are described in the Teacher Edition, but that use is not claimed, or claims are contradictory.

Patterns

- *Mathematical representations are needed to identify some patterns.*
  - Lesson 5: "Present slide K. Say, One way we can test to see if this is really an anomaly is by checking to see what speed each of these waves were traveling. Remember that speed is just distance over time. Miles per hour. Kilometers per second. Speed is just a measure of how far something goes in a certain amount of time. Model the calculation first with the dot at 2,000 km. The P-wave appears to arrive at about 3 minutes, and the S-wave appears to arrive at about 11 minutes. 2000km/(3*60 seconds) = 11.1 km/s 2000km/(11*60 seconds) = 3 km/s. Ask students to look back to the reading to confirm that these speeds are accurate. Then ask students to choose a data point to test on their own. Split the class down the middle and ask one half of the class to test another data point from Part 1 of the graph. The rest of the class should test the anomalous data. Give students time to work out the math, and then ask them to share their findings with a show of hands" (Teacher Edition, page 140). Students use a mathematical representation of speed to analyze the data in the graph to determine the speed of P-waves.
  - Lesson 8: "Analyze and Interpret data in groups. Display slide V. Have students work in a group to analyze their graphs to approximate the times (on average) when there was 50% and 25% of parent element left. Space is provided on Analyzing decay trends for recording such averages from up to 6 conditions. Some groups may only get to

completing this table for a smaller sub-set of conditions (e.g.[sic] 2 or 3), which is fine. This should take about 4 minutes" (Teacher Edition, page 199). Students identify patterns in their data and develop a mathematical model of decay by looking how much time it takes a sample to decay to 50% and 25% of the original sample.

- *Empirical evidence is needed to identify patterns.*
    - Lesson 8: Students collect data from a netlogo simulation, and do not use empirical evidence in order to identify patterns related to geologic activity. "How do the patterns across your graphs compare? How do these patterns compare to your predictions?" (Teacher Edition, page 199).
    - Lesson 9: Students review map data about the ages of rocks (PPT slides D and F) in order to determine what is going on with the age of rocks in Afar. "If the crust in the Afar region is basalt, does that mean a new ocean is forming there?" (Lesson 9, slide U).
    - Lesson 10: Students use the radiometric data to identify matters that build explanations. "What were the patterns we identified about the ages of oceanic and continental crusts? How can our consensus model help us explain how the flow of matter through and between Earth's systems creates these patterns?" (PPT slide N). In this lesson students identify patterns using a computer simulation model, not empirical evidence.
- *Classifications or explanations used at one scale may fail or need revision when information from smaller or larger scales is introduced; thus requiring improved investigations and experiments.*
    - Lesson 5: "Does this model of the Earth explain why the surface of Afar region is so active (breaking, earthquakes, volcanos), and other locations are not? What else do we need to know about the mantle to figure this out?" (Lesson 5, slide R).
    - Lesson 5: "Present Slide Z. Give students 5 minutes to respond to the final questions on the handout before they share their ideas if they have not already. Revise our model to include local differences in the matter in the mantle. Pose the first two questions on the slide: What have we figured out that can help explain the plate motions we observed? How should we revise our Earth's Interior Model to reflect our new understanding about the mantle?" (Teacher Edition, page 149).
- *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.*
    - Lesson 1: Although this element is not claimed, there's opportunity for students to develop this element. "SUPPORTING STUDENTS IN DEVELOPING AND USING PATTERNS In high school, students should practice recognizing patterns at multiple scales. In this data set, they have the opportunity to observe several different spatial scales. When patterns change together at multiple scales, it can provide evidence for correlation, or even causality. In this unit, students will explain how unbalanced forces arising from properties of Earth's interior cause surface effects at both global and local scales. These surface effects occur in recognizable patterns that allow geologists to make inferences about the behavior of Earth's mantle" (Teacher Edition, page 46).
    - Lesson 5: "Introduce the modeling tool SubMachine. Present slide T. Say, The tool we are going to use lets us generate a model of the seismic wave anomalies over a much smaller scale and in greater detail, at any location within Earth's mantle. We can use it to 'see' underneath the Earth's surface at specific parts of the world and find out if the speed of energy transfer through the mantle material in that region is above average, below average, or close to average" (Teacher Edition, page 144) "Do you see any patterns between some surface features and the seismic velocity anomalies in the

mantle beneath them? If so, what are they?" (P.2 Lesson 5 Handout Investigating Cross-sections of, page 6). Teacher poses the question "How does the scale of these mantle anomalies compare to the scale of the anomalies we used to figure out Earth's layers?" (Lesson 5, slide BB).

Cause and Effect

- *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.*
    - Lesson 1: "Document how this region might change in the future (after). Consider how the mechanisms in your model above might cause the region to change over time, and how quickly these changes might occur… Consider the earthquake case you read about. What will happen to that region in the future, and how quickly will these changes happen? What mechanisms might be causing changes and what interactions might be happening between those mechanisms? Use words and/or pictures to share your ideas below" (Initial Afar Model Handout).
    - Lesson 3: Students explore cause and effect relationships in complex natural systems when they read about rock deformations. The NGSS dimensions claims "Students use data from a reading to make qualitative claims about how differences in the magnitude of forces (cause) 1) acting on different materials would result in similar effects in their structure (elastic deformation). This data includes ratios that reference the amount of deformation at a very small scale" (NGSS elements, page 5). However, the question asks students to think about: If an engineer tested similar-sized samples of two different materials from the data table shown here, which one of those materials would require application of higher magnitude forces on it, to produce the same amount of elastic deformation as the other material? This CCC element is not necessarily exploring smaller scale mechanisms just yet (gets covered in Lesson 4).
    - Lesson 4: "Emphasize that we should now be able to say that everything that happens at a very small scale – a particle level, can explain changes we are seeing in the plates at a much larger scale – including things like earthquakes and cracks in the plates. And part of that explanation connects to some amount of elastic deformation steadily increasing over time in the system" (Teacher Edition, page 126).
    - Lesson 7: In the "Cause-Effect Model" Handout students write cause and effect relationships for how atomic radioactive interactions can cause the energy needed for convection in the mantle. However, there isn't sufficient instruction or scaffolding to make it clear to students that this is what they should do.

Scale, Proportion and Quantity

- *Some systems can only be studied indirectly as they are too small, too large, too fast, or too slow to observe directly.*
    - Lesson 1: "What to do: Focus students on the cross-cutting concepts of patterns, cause and effect, and scale, proportion, and quantity by posing the following questions: 1. What kinds of questions do we have about changes to the Afar region and our other earthquake cases over different scales of time and space? 2. What kinds of questions do we have about parts of this system that are too large, too fast, or too slow to study directly?" (Teacher Edition, page 49).
    - Lesson 2: "SUPPORTING STUDENTS IN DEVELOPING AND USING SCALE, PROPORTION, AND QUANTITY This is a moment where students have an opportunity to use an important crosscutting concept for a phenomena[sic] of their choice. This can help

them see the generality of this idea for helping making sense of phenomena beyond those that are the focus of this unit: Some systems can only be studied indirectly as they are too small, too large, too fast, or too slow to observe directly" (Teacher Edition, page 64). The use of this CCC element is unclaimed in this lesson.

- Lesson 4: "Emphasize that we should now be able to say that everything that happens at a very small scale - a particle level, can explain changes we are seeing in the plates at a much larger scale - including things like earthquakes and cracks in the plates. And part of that explanation connects to some amount of elastic deformation steadily increasing over time in the system" (Teacher Edition, page 126) The effects of small-scale changes on larger-scale observations are discussed but not the idea that some systems can only be studied indirectly because they are too large or slow. Student prompts and activities for Lesson 4 fit better with the listed element for **Cause and Effect**.
- Lesson 5: In the handout "How do scientists measure Earth's interior" question #1 asks students to reflect on this concept: "Scientists need indirect evidence to study the interior of the Earth. What other systems have you studied that require indirect evidence, and why?"
- Lesson #11: The following is claimed: "Students develop models of forces acting on components of the crust and mantle system that are too slow and large to be observed directly. The process of plate movement occurs at such a slow rate that it is hard to observe directly, and observable movement generally occurs over large periods of time. Similarly, the scale of a plate is too large to study directly, and the forces acting on the plate cannot be studied on that scale directly." The teacher is instructed to, "Say, It seems we are saying that these properties are variables that can affect the forces acting on plates. One way to understand how a variable can affect the behavior of a system is by changing it. What are some of the ways we can change a variable to investigate its effect? Look for students to suggest that by increasing it, decreasing it, or removing it. Ask students if we can test these ideas directly. Look for them to say that we cannot because we have no control over the variables, the plates are too large, and the motion of the plates is too slow for us to observe directly" (Teacher Edition, page 265). This might not be enough for students to understand this CCC.
- Lesson 12: "Students use bottles on ramps to study and make sense of the force of gravity acting on the parts of plates and discuss the use of a model system that is small enough and can change motion within observable timescales, since actual plate forces and motion are too slow and large to observe directly." The lesson guides teachers to state: "Okay, we want to investigate the role of gravity acting on plates, but we know that we cannot investigate plates directly. Similar to our friction investigation, we are going to have to use a simpler object in the classroom" (Teacher Edition, page 286). And then for day two, the teachers is directed to remind students: "Be sure that the discussion talks about not only the bottle and gravity on an incline, but also the forces on plates we are modeling" (Teacher Edition, page 290). Since this is coming from the teacher, students may not show understanding of use or development of this CCC.

- *Patterns observable at one scale may not be observable or exist at other scales.*
  - Lesson 1: "As the class looks at the earthquakes they can also look for potential patterns related to earthquakes that might help explain the events at Afar. Pose the two prompts on the slide: What patterns might you notice when looking at any potential earthquakes? At what scale might you see those patterns?... Determine the scale at a plate boundary line. Display [url] . Students should notice that they do not

need to zoom in on the West coast and other plate boundaries to see earthquake patterns in lines. These earthquakes are clustered along a plate boundary, and there are many earthquakes on this line. Determine the scale at which we see lines of earthquakes inside of the North American plate. Display slide I. Pose the first prompt on the slide: Do you think that all earthquake lines or clusters are visible at the same scale?"

  - Lesson 7: The following is claimed: "Students use the concept of strong forces that only exist at a nuclear scale to explain patterns of convection at a global scale" (NGSS dimensions). However, patterns within these scales are not explicitly covered.

- *The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs.*
  - Lesson 2: "SUPPORTING STUDENTS IN DEVELOPING AND USING SCALE, PROPORTION, AND QUANTITY This is the first attempt to apply a model across very different scales in this unit, but comes after identifying earlier in the lesson - that the same data at different scales can be to argue for why a system appears stable at one scale but changing at another. Students also reflect on whether (and how) using thinking at/across different scales helped them figure something out in their progress tracker, even though this artifact is not used as a formative assessment. The same self reflection prompts related to the use of this CCC will continue over the course of the unit, each time a new progress entry is made" (Teacher Edition, page 76). This element and its use are unclaimed in the unit.

Energy and Matter

- *The total amount of energy and matter in closed systems is conserved.*
  - This element is claimed in the materials overview but it is not claimed in the NGSS dimensions handout in any of the lessons.
- *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.*
  - Lesson 3: "Say, In our prior unit, (material.pe.n), we explained many phenomena by thinking about energy transfer through the system. Let's use that lens again to try to explain what is happening in this system… . Give students 1 minute to Turn and Talk with the first prompt:. How are matter changes related to energy transfers we observed in this system? When did we see evidence of energy transferred in or out of the system?... As they share, ask students to identify which of the five sections of time that we divided the system behavior into was where we saw evidence of energy being transferred out of the system. Students will say the fourth section (the second Then very quickly). Then ask students to identify which of the five sections of time was where we saw evidence transfer into the system was occurring. Students will say the second section (the first Then very quickly). Add these energy transfer notations to the board" (Teacher Edition, pages 100–101).
  - Lesson 4: "SUPPORTING STUDENTS IN DEVELOPING AND USING ENERGY AND MATTER One of the purposes of the prompts that you include in the M-E-F poster is to assist students in making sense of the changes in energy within a system. By prompting students to observe macroscopic changes in matter and the net force acting on the system, they can begin to identify how interactions among different components of a system contribute to explaining the changes in matter and energy in a system, both macroscopically and at the particle level" (Teacher Edition, page 121). The use of this CCC element is unclaimed in this lesson.

- Lesson 5: "SUPPORTING STUDENTS IN DEVELOPING AND USING ENERGY AND MATTER Students might say that motion or compression or vibration is moving through the solid. Point to the M-E-F poster developed in an earlier lesson to prime them to be thinking about matter-energy relationships. Use probing questions to help them clarify their thinking, and layer on the appropriate scientific vocabulary to their ideas if necessary. Some questions you might ask include: When matter changes its motion, what is transferring through it, according to our M-E-F triangle? When you say vibration, what do you mean? Is a vibration something that moves, or is it evidence of something else that is moving or transferring?" (Teacher Edition, page 138). The use of this CCC element is unclaimed in this lesson.

- *Energy cannot be created or destroyed — only moves between one place and another place, between objects and/or fields, or between systems.*
  - This element is claimed in the materials overview but it is not claimed in the NGSS dimensions handout in any of the lessons.

Stability and Change

- *Much of science deals with constructing explanations of how things change and how they remain stable.*
  - Lesson 2: "Introduce 'stability' as a relative measure. Present slide F. Emphasize that the plate motion data measured over a day isn't the only example where something that appears stable at one scale, but is actually changing at another scale. Introduce a second example. Choose an object in the room that is stable and discuss the prompts below…Under what conditions is it stable? What if we changed the temperature in the room? What if we changed the temperature and looked at a particle scale? What if we left the table here for hundreds of years? Would it still be stable?" (Teacher Edition, page 64).
  - Lesson 3: "Again ask students if the forces on each piece of matter in the system are balanced (net force of zero) or unbalanced (net force does not equal zero) in the current state of the system and how we can tell. Listen for the same ideas as before: The forces on each piece of matter are balanced because they are all stationary ('stable'). The net force on each part of the system (in a free body diagram) would be zero. The matter is not changing… What was the approximate scale of time that it took the system to go from the starting stable state to its current stable state? If you could see this transition in slow motion, what changes in the system do you think you would see? Are the forces balanced, or unbalanced during this transition? How can we tell?" (Teacher Edition, pages 97–98).
  - Lesson 4: "How would the scale of a plate, and the number of particles that make up the matter in it, affect the amount of energy that can be stored in the electric fields between the particles before part of it reaches an elastic limit. We know the motion of the plates is relatively slow. What does that tell us about why there are periods of apparent stability between one earthquake and the next one in any specific region?" (Teacher Edition, page 126).
- *Change and rates of change can be quantified and modeled over very short or very long periods of time. ~~Some system changes are irreversible.~~*
  - Lesson 6: "SUPPORTING STUDENTS IN DEVELOPING AND USING STABILITY AND CHANGE Look for students to explain that the movement of the mantle is predictable and also cyclical based upon the changes that occur to the matter due to the increased or

decreased energy of the sample. This change happens over a large period of time" (Teacher Edition, page 171). The use of this CCC element is not claimed in this lesson.

- Lesson 13: "Based on your knowledge of changes to Earth's systems, do you think this process of the rift failing happened over a long period of time or a short period of time? Use the class Scale Chart to explain the spatial and temporal scales over which the events would occur, as well as any connections between those changes" (Midcontinent Ridge Assessment) This element is claimed for Lesson 13 but the student task in this lesson does not ask students to quantify the rates of change.

Suggestions for Improvement

Science and Engineering Practices

- Ensure that all claimed SEP elements, especially those that are the focus of the unit, are used and/or developed at the high school level. For example: "*Make a quantitative and/or qualitative claim regarding the relationship between dependent and independent variables*" is claimed as a focal element. However students are not provided with the opportunity to develop this element and only use it in one lesson.

Disciplinary Core Ideas

- Consider providing additional opportunities for students to further develop the elements that are only covered in one lesson.
- Wherever students are developing grade-appropriate science DCIs, consider claiming the elements in the unit overview and for each lesson.

Crosscutting Concepts

- Ensure that student activities, prompts, and questions match all parts of the elements claimed and that students are engaged with these CCCs at the high school level.
- Consider the alignment of the CCCs which are claimed, and those that are intentionally supported.

I.C. INTEGRATING THE THREE DIMENSIONS

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

Rating for Criterion I.C. Integrating the Three Dimensions	Extensive *(None, Inadequate, Adequate, Extensive)*

The reviewers found extensive evidence that student performances integrate elements of the three dimensions in service of figuring out phenomena and/or designing solutions to problems because there are numerous events where students are figuring out the unit phenomenon while using elements of all three dimensions together.

Examples of student performances that integrate elements of all three dimensions:

- Lesson 6: "Use the evidence we obtained from the mantle tank video to create a model to describe and explain why the matter in the tank is moving in the way we observed. Choose at least one of the following perspectives to develop within your model: Matter (particle level interactions) Energy Forces" (Mantle Take Model Handout). Students integrate the following elements in this activity:
    - SEP: *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.*
    - DCI: *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.*
    - CCC: *Energy drives the cycling of matter within and between systems.*
- Lesson 7: "With their round 2 group, ask students to use the answers to all the cause-effect questions to fill out the Cause-Effect Model handout (whichever version you choose) to explain where the energy comes from to drive convection" (Teacher Edition, page 180). In this handout, students must make claims about cause-effect relationships about how radioactive decay can cause the energy and motion of the mantle they have learned about based on their readings and previous lessons. Students integrate the following elements in this activity:
    - SEP: *Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) ~~and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future~~.*
    - DCI: *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*.
    - CCC: *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.*
- Lesson 8: "Analyze and Interpret data in groups. Display slide V. Have students work in a group to analyze their graphs to approximate the times (on average) when there was 50% and 25% of parent element left." Students integrate the following elements in this activity:
    - SEP: *Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations.*
    - DCI: *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.*
    - CCC: *Mathematical representations are needed to identify some patterns.*
- Lesson 10: "1. Make a prediction about how the surface of East Africa will look in the future. Use drawings and/or words to describe your prediction. 2. Use drawings and/or words to explain how the interactions between the plates and the mantle will cause the surface changes in Afar and Africa that you are predicting. Include any relevant source(s) of evidence from our investigations and your progress trackers to support your prediction. Revise your prediction and explanation on the front of this page before you continue. 3. A prediction about the future of a system usually includes the time it will take for the system to change in the ways described by the prediction. 3a. Approximately how long do you think it will take for the Afar region to look the way you are predicting? Why do you think so? 3b. What are the limitations and

assumptions of the models of the Earth and plate tectonics that we have been working with that could affect the accuracy of your prediction? How would these limitations or assumptions influence your prediction?" (P.2 Lesson 10 Handout Predicting the Future). Students integrate the following elements in this activity:

- SEP: *Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.*
- DCI: *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.*
- DCI: *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.*
- CCC: *Models can be used to predict the behavior of a system, but these predictions have limited precision and reliability due to the assumptions and approximations inherent in models.*

Suggestions for Improvement

None.

I.D. UNIT COHERENCE

Lessons fit together to target a set of performance expectations.

i. Each lesson builds on prior lessons by addressing questions raised in those lessons, cultivating new questions that build on what students figured out, or cultivating new questions from related phenomena, problems, and prior student experiences.
ii. The lessons help students develop toward proficiency in a targeted set of performance expectations.

Rating for Criterion I.D. Unit Coherence	Extensive *(None, Inadequate, Adequate, Extensive)*

The reviewers found extensive evidence that lessons fit together coherently to target a set of Performance Expectations (PEs) because the lessons are sequenced coherently in a way that builds on student questions and prior learning and there are sufficient opportunities for students to build proficiency in the targeted learning for all three dimensions.

The unit uses "navigation" steps, to support coherence from the student perspective. Navigation begins and/or ends each lesson, which sometimes includes revisiting the DQB or establishing or reminding students what they have learned and what questions remain that will be answered next. Examples are below:

- Lesson 1: "Navigate with a stop and jot. Present slide AA. Pose the prompts on the slide and allow students to consider what could be happening at the land where an earthquake occurs. What could be causing the land to be moving or crack? Does land only move and crack during an earthquake, or could it happen where there is no perceptible shaking? Ask for volunteers to share their responses with the class. Encourage students to respond to each other's ideas to draw out a variety of thoughts. Tell students that we will have to explore the changes that might occur to the land in our next lesson" (Teacher Edition, page 51).
- Lesson 2: The lesson begins with "Remind the class about the anchoring phenomenon. Say, Last time we explored data from earthquakes and cracks in the ground that sometimes open up after them. We saw this had happened at multiple locations across the Earth, beyond the one we started with in the Afar Region in 2005. Display slide A. Instruct students to take a half a minute to think about the questions on the slide on their own. Then discuss these as a class. Suggested prompt/ Sample student response: What could be causing the land to be moving or crack? Lava underneath is pushing the ground from below. The Earth's plates are moving. Material below the plates is interacting with the material above it. The land in some places, like Afar, might be too dry, so it cracks. Does land only move and crack during an earthquake, or could it happen where there is no perceptible shaking? Accept all answers What measurements or data would you want to analyze to see if any of these things are happening before this type of phenomenon occurs? Data about whether the land in the region is moving or whether it is changing elevation over time. Samples of the rocks from the surface or below the surface. Something like sonar or radar images to see what is happening below the ground. Weather or climate data related to rainfall and humidity. Connect this to the scope of the next few lessons. Say something like, Let's plan to analyze some of these different types of data sets over the next couple of lessons" (Teacher Edition, page 61). The first step of exploring how forces interact with matter may not be intuitive to students after their experience in Lesson 1.
- Lesson 2: The lesson ends with "Brainstorm additional outcomes and ways to investigate this. Display slide KK. Read the text at the top of the slide: In the first set of investigations we carried out, balanced forces on a stationary object appeared to our unaided eyes to produce no change in its motion. It remained stationary. As a class, discuss the two slide prompts: Suggested prompt Sample student response: If you keep increasing the magnitude of these forces acting on a solid object, what do you predict would happen to it? It could break. It could bend. It could crack. Say, Let's plan on doing some of those sorts of things and analyzing that sort of data in our next lesson" (Teacher Edition, page 88–89).
- Lesson 3: "Recall predictions. Display slide A. Have students recap some of the predictions we made last time around increasing the magnitude of balanced forces acting on a stationary object. Listen for the following ideas: •It could break •It could bend •It could crack" (Teacher Edition, page 96).
- Lesson 3: "Pause discussions. Display slide K. Have students take a minute to record the new question they now have. Remind students to write their question(s), one per sticky in marker, with their initial on back in pencil so you can collect them at the end of the class. Ask students to stick these sticky notes on to Forces Acting on Rocks to prepare to turn both of these in. Before collecting these, though, have students share some of their questions from either their sticky note(s) or from their response to question 4 of Forces Acting on Rocks with the class. Emphasize

that this seems to indicate that we need some additional ways to investigate these questions next time" (Teacher Edition, page 105).

- Lesson 4: "Review questions from last class. Present slide A, which should now have some of the questions that students generated at the end of the last lesson on them. Give students a half minute to review them after considering the prompt on the slide: How might answering these questions help us understand why most earthquakes tend to happen near plate boundaries, while others, like Afar, do not? Accept all answers. Foreground at least three categories of phenomena. Say, Let's see if we can apply our ideas about matter, energy, and forces, to make progress on some of these questions today - by using some different types of models to explain the different types of phenomena you all were referencing in your new questions. Some of those phenomena are related to earthquakes, some are related to cracks, and some are related to the elastic behavior of matter. Write these three categories of phenomena on the board: Earthquakes Cracking Elastic behavior of all matter" (Teacher Edition, page 113).
- Lesson 4: "Navigate into the next lesson. Present slide CC. Ask students to raise their hand in response to the prompt: Can we fully explain what is happening at Afar or do we need more information/data? Establish agreement that since Afar isn't happening at a plate boundary, something must be going on here different than what we think is happening for most earthquakes or the volcanoes we explained in the EET that are occurring near a plate boundary and we need some additional data/information to figure out these sort case sites that appear to be exceptions" (Teacher Edition, page 129). Students might not notice that Afar is not located at a plate boundary, or they may not understand why they are studying interactions at plate boundaries.
- Lesson 5: "Problematize the Afar example not being at a plate boundary. Present slide B. Say, 'But we noticed in Lesson 1 that the earthquakes in East Africa that we thought were connected to the Afar region did not appear to be along an established boundary, right?'" (Teacher Edition, page 136).
- Lesson 6: "Revisit the Lesson 5 Exit Ticket. Display slide A. Remind students that at the end of Lesson 5, they had individually considered the heterogeneous mantle. Students recognized that the mantle moved, but were trying to explain how the matter of different temperatures might affect the flow within earth's interior. Have students Turn and Talk about what they wrote on their exit ticket at the end of Lesson 5. After a minute or two, have a few students share their ideas. Present slide B. Say, Let's work on connecting these ideas to the mantle and our understanding of how it moves. Pose the first two questions on the slide: How is temperature connected to matter, energy, and/or forces? When flowing matter is heated, what changes at the particle level?" (Teacher Edition, page 158). The teacher provides students with the questions rather than guiding students' questions to lead to the driving questions.
- Lesson 7: "Display slide A and say, we figured out that rock in the mantle is moving. As rock deep in the Earth heats up, it rises toward the surface. Then it cools down and sinks back down again. This cycle depends on heat deep in the Earth. What ideas did we have about where the heat might be coming from to drive convection in the mantle?" (Teacher Edition, page 177).
- Lesson 8: "How could such comparisons help us better understand what is happening at Afar and what might happen there in the future? Knowing when rock was formed in different parts of the world, could help us figure out how long the processes going on Afar might keep going on. If the rock in Afar is much younger than the rest of the region, it would suggest it is a relatively recent phenomenon. We could compare Afar with places that have much older rocks. That could give us clues as to what could happen to Afar in its far future. So do you think that looking at more data will help us find patterns? The more data we have the more patterns we can find that will help us determine where Afar fits into those patterns. Navigate into the next lesson by

saying, It sounds like more data can help us to find patterns. Let's plan to investigate your idea of looking into how the age of rocks in Afar compare to those found in other places to test our predictions next class period" (Teacher Edition, page 207).

- Lesson 9: "Turn and talk about the age of Afar rock to motivate a comparison. Say, In the last lesson, we figured out that we can date rock using radioactivity. Using this method, the youngest basalt in the Afar region is less than a million years old. But we weren't sure what this meant, and were wondering how it compared" (Teacher Edition, page 213). This last statement is teacher-directed and it may not be clear to students that their questions are driving their learning.
- Lesson 9: "Point to a convergent boundary on the map where subduction is occurring, such as the western edge of South America. Accept all ideas, and point to places where we still have questions and controversy. We still have a lot of questions about what happens at these places where plates meet, and in particular we want to know about what is happening when these two types of crust meet up. We want to start by looking at these boundaries between plates and find out more about what is happening to the material at those boundaries. Administer an Exit Ticket. Ask students to respond to the prompt on the slide as an exit ticket. What do you think might be happening at the places where these two types of crust meet up, and why do you think that?" (Teacher Edition, page 229).
- Lesson 10: "Remind students where we are coming from. Present slide A. Say, Last time we left with a lot of questions about what happens at plate boundaries where plates meet, and in particular, we wanted to know about what is happening when oceanic and continental crusts meet up" (Teacher Edition, page 232). The previous lesson ended with the teacher stating, "We want to start by looking at these boundaries between plates and find out more about what is happening to the material at those boundaries" (Teacher Edition, page 225).
- Lesson 10: "Present slide O. Say, We can use models to explain data, and we can use models to make predictions about events in the future. We have used so many different types of evidence during this work. Let's see if we can use this evidence, and the model we made, to improve our predictions and explanations about what will happen to Afar in the future. You can change or add on to the predictions and explanations you developed at the beginning of the class" (Teacher Edition, page 255).
- Lesson 11: The lesson begins with, "Say, Last time we were thinking about the forces that could be acting on the plates that could help us explain the difference in the ways plates are moving. Which forces do we think are acting on plates that could explain the motion we observed? Take the piece of chart paper titled Forces and Variables and create a T-chart with 'Forces acting on plates' on the left. Keep a record of student ideas about forces on this side of the chart, and leave the second column empty at this point. Present slide C. Say, So we think that there are multiple forces at once acting on a plate. Let's work in groups to develop a model that can help us illustrate the forces acting on a plate and what would happen to the motion of a plate when multiple forces are acting on it at the same time" (Teacher Edition, page 263). This next step in the investigation is teacher directed.
- Lesson 11: The lesson ends with, "Present slide Y. Make sure the Forces and Variables poster is visible to all students so they can see the forces and plate variables that should be the focus of the next investigation. Say, Okay, I think we made some progress, but it seems we still have some questions about how forces are acting on plates. Ask students to take a moment and record their ideas related to the prompt on the slide as an exit ticket in their notebooks: Which other force(s) should we investigate that could help us explain why some plates change motion differently than others? Tell students that in our next class period we will revisit this prompt and consider our ideas as a class" (Teacher Edition, page 274).

- Lesson 12: The lesson begins with, "Say, Last time we investigated the role of friction on the motion of an object, and we found that some plate variables affect the force of friction acting on a plate. But we think there are other forces involved. Let's consider the force that we should investigate next. Give students a moment to review what they wrote on their exit tickets at the end of the last lesson. Ask a few students to share. Look for students to suggest that they should investigate the force of gravity. If they do not mention gravity, point to the Plate Interactions poster to focus students' attention to the motion of plates sliding down inclines into the mantle" (Teacher Edition, page 283).
- Lesson 12: During the course of the investigation, students need to connect their experience from Lesson 2 on breaking down force components. After students analyze data, they have to think about how this connects to the following phenomenon: "What do our lab results tell us about the more complex plate systems? Use free body diagrams, words, and/or drawings to connect our lab findings with the stability and change of plate motion over long time scales" (Measuring Forces on Inclines Investigation, section 4).
- Lesson 13: "We've figured out so much! I bet we can answer many of our questions on the Driving Question Board. Mark patterns in questions answered using the sticker dots. Facilitate the students in identifying patterns in DQB questions. Focus the discussion on identifying (1) questions we agree that we can answer, (2) questions that we have at least a partial answer to, and (3) questions we cannot answer at all. Choose one color of sticker dots to mark each of these categories. Hand out each student one set of the sticker dots and allow them to come up to the DQB and add their stickers to DQB questions" (Teacher Edition, page 301).

The lessons help students develop proficiency in a targeted set of PEs.

- In the Unit Overview Materials document the targeted NGSS PEs are identified as the following and students develop elements from all of these performance expectations throughout the unit (see Category 1.B):
    - **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.*

Suggestions for Improvement

Currently, some of the transitions from one lesson to another are teacher-driven and may seem incoherent from the students' perspectives, especially for students who may have missed a lesson. Consider providing opportunities for students to revisit their own questions more frequently and/or for the teacher to provide guiding questions for the students to suggest next steps rather than having the teacher make those steps in the form of statements.

I.E. MULTIPLE SCIENCE DOMAINS

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

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

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

Rating for Criterion I.E. Multiple Science Domains	Extensive *(None, Inadequate, Adequate, Extensive)*

The reviewers found extensive evidence that links are made across the science domains when appropriate because the unit integrates Earth and space science (ESS) DCIs with physical science (PS) DCIs and uses CCCs to explicitly make connections across science domains and/or science courses.

Disciplinary core ideas from both ESS (**ESS1.C**, **ESS2.A**, **ESS2.B**) and PS (**PS1.C**, **PS2.A**, **PS2.B**, **PS3.A**, **PS3.B**, **PS4.A**) are necessary to make sense of the Afar region phenomenon that students are engaged with throughout the unit. The use of ESS and PS DCIs are integrated in some individual lessons. For example, lesson-level PEs include both ESS and PS DCIs in the following Lessons: 3, 4, 5, 6, and 7. (Teacher Edition, pages 312–315).

There are some instances where CCCs are used to make connections across science domains and science courses. For example:

- Connections within the unit:
  - Lesson 5: In order to understand what might be below earth's surface, students read about p and s waves. They look for patterns in order to see whether seismic waves are moving at expected speeds (slide L). Teachers are guided to ask the following questions in reference to the graphs: "Use probing questions to help students clarify their thinking as they make connections between the patterns that they identified, and the reality of seismic waves moving through matter. Some examples of questions might include: Which pattern are you explaining right now? Can you point to the pattern on the slide? What about this pattern right here? What does that tell us about the speed of the seismic wave for waves that pass all the way through the center of the Earth? What information can we draw from the reading that could help us explain that pattern? Take a moment to look back at the section on seismic waves" (Teacher Edition, page 141). The connection between Earth and space science and physical science using the CCC of **Patterns** is implied and students may not be aware that they're making this connection.
  - Lesson 5: Students also explore waves on a local scale in order to understand the Earth's mantle and are asked to reflect on how changing scales can help explore what is going on in Afar. Teachers are guided: "Foreshadow convection by focusing on scale and change. Present slide BB. Pose only the first question on the slide: How does the scale of these mantle anomalies compare to the scale of the anomalies we used to figure out

Earth's layers? Call students' attention to the Scale Chart. Ask students to use the chart to compare the scale of the velocity anomalies that told us about Earth's layers to those that told us about mantle matter differences at a local scale. Then ask them to consider the timescale. Students should realize that while we know that these anomalies occur on both a global and a local scale, we don't know where they would go temporally. Say, We don't know where to put these on the y-axis, because we don't know on what time scale these anomalies even exist. Are they forever? Do they change over time? And if so, what timescales?" (Teacher Edition, page 150). The connection between Earth and space science and physical science using the CCC of **Patterns** is implied and students may not be aware that they're making this connection.

- Connections to other units:
  - There are explicit call outs in the Teacher Edition to the focal CCC. Two examples are below:
    - Lesson 4: "SUPPORTING STUDENTS IN DEVELOPING AND USING ENERGY AND MATTER You may want to ask students for additional examples of phenomena from their prior work in chemistry that involved explaining energy changes in the system in terms of kinetic energy of the particles and/or energy stored in fields. These are the examples student may cite: From OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit): The phenomena was melting polar ice caps and sea level rise due to the changes in the atmospheric composition. The particles were molecules that made up water, land, and air, and their motion was related to temperature changes in the system. From OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit): The phenomena was lightning. The particles were the displaced electrons in the air, clouds, ground, and metal and the positive nuclei left behind. The fields were electric fields between places where excess charges accumulated). From OpenSciEd Unit C.5: Which fuels should we design our next generation vehicles to use? (Fuels Unit): The design problem was related to alternate fuels for providing energy. The particles were atoms and shared electrons in bonds within molecules (for combustion reactions or batteries) or protons and neutrons (for fission reactions). The fields were electric fields for the former and electric fields and fields from strong nuclear forces for the later" (Teacher Edition, page 122).
    - Lesson 5: "SUPPORTING STUDENTS IN DEVELOPING AND USING SCALE, PROPORTION, AND QUANTITY In this moment, students consider connections across disciplines by discussing other systems they have learned about that cannot be studied directly. Help students see that scale affects how we collect data about a system. Some examples they might come up with include the solar system, the electrical grid, tectonic motion, or an atom. If the opportunity comes up, point out that some systems are difficult to study because of temporal scale, in addition to spatial, and point to the scale chart we made in an earlier lesson. An example might be natural selection and adaptation, or the life cycle of the Sun" (Teacher Edition, page 137).

Suggestions for Improvement

None

I.F. MATH AND ELA

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

Rating for Criterion I.F. Math and ELA	Extensive *(None, Inadequate, Adequate, Extensive)*

The reviewers found extensive evidence that the materials provide grade-appropriate connections to the Common Core State Standards (CCSS) in mathematics, English language arts (ELA), history, social studies, or technical standards because every lesson includes a connection to at least one ELA or mathematics standard, and many include multiple connections. These connections are explicit opportunities for students to develop their mathematics and ELA skills.

Students use and develop mathematics concepts and skills over the course of the unit, including graphing, calculations, and the use of vectors. For example:

- **CCSS.MATH.CONTENT.HS.N-VM.1**. *Represent and model with vector quantities. Recognize vector quantities as having both magnitude and direction.*
    - Lesson 1: Students will represent external forces acting on an object using a free-body diagram representation (Teacher Edition, page 90).
    - Lesson 11: Students review that forces are vector quantities and have both magnitude and direction (Teacher Edition, page 275).
    - Lesson 12: Students review that forces are vector quantities and have both magnitude and direction (Teacher Edition, page 293).
    - Lesson 13: In the assessment, students use vectors to describe the magnitude and direction of multiple forces acting on Laurentia and Amazonia before and after their separation (Teacher Edition, page 303).
- **CCSS.MATH.CONTENT.HS.N-VM.3** *Represent and model with vector quantities. Solve problems involving velocity and other quantities that can be represented by vectors.*
    - Lesson 2: *The engagement with this type of representation is supported using different tools, including physical cutouts students can use to identify connections between vector components, and graphical representations to make*
    - *sense of the magnitude and direction of vectors* (Teacher Edition, page 90).
    - Lesson 11: "Students also observe that forces vectors balance to a net force of zero on an object that is moving at a constant velocity and use this concept to measure the force of friction on a sliding object" (Teacher Edition, page 275).
    - Lesson 12: "Students use the concept of vector components within the context of forces to solve for the force of gravity on an object from measured forces that balance with the components of gravity" (Teacher Edition, page 293).
- **CCSS.MATH.CONTENT.HS.A-CED.2** *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.*

  - Lesson 5: In this lesson (Day 1), students analyze a linear graph. Students use an equation (mathematical model) to test several data points in order to identify anomalous patterns in seismic wave velocities. Students respond to a reflection question during the navigation into Day 2 on how mathematical representations helped them identify patterns and anomalies in seismic velocities to support their reasoning (Teacher Edition, page 151).
- **CCSS.MATH.CONTENT.HSA.SSE.A.1.B** *Interpret the structure of expressions. Interpret complicated expressions by viewing one or more of their parts as a single entity.*
  - Lesson 8: "As students use mathematical thinking to compare patterns from the results of their investigations to those in an equation of exponential decay. They will also use this equation to determine the age of rocks from Afar" (Teacher Edition, page 207).
- **CCSS.MATH.CONTENT.HSG.SRT.C.8** *Use trigonometric ratios and the Pythagorean Theorem to solve right triangles in applied problems.*
  - Lesson 12: "Students use the Pythagorean Theorem to identify the relationship between the components of gravitational force acting on an object on an incline. This builds on the ideas that students develop at the end of 8th grade, where they learned to apply the Pythagorean Theorem to determine the unknown side lengths in right triangles in real-world and mathematical problems in two dimensions. Use both mathematical and geometrical representations to support students' sense making of this relationship" (Teacher Edition, page 293).

Students use grade-appropriate ELA skills including reading, writing, speaking, and listening throughout the unit. The reading materials are predominantly expository texts, limiting student exposure to varied materials such as narrative stories, news articles, journal articles etc.

- **CCSS.ELA-LITERACY.RST.9-10.1** *Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.*
  - Lesson 1: Students read of an earthquake case and compare and contrast the earthquake cases with information from the Afar Storymap text. Students also compare their case to other cases to determine what the cases have in common, citing specific evidence from the text. There are also Common Core Speaking and Listening standards targeted in this lesson (Teacher Edition, page 51).
- **CCSS.ELA-LITERACY.SL.9-10.1** *Initiate and participate effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on grades 9–10 topics, texts, and issues, building on others' ideas and expressing their own clearly and persuasively*.
  - Lesson 1: Students discuss earthquake cases in diverse groups and share text-based information about their cases with each other, building on each other's ideas to find similarities between the sites and the Afar case. Students also engage in the sharing of their initial models with partners and in the larger consensus discussion. In addition, students share their ideas across multiple diverse groups throughout the lesson (Teacher Edition, page 51).
  - Lesson 4: "Four discussions are integrated into this lesson — two with different pairings of students for analysis of videos on day 1, one with a small group member to compare different investigation findings and one whole class consensus discussion on day 2. These give students multiple opportunities to engage in this speaking and listening standard. The focal community agreement for this lesson further foregrounds the importance of student contributions that are recognized and valued by their peers and

the last question on the electronic exit ticket (EET) have students reflect on this as well" (Teacher Edition, page 130).
    - Lesson 6: "Students engage in discussions about the convection of the mantle tank and Earth's mantle, coming to consensus on thermal convection. Students also revisit the DQB and share any new questions they can answer as a class" (Teacher Edition, page 171).
- **CCSS.ELA-LITERACY.SL.9-10.1.A** *Come to discussions prepared, having read and researched material under study; explicitly draw on that preparation by referring to evidence from texts and other research on the topic or issue to stimulate a thoughtful, well-reasoned exchange of ideas.*
    - Lesson 1: "Students utilize information from their case reading and the Afar storymap to engage in the consensus discussion, where they use evidence from texts to engage in a thoughtful exchange of ideas related to the potential cause for the earthquake and potentially related surface features in the earthquake regions" (Teacher Edition, page 51). The reading materials include a story map website infographic and curated case studies in the form of expository text.
- **CCSS.ELA-LITERACY.11-12.RST.2** *Determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.*
    - Lesson 5: "This standard shows up because students determine the central ideas from two readings. They use the Making Sense questions and the class discussions to paraphrase the important ideas" (Teacher Edition, page 151). The two readings "The Mantle and the Moho" and "Earth's interior Models" are textual readings. The interior model has a citation from IRIS.
    - Lesson 7: "This standard shows up because students determine the central ideas from the readings. They must paraphrase the important ideas in order to distill the cause-and-effect mechanisms required to create our consensus causal chain model" (Teacher Edition, page 185). The radioactive decay readings are expository texts.
- **CCSS.ELA-LITERACY.11-12.RST.9** *Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.*
    - Lesson 5: "This standard shows up because students synthesize information from two readings, a simulation, and tomography models to develop a coherent understanding of Earth's interior and how scientists use evidence from seismic waves to investigate it" (Teacher Edition, page 151).
    - Lesson 7: "This standard shows up because students synthesize information from multiple readings to develop a coherent understanding of how radioactivity drives convection in Earth's interior. Each reading is not sufficient to describe the phenomenon. The class works together to create a coherent understanding" (Teacher Edition, page 185).
- **CCSS.ELA-LITERACY.SL.11-12.1.A** *Come to discussions prepared, having read and researched material under study; explicitly draw on that preparation by referring to evidence from texts and other research on the topic or issue to stimulate a thoughtful, well-reasoned exchange of ideas.*
    - Lesson 8: "Make sure all students have access to the copy of the spreadsheet shared within each group. Give students some time to make sense of their data in their small groups before working in their new jigsaw groups. This will allow students to come prepared to have a richer discussion and participation with their peers" (Teacher Edition, page 207).

- **CCSS.ELA-LITERACY.RST.9-10.1** *Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.*
    - Lesson 9: "Students who would like to learn more about crustal composition have the opportunity to read more about the chemical composition of granite and basalt. If students engage in this opportunity, they are also given the opportunity to research the topic and share what they have learned with the class" (Teacher Edition, page 225). This is one of the two lessons where students have the opportunity to utilize an infographic — "Age of crustal rocks" with citation from NOAA. The extension reading provided is a simple text.
- **CCSS.ELA-LITERACY.RST.11-12.9** *Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.*
    - Lesson 10: "Students synthesize information from multiple sources, including the reading about magma and the computer simulation of plate interactions, into a coherent understanding of plate tectonics as a unifying theory that explains multiple phenomena in the Earth system. This includes how interactions involving the transfer of energy and matter at plate boundaries lead to the development of distinctive surface and ocean-floor features, characteristic patterns in the ages of rock, and distinctive patterns in earthquake depth" (Teacher Edition, page 256). The reading "Magma's origins" is another expository text. This is the second lesson where students use texts that aren't expository in nature. An infographic is utilized that is titled: "Rate and Direction of Plate Movement."
- **CCSS.ELA-LITERACY.SL.11-12.4** *Present information, findings, and supporting evidence, conveying a clear and distinct perspective, such that listeners can follow the line of reasoning, alternative or opposing perspectives are addressed, and the organization, development, substance, and style are appropriate to purpose, audience, and a range of formal and informal tasks.*
    - Lesson 11: "Students present their lab findings to the class, citing their collected evidence from lab observations" (Teacher Edition, page 275).

Suggestions for Improvement

Consider increasing the variety of textual formats. For example:

- News articles could potentially bolster the case studies readings in Lesson 1.
- More texts could also be modified from journal articles such as "Forces Acting on Rocks" from Lesson 3.

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

CATEGORY II

NGSS INSTRUCTIONAL SUPPORTS

II.A. RELEVANCE AND AUTHENTICITY

II.B. STUDENT IDEAS

II.C. BUILDING PROGRESSIONS

II.D. SCIENTIFIC ACCURACY

II.E. DIFFERENTIATED INSTRUCTION

II.F. TEACHER SUPPORT FOR UNIT COHERENCE

II.G. SCAFFOLDED DIFFERENTIATION OVER TIME

II.A. RELEVANCE AND AUTHENTICITY

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

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

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

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

Rating for Criterion II.A. Relevance and Authenticity	Extensive *(None, Inadequate, Adequate, Extensive)*

The reviewers found extensive evidence that the materials engage students in authentic and meaningful scenarios that reflect the real world because the anchoring phenomenon was carefully selected to be engaging to students, and the teacher is guided to help students make personal connections between the phenomenon and their experiences and communities outside of school.

Students engage with the unit phenomenon through images and text, and related personal experiences, which is as direct as possible given that most geologic events happen at a scale at which they cannot be directly observed. The phenomenon can be interesting and important for students and encourage curiosity. For example:

- Lesson 1: "This lesson utilizes earthquake cases from several locations across the US and North America. Earthquakes happen in many places, however, in this region. Consider making a more localized earthquake case for students to investigate using information from Local Case Creation. Add the localized case to the Case Comparisons case set" (Teacher Edition, page 30).
- Lesson 1: "Present slide A and read the summary on the slide: In October 2005 people in north east[sic] Africa took this photo of a huge crack in the ground that was not there before. Point out that the image has a series of people standing along the side of this crack on the left side of the photos in order to give students a sense of the spatial scale of the crack. Pose the question on the slide to elicit students' initial ideas about this phenomenon" (Teacher Edition, page 32)
- Lesson 1: "Share the story map link with students. Share https://arcg.is/1mWzu9 and distribute computers to students. It is recommended to have students access this Storymap individually, but groups of 2-3 are also an option. Instruct students to spend time reading through the story map, which has information about what happened in the Afar region in 2005, and record what they notice and wonder on their T-chart" (Teacher Edition, page 33).

Students are provided opportunities to connect the unit phenomena to their own experiences, or the experiences of members of their communities. The teacher is provided guidance on how to connect the phenomenon to students' experiences, and support students in the event that the personal connection to the phenomenon brings up difficult or upsetting experiences. For example:

- "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 one, three, four and five were chosen because they have high relevance to students' everyday experiences and communities. The phenomenon in this unit is playing out at a timescale where 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). While 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 homogenous 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" (Teacher Edition, page 11).
- "In this unit, students will 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.'… 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" (Teacher Edition, page 23).
- Lesson 1: "Tell students they can go home and ask trusted friends and adults about their experiences before, during, and after an earthquake, a volcano, or some other sudden change to Earth's surface as well as what they noticed. The trusted friends and adults can also share about earthquakes that they have not experienced, but have heard about in the past. Tell students that they can record the stories in any way they see fit, or they can just listen. Let them know that they will be invited to share the stories next class period, but that they will not be required to tell these stories" (Teacher Edition, page 39).
- Lesson 3: Teacher is prompted to ask students "what other materials that you've seen exhibit elastic behavior, like the foam?" (Lesson 3, Slide 9).
- Lesson 5: "This simulation has the option of choosing any number of historical earthquakes. The default Earthquake is the 1994 Northridge Earthquake in Southern California. If there is any history of large Earthquakes in your area, click 'load new quake' and look for an earthquake that might be more interesting and relevant for students in your area. Connecting phenomena to place can support students in seeing connections between their lives and the science content" (Teacher Edition, pages 143–144). There are only 13 earthquakes available, which might make it hard to find one that feels relevant to students in certain locations.
- Lesson 8: "Connect to Related Phenomena. Present slide H. Say, In order to figure out how much of each of these different elements there are in these rocks, scientists study the individual crystals that make up these volcanic rocks. Before we see how they do that, let's think about our own related experiences with rocks. Take a poll on this question: How many of you have found solid rocks that had what looks like tiny crystals in them of different colors or sizes? Most students will raise their hands to indicate that they have. Follow-up by saying, Solid rocks that

have small crystals in them typically are ones that have been either partially melted or fully melted in the past, before cooling back down. That cooling down is what causes crystals to form in the rock" (Teacher Edition, page 195).

- Lesson 9: Students feel the two different kinds of rock "Let's look at these two types of crust (actual rock samples). Ask each group to pass the rocks around, holding them in their hands. Explain which rock is granite (continental) and basalt (oceanic). Ask students to make observations of the two rock types using the first prompt on the slide" (Teacher Edition, page 220).

The unit includes opportunities for students to connect their explanations of phenomenon to a problem from their own experience and/or their community. For example:

- Lesson 1: "Project slide E. Say, We just learned that the people in Afar experienced several phenomena- earthquakes, a volcanic eruption, and a giant crack in the ground. Do any of you have experience with the phenomena we see in the Afar region? Motivate looking deeper into earthquakes. Allow students to generally share if they have had experiences with these phenomena. Students may mention experiences with all three of these phenomena, but most students will have seen or heard of earthquakes, and some with cracks in the ground. Consider doing a show of hands for each phenomena[sic] in Afar to elicit if students have had experiences with these phenomena" (Teacher Edition, page 34).
- Lesson 7: The last question in the Exit Ticket asks, "Radioactivity drives mantle convection deep inside the Earth. But there is also naturally occurring radioactive material on Earth's surface, and humans use radioactive materials in technology. Where else have you heard about radioactivity occurring naturally or being used?"
- Lesson 8: "Present slide H. Say, In order to figure out how much of each of these different elements there are in these rocks, scientists study the individual crystals that make up these volcanic rocks. Before we see how they do that, let's think about our own related experiences with rocks. Take a poll on this question: How many of you have found solid rocks that had what looks like tiny crystals in them of different colors or sizes?" (Teacher Edition, page 195).

Suggestions for Improvement

Consider providing teacher support and student opportunities for students to think about how they can use the information related to the Afar region to potentially solve a problem in their own community.

II.B. STUDENT IDEAS

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

Rating for Criterion II.B. Student Ideas	Extensive *(None, Inadequate, Adequate, Extensive)*

The reviewers found extensive evidence that the materials provide students with opportunities to both share their ideas and thinking and respond to feedback on their ideas because there are repeated structures in place for students to give and receive peer feedback and track their thinking and how it has changed throughout the unit. However, there are some missed opportunities for students to explicitly receive feedback both from the teacher and their peers.

There are a variety of whole-class discussion types that enable students to hear each other's ideas, express and justify their own ideas, and revise their thinking. For example:

- Lesson 1: "STRATEGIES FOR THIS CONSENSUS DISCUSSION Your role as a facilitator in a consensus discussion is to press students to take stock in where the class agrees and where the class disagrees. Tell students explicitly that you will not write down everything they say. Say, Remember that my role here is to put ideas back into the public classroom arena so we can debate them and clarify where we stand as a class, even if that means that we agree that we have a few areas of disagreement. So you might hear me say, What do others think of that idea? With a show of hands, how many students agree with that idea, how many disagree? I will only write something down when we have taken stock of it as a class. Encourage as many students as possible to contribute to this discussion. The model should represent the diverse thinking of all students, if possible. Be careful not to favorably respond to any one idea over others so as not to give away what might be going on in the phenomenon" (Teacher Edition, page 44).
- Lesson 2: "Facilitate a building understanding discussion. Present slide R. Give students Investigation A&B back if they were collected in the prior class period. Give students two minutes to individually review what they wrote on Investigation A&B." Later, the following guidance is also provided: "The purpose of this discussion is to help students argue for ideas based on the evidence they have. You may want to explicitly remind students of your role in this type of discussion. Before starting saying something like 'I am going to press for evidence in this discussion, regardless of whether I agree or disagree with what you are claiming. I will ask others if their evidence supports or refutes that finding as well'" (Teacher Edition, page 73).
- Lesson 2: "Once students have completed their written responses, display slide V and facilitate a consensus building discussion around the prompts on it with the whole class: Do we think the free-body diagram any of us created is a reasonable model to use for explaining why the Caribbean plate is not moving? Why or why not? STRATEGIES FOR THIS CONSENSUS DISCUSSION The purpose of this discussion is to establish agreement around two key points listed below. Ask students to restate others' ideas and indicate which parts of those ideas they agree or disagree with, in order to reach consensus quickly on these points" (Teacher Edition, page 76).
- Lesson 3: Students engage in a turn-and-talk routine to apply what they learned about M-E-F to the earthquake phenomenon. "Use the ideas from the reading and the M-E-F poster to help explain either of these phenomena" (Lesson 3, slide K).
- Lesson 4: Students engage in a scientist circle to express their ideas related to the "particle investigation" handout (Lesson 4 slide T to AA). There are no directions provided to students on how to provide each other with feedback. There is some guidance for the teacher to keep the discussion going, however it is not in the form of feedback. "You might want to emphasize the limitations of using the concept of potential energy to describe the energy stored in a system, especially if your students are already familiar with it…" (Teacher Edition, page 125) and "Point out that this new way we are considering how energy is stored in systems, related to elastic deformation, involves thinking about the motion of the particles in the matter and the energy stored in the field based on their position in space relative to each other. Emphasize that…" (Teacher Edition, page 128).
- Lesson 6: "Compare explanatory models of the movement of matter in the mantle tank. Present slide L. Go over the directions shown on the slide: Look for a person who used the same perspective to explain the motion of matter in the mantle tank. Each person will have a minute

to explain their model. After each partner has shared, look for: Similarities between models Differences between models Areas of uncertainty Areas of disagreement After a few minutes, Present slide M, this time asking students to look for a partner who used a different perspective to explain the movement of matter in the mantle tank. Direct students to consider the new prompts on the slide: How both models combined help explain the movement of matter Areas of uncertainty Areas of disagreement Ask students to record ideas for changes or new understanding you develop from comparing your model with partners on Mantle Tank Model for use in the next class" (Teacher Edition, page 165).

- Lesson 9: Students conduct a turn-and-talk routine and whole class discussion to share-out their ideas. "Turn and Talk: How might the different densities of these rocks affect what is happening at those boundaries?" (Lesson 9, slide S). Teacher guidance for the class discussion on the next slide is as follows: "If students do not easily suggest this, consider bringing up slide B to remind students that the rock in the Afar region is relatively new, and direct students back to our investigation and the rock types to consider what type of rock is present. Ask, What does that mean about what's happening in the Afar region, based on our model? Students should have some ideas about how similar processes to what is happening in the lines along the ocean floor might be happening in the Afar region. If students are stuck, point them back to the model the class just made" (Teacher Edition, page 220).
- Lesson 11: "Purpose of the discussion: To share ideas about the forces acting on plates. Push for elaboration of evidence and reasoning, and encourage other groups to critique and provide alternative explanations. The end goal of this discussion is to motivate the need to identify how characteristics about plates affect these forces" (Teacher Edition, page 264). "Compare and discuss revised models. Present slide F. Have students participate in a gallery walk to compare their models with their peers, looking for similarities and differences among models. After a few minutes, ask students to return to their seats." Students view each other's revised models and compare, but do not give each other feedback. Students do a round robin to share ideas on how to do an investigation surrounding friction. Teacher guidance for feedback is limited. "As groups present their findings, invite other groups to ask clarifying questions or offer wonderings about the role of friction" (Teacher Edition, page 272). Then students proceed to carry out the investigation. They analyze data with each other and contribute to a whole class discussion: "Share your results with the class ● Describe your data. ● What relationship does your data support? ● What was your conclusion about how your variable affects friction? Was this the same as your hypothesis? ● Does this agree or disagree with the data other groups have presented?" (Lesson 11, slide U). Students hear each other's ideas, but explicit feedback is not provided.

Students receive feedback through some assessments and activities. There are limited opportunities for students to receive written feedback from their peers. Opportunities and protocols for students to use this feedback and revise their thinking in writing is not always provided.

- Lesson 2: "What to do: If you collect Investigation A&B, you can provide written feedback on this assessment opportunity, otherwise you can visit groups and provide verbal feedback/guidance. If you do the latter, and a group seems to be done with their data collection, ask them to share with you their ideas about the last prompt on the slide" (Teacher Edition, page 73).
- Lesson 4: "Revise Scale Chart. Present slide AA. Emphasize that we should now be able to say that everything that happens at a very small scale – a particle level, can explain changes we are seeing in the plates at a much larger scale - including things like earthquakes and cracks in the plates. And part of that explanation connects to some amount of elastic deformation steadily increasing over time in the system" (Teacher Edition, page 126).

- Lesson 5: "Then present slide AA. Give students about five minutes on their own to revise their models following the directions on the slide: Add labels, symbols, drawings, and/or annotations to your model of Earth's interior to reflect our new understandings about the mantle and its matter" (Teacher Edition, page 149). In this example students are provided clear directions on how to make revisions.
- Lesson 6: "Compare explanatory models of the movement of matter in the mantle tank. Present slide L. Go over the directions shown on the slide: Look for a person who used the same perspective to explain the motion of matter in the mantle tank. Each person will have a minute to explain their model. After each partner has shared, look for: Similarities between models Differences between models Areas of uncertainty Areas of disagreement After a few minutes, Present slide M, this time asking students to look for a partner who used a different perspective to explain the movement of matter in the mantle tank. Direct students to consider the new prompts on the slide: How both models combined help explain the movement of matter Areas of uncertainty Areas of disagreement Ask students to record ideas for changes or new understanding you develop from comparing your model with partners on Mantle Tank Model for use in the next class" (Teacher Edition, page 165).
- Lesson 7: "What to do: Provide feedback for students using the suggestions in the key. This feedback will be useful for students as they join their jigsaw groups later to compare and integrate their ideas with those obtained by their peers" (Teacher Edition, page 178).
- Lesson 12: "Revisit and revise plate model from Lesson 10. Present slide AA. Be sure that the Plate Interactions poster from Lesson 10 is visible to all students. Ask students to review the model and individually consider what should be added from the friction and gravity investigations. Give students a couple minutes to consider this on their own. Say, Let's bring our ideas together and add to or revise our consensus model. Ask students to share and discuss their ideas for changes to the model and update the consensus model on the Plate Interactions poster from Lesson 10" (Teacher Edition, page 293). In this example, students have an opportunity to reflect and discuss revisions, and make some written changes. However, it is not explicit to students how they might need to revise their models.

The progress tracker enables students to document their thinking at key points throughout the unit and serves as an artifact of how their thinking has changed over the course of the unit. For example:

- Lesson 2: "Remind students the tracker is not intended to be a record of the 'right' answers--it is a record of our changing thinking over the course of a unit, and should be a place where students feel comfortable reflecting on what they do not know or do not yet understand. Connect to crosscutting concepts. Explain that in every unit you will introduce a slightly different format progress tracker to students, to help support a different way of reflecting on how we are figuring things out. These different ways of tracking our thinking could help us develop more generalizable approaches to figuring things out beyond this unit and even beyond this course. Point out that the lenses section includes some crosscutting concepts that scientists and engineers find useful not just in physical science and earth and space science, but in other science disciplines as well. Add to progress trackers Have students fill out one page of the progress tracker now. Give 6 minutes for this. See Progress Tracker Examples for a sample entry" (Teacher Edition, page 87).
- Lesson 6: "Update progress tracker. Display Slide T. Say, Now that we have developed our convection model including what is happening from a matter, energy and force perspective, add an entry to your progress tracker that helps answer this lesson's question: How is temperature related to the behavior of the matter in the mantle? Give students time to update their trackers. Students may write something like, 'The mantle is composed of heterogeneous samples of matter that have different energy levels. The parcels with a higher average kinetic energy will be

pushed to the top of the mantle by the more dense parcels underneath that have a lower average kinetic energy. This cycle will continue where more dense parcels of matter push up the less dense mantle parcels of matter.' Students may also reference any of the three lenses used throughout this lesson to help them figure out these ideas, since all three checkboxes on the progress tracker were utilized in at least one point in this lesson" (Teacher Edition, page 171).

- Lesson 9: "Add to progress trackers. Project slide V. Give students a couple of minutes to add their new ideas to their progress trackers. Make sure they can see the poster the class developed together earlier. Students may add ideas related to the creation of new crust over geologic timescales containing basalt at the ridges, which is made of material that is more dense than the commonly found granite on continental crust. Students also may cite change over time as a crosscutting concept that helped them, since students considered small changes over large periods of time to create the new crust at the plate boundaries that are spreading apart, as with the Afar region or the Mid-Atlantic Ridge. Students could also cite thinking across different scales, since they zoomed out to the world view after analyzing the more local view of a particular boundary where two plates are spreading in different directions from each other" (Teacher Edition, page 222).
- Lesson 12: "Update progress tracker. Present slide CC. Ask students to turn to their Progress Tracker in their science notebooks and to record what they figured out in Lessons 11 and 12 through investigating friction and gravity. Give them the rest of class time to update the trackers" (Teacher Edition, page 293).

Suggestions for Improvement

Consider providing more explicit opportunities for peer feedback, along with structured and explicit opportunities to incorporate this feedback.

II.C. BUILDING PROGRESSIONS

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

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

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

Rating for Criterion II.C. Building Progressions	Adequate *(None, Inadequate, Adequate, Extensive)*

The reviewers found adequate evidence that the materials identify and build on students' prior learning in all three dimensions because prior student learning is identified for all three dimensions, although not at the element level, and the materials describe how the learning will be built upon, but rarely for the SEPs or CCCs.

Related evidence include:

- Unit Overview Materials: "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 are conserved in nuclear processes (Electrostatics Unit and Fuels Unit),This unit uses and builds upon Disciplinary Core Ideas (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) The 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)" (Unit Overview, page 18).
- Unit Overview Materials: "This unit uses and builds upon high school level Science and Engineering Practices (SEPs) and Crosscutting Concepts (CCCs) that students should have previously developed in OpenSciEd High School Biology and Chemistry, and will continue to build in future units. The progressions of these practices and concepts across the program are as follows…" (Teacher Edition, page 19). The materials show which SEPs and CCCs are developed in which OpenSciEd units throughout the three high school science courses. However, specific elements are not identified.
- Each lesson has a cover page summary of what happened in the previous lesson, what is happening in the current lesson, and where the next lesson is going (Teacher Edition, page 227).
- The "Where are We Going and NOT Going" Sections of most lessons describe how elements of the three dimensions will be built upon in the lessons. These primarily focus on the DCI elements but occasionally address CCC or SEP elements. For example:
    - Lesson 3: "This lesson builds a foundation for understanding balanced vs. unbalanced forces, in terms of net force and the relation of these to stability and change in motion. Although this is a middle school idea, summing forces to determine if the resulting net force is zero or not zero is limited to considering only one-dimension as it was in middle school grades. According to pilot testing, ideas about force interactions on, in, and in between plates do not tend to show up on students' initial models created in the prior lesson, so it is essential that they be redeveloped and added before moving on to high school level ideas about forces in subsequent lessons. This lesson is designed to coherently build ideas related to the following disciplinary core idea from middle school: PS2.A. Force and Motion… In order to understand the dynamic interactions of Earth systems and the resulting changes, students need an operational definition of what is changing and which types of interactions to track. Work in the prior unit had students focused on monitoring changes in energy and matter. However, although we recognize that these two factors often occur simultaneously, we lack a mechanism to explain the interactions between systems. Therefore, forces will serve as the primary interaction mechanism for the remainder of the course. This lesson reintroduces the concepts of balanced and unbalanced forces from middle school, serving as a foundation for comprehending the feedback effects caused by force interactions, energy transfer, and

changes in matter between Earth systems in this lesson and upcoming ones. The work we are doing with net force takes the idea beyond middle school level understanding which is limited to forces in one dimension. To integrate these ideas into a sensemaking framework, we introduce a key anchor chart, the Matter, Energy, and Forces poster (M-E-F poster). This poster will become a public record of important ideas and questions students can ask to explore the dynamic interactions between matter, energy, and forces over the course of this unit and subsequent units. Major additions to this poster will be made in the next two lessons" (Teacher Edition, page 59).

- Lesson 4: "This lesson is designed to coherently build ideas related to the following disciplinary core ideas: ESS2.B.2… Students are recalling from prior experience in their High School OpenSciEd chemistry course, rather than inventing the following ideas in this lesson. These ideas will be briefly discussed in this lesson and were developed in these prior units: From OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit): Charged particles (electrons and protons) and their interactions. Any qualitative (or quantitative) reference to force vs. distance relationships from Coulomb's law. Electric fields as a part of system From OpenSciEd Unit C.3: How could we find and use the resources we need to live beyond Earth? (Space Survival Unit): Bonds are stable states where the attractive forces on two atoms from each other and their shared electrons are balanced. Students evaluate different models through self-selected crosscutting concept lenses on day 1 of this lesson. Two of these lenses were established in lesson 2 (stability and change and scale). A third lens was started in lesson 2 and expanded in lesson 3 (cause and effect in M-E-F relationships" (Teacher Edition, page 112).
- Lesson 5*: "*For the wave properties DCI above, ideas struck out about the type of wave will be developed in OpenSciEd Unit P.5: How do we use radiation in our lives and is it safe for humans? (Microwave Unit). For the Earth Materials and Systems DCI above, ideas struck out about changes to Earth's surface will be covered later in this unit as students begin to look for clues as to what happened to Afar in the past, and what will happen to Afar in the future. This lesson is addressing ideas that are fundamental to the performance expectation 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 These ideas are not necessarily well articulated in DCIs. Some of these ideas include mantle heterogeneity at multiple scales, and the connection between surface features and activity in the Earth's interior. In Lesson 6, students will make the connection between heterogeneity and convection, building toward the following DCI: ESS.3: Plate Tectonics and Large-Scale System Interactions" (Teacher Edition, page 135).
- Lesson 11: "For the Earth materials and systems DCI above, we investigate friction to discuss how mantle motion could affect plate motion as well as how gravity acts on objects on an incline to discuss slab pull. Students have previously discussed the movement of denser materials towards the interior in Lesson 6 and will also explore how gravity acts on plates at different boundaries to explain why some are moving more than others in the next lesson. Students will explore how gravitational forces are related to plate motion in the next lesson. In this lesson, students will establish that forces are balanced on objects moving at a constant velocity and how this can be used to measure the force of friction on an object. This concept and technique will be built on in OpenSciEd Unit P.3: What can we do to make driving safer for everyone? (Vehicle Collisions Unit)) when learning about vehicle breaking times. This lesson is designed to

support students toward the Next Generation Science Standards (NGSS) Nature of Science Understanding titled Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena (Appendix H). The relevant understanding element reads: Scientists often use hypotheses to develop and test theories and explanations" (Teacher Edition, page 262).

Suggestions for Improvement

In the "where we are going" section of each lesson, consider including the same level of detail about how DCI knowledge will be built upon in the lesson for SEPs and CCCs.

II.D. SCIENTIFIC ACCURACY

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

Rating for Criterion II.D. Scientific Accuracy	Extensive *(None, Inadequate, Adequate, Extensive)*

The reviewers found extensive evidence that the materials use scientifically accurate and grade-appropriate scientific information. There are call outs to the teacher when there might be scientifically misleading information to the students. Additionally, the unit materials attend to the nature of science ideas.

Related evidence include:

- Lesson 2: "The Caribbean Plate is actually missing GPS motion data. The claim that there seems to be no measurable motion of this plate is based on the limited data available to students at this time, as provided by this map. Missing motion data is the case with the smaller plates on this map as well. All of these plates do have GPS motion data associated with them, that is more apparent when viewed at a different scale. They were not visible however for the scale chosen for the rendering of the entire world map. Leaving out the rendering of some parts of the vector data set for smaller parts of a system, is a common visualization choice that is built into computer programs that allow the user to zoom in or out of the parts of the system, to adjust the scale it is being viewed at. One reason this visualization choice is made so that the vectors that overlap other parts are not mistakenly attributed to the wrong part of the system. That same visualization choice was made for this map and is a useful artifact to keep included for student sense making in the next part of the lesson. In reality, the Caribbean Plate is moving eastward at a rate of 2.2 cm/year relative to the South American plate" (Teacher Edition, page 63).
- Lesson 4: "Scientists sometimes refer to the energy stored in systems like this as potential energy. But referring to it as potential energy can be problematic because it makes it hard to track or describe what part of the system the energy is actually stored in. Potential energy alone, as a phrase, also does not provide us any explanatory power, because it is often isolated

from thinking about unbalanced forces which we have uncovered is the mechanism behind all energy transfer" (Teacher Edition, page 125).

- Lesson 5: "This lesson is designed to support students toward the Next Generation Science Standards (NGSS) Nature of Science Understanding titled Scientific Knowledge is Based on Empirical Evidence. (Appendix H). The relevant understanding element reads: Science includes the process of coordinating patterns of evidence with current theory" (Teacher Edition, page 135).
- Lesson 5: "SUPPORTING STUDENTS IN THREE-DIMENSIONAL LEARNING This is an opportunity to make it explicit to students that the process we are practicing by coordinating patterns in the evidence with a current model is one that scientists often use to build theory. This lesson will support students toward the Next Generation Science Standards (NGSS) Nature of Science Understanding titled 'Scientific Knowledge is Based on Empirical Evidence'" (Appendix H). The relevant understanding element reads: "Science includes the process of coordinating patterns of evidence with current theory" (Teacher Edition, page 142).
- Lesson 6: There is teacher guidance to make sure students do not confuse the pellets in the model for particles. "If students pose the idea of the pellets representing the mantle at the particle level, be sure to discuss how the pellets behave in the liquid and how this is different from particle behavior. For example, the pellets:[sic] are not vibrating around and bouncing off each other stay consistently spaced in the liquid and will not visually show density. It might also be helpful for students to propose that the pellets represent smaller parcels of matter in the mantle" (Teacher Edition, page 161).
- Lesson 9: "Research suggests that many students develop persistent, contextualized mental models for tectonic plates that are not aligned with current scientific understanding. They often believe that the plates are located somewhere underground, rather than being inclusive of Earth's surface. Additionally, students may visualize plates as moving chunks that have large spaces in between, like rafts or subterranean bumper cars. Language that describes plates as 'moving toward each other' or 'moving away from each other' can reinforce this model. A more accurate mental model is that of a cracked shell. The plates are essentially continuous, like an eggshell before it breaks, but there are zones (plate boundaries) where new crust is being created or destroyed. These constructive and destructive processes define divergent and convergent boundaries, respectively. We will not define divergence or convergence in this lesson, but it is important to discuss plates and plate boundaries in a way that helps students build accurate mental models. For example, you can describe the rocks in the ocean floor as 'spreading in opposite directions' rather than 'moving away from each other'" (Teacher Edition, page 214).
- Lesson 11: "Develop hypotheses in small groups. Present slide Q. Say, With your group, think for a moment about the dependent and independent variables that you will want to investigate. Whenever we design an investigation, it is helpful to develop a hypothesis about how these variables will affect the friction force between surfaces. A hypothesis is often used to make predictions about the relationship between variables that can be tested by finding evidence that either supports or refutes it. Let's see if we can format our thinking as a hypothesis before we jump into the investigation. Have them work with their group to create a hypothesis for the variable they will investigate and record it in their notebooks, using the sentence stem on the slide: If _______________ , then when we ____________ we[sic] will observe _____________________________ because _________________________________ . The goal of the sentence stem is to support students in not only thinking about how changing one variable will affect the other, but to also think about the cause or explanation of that relationship. An example student hypothesis using the sentence stem on the slide is: If mass

positively affects the force of friction, then when we increase the mass we will observe the friction force increasing because the object is heavier" (Teacher Edition, page 270).

- Lesson 12: "A major concept that is being further developed across this unit is that of balanced and unbalanced forces. In this lesson, the concept of balanced forces being equal strengths and opposite directions is important. However, it is important to note that these are NOT Newton's Third Law force pairs as they are acting on the same object. If students use language such as 'action/reaction' or bring up Newton's Third Law, emphasize that those are concepts related to interaction forces between two objects as opposed to multiple forces on the same object balancing with each other" (Teacher Edition, page 285).
- Lesson 13: In the final assessment the transfer task is titled "Midcontinent Ridge transfer Task." This phenomenon is called the Midcontinent Rift and is referred to as that title throughout the rest of the task.

Suggestions for Improvement

None

II.E. DIFFERENTIATED INSTRUCTION

Provides guidance for teachers to support differentiated instruction by including:

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

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

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

Rating for Criterion II.E. Differentiated Instruction	Extensive *(None, Inadequate, Adequate, Extensive)*

The reviewers found extensive evidence that the materials provide guidance for teachers to support differentiated instruction because the unit materials support teachers in anticipating the specific needs of students and how to address them. Strategies for reaching a wide variety of learners, including those who have already met the PEs are provided throughout the teacher materials. There are some suggestions for how to adjust materials for students who haven't achieved prior content mastery or are struggling to meet expected content mastery as the unit progresses.

Differentiated strategies address the needs of a variety of student learners, such as multilingual learners and students with disabilities. For example:

- Lesson 1: "ATTENDING TO EQUITY Universal Design for Learning: Not all students will perceive the text in the same way. Consider offering alternatives for information conveyed by text by providing an auditory option. This can be done by using text-to-speech capabilities of different electronic platforms with the google doc or PDF versions of the text, allowing for a partner or 'intervener' to read the text out loud, or by creating a narrated video of each case where images are included, among other potential alternatives" (Teacher Edition, page 37).
- Lesson 1: "ADDITIONAL GUIDANCE A rich, well utilized visual and textual environment can be helpful for emerging multilingual learners to access content. If there is wall space available, consider creating a chart detailing the similarities and differences listed above that can be utilized when students create their initial models, consensus model, and in later lessons for navigation to determine what makes the Afar earthquake different from the other case sites that still needs explanation. Document the similarities and differences on a piece of chart paper, with one side labeled 'similarities' and the other side 'differences.' If the class chart is not created, ask students to refer back to their handouts as needed" (Teacher Edition, page 41).
- Lesson 2: "ATTENDING TO EQUITY Universal Design for Learning: This might be a good place to reference prior use and representations of this word. This can help students build an idea of what magnitude means from past experiences to better understand what it means in this context. For example: We did not realize the magnitude of the problem. The amount of damage from an earthquake is often related to its magnitude The later bullet is how students came to understand its use in the OpenSciEd Middle School Unit 6.4: Plate Tectonics and Rock Cycling (Everest Unit). It is not important at this time to distinguish that measure of earthquake magnitude is a measure of energy transfer to the surroundings from the source" (Teacher Edition, page 70).
- Lesson 4: "ATTENDING TO EQUITY Universal Design for Learning: Provide multiple means of representing these findings. In Investigation 1, students can record both qualitative and quantitative data. They can also use tables or graphs. If they record only quantitative data, encourage them to write a conclusion summarizing their findings. If they include only qualitative data, encourage them to support their ideas with a couple of data points. For Investigations 2-4, which are brief, encourage students to record several observations at the very least. Adjust the simulation speed using the setting located at the top. Some students with disabilities might benefit from using a lower speed to more easily track changes in the system" (Teacher Edition, page 120).
- Lesson 4: "ADDITIONAL GUIDANCE Supporting Emergent Multilingual Learners If students use words like stress or strain and to refer to what was happening in the simulation outcomes, it may be helpful to reinforce that these are also ways that scientists sometimes describe matter changes. Help all students use a common understanding, and increased relevance, for the use for these words at this point, by both mapping the use of those words to a) everyday language use and to b) the M-E-F model. Start with asking students for examples of where they have seen someone use a strainer in food preparation to help separate something. Reference the matter change corner of the M-E-F model and say the scientific measure of strain has a similar meaning in that it is a measure of how much the matter separates - specifically it is the ratio of amount of deformation to the original length of the sample. Then ask for an example of how a person that is feeling pressure or stress is used in everyday language. Ask for examples of external things that can produce that internal feeling. Reference the matter force corner of the M-E-F model and say the scientific measure of pressure or stress is similar in that it is measure of the internal forces within an[sic] section of the solid which are often in response to external forces - and specifically it is a ratio measure as well - either the ratio of force to area (of matter), or force per

particle. Keep in mind that these words are not needed in future lessons, so do not need to be a part of students' Personal Glossary" (Teacher Edition, page 124).

- Lesson 5: "ATTENDING TO EQUITY Universal Design for Learning: Watch for students to move their hands back and forth, even if they are not articulating back and forth motion using words, and then highlight this by saying, 'It looks like you are moving your hands back and forth like this.' Allowing students to express their ideas using multiple modalities such as gesture supports student ownership of their learning by giving students choice, access, and control in navigating their own understanding around the science ideas. It can also support students who are emergent multilingual learners" (Teacher Edition, page 138).
- Lesson 6: "ATTENDING TO EQUITY Universal Design for Learning: As a second option, consider separating out the video into the series of timestamps below to help students perceive the movement of the mantle tank. Students who could benefit from seeing the video on their devices up close could start and stop each video along with the class, giving them increasing access to this task. ATTENDING TO EQUITY Universal Design for Learning: When asking students to describe how the matter is moving in the mantle, encourage them to use their hands and arms to represent this motion. These visual, non-linguistic supports can increase the ability of students to understand the concepts, especially for students who are new learners of the dominant language of the classroom" (Teacher Edition, page 162).
- Lesson 7: "ATTENDING TO EQUITY Differentiation Opportunity/Support for Emergent Multilingual Learners: Although all are leveled between 8th and 9th grade, Matter is the longest at over 1000 words, and Forces is the shortest, at under 800 words. You can use this to organize students who may need additional support for literacy in the Forces group, where they will have less text to read. We do NOT recommend homogenous groupings, but rather creating mixed-ability groupings, with a higher proportion of students who need more support in the Forces group" (Teacher Edition, page 178).
- Lesson 9: "ATTENDING TO EQUITY Universal Design for Learning: Some students may not be able to see the thin color strips of the oceanic crust as they are added to the paper. Create a larger representation by adapting this model for students to use two desks pushed together in place of books and large chart paper in place of the loose-leaf paper. Have students grab the chart paper with both hands and slowly pull outward. As this occurs, pause every 8"-12" and create bold and contrasting stripes using a colorblind friendly palette. You could also have premade 8"-12" strips of different color chart paper to quickly tape to the chart paper emerging from between the desks instead of coloring on the chart paper" (Teacher Edition, page 213).
- Lesson 10: "ATTENDING TO EQUITY Supporting emergent multilinguals: The names 'convergent' and 'divergent' clearly describe relative motion at a boundary. Students may or may not be familiar with these terms in general. It is worth taking a few moments to establish a common understanding of what 'converge' and 'diverge' mean independent of tectonic plates. You can use hand gestures to represent these motions. You can also make connections to other, more familiar words. For example, 'divide' is like 'diverge' and illustrates something being broken apart or split into smaller pieces. Transform plate boundaries are so named because they connect to other plate boundaries. The word 'transform' does not describe a direction of motion, but refers to the transformation (change) of relative plate motion or the site of plate motion. Students do not need to know this etymology, but it may help them understand the overall convention of naming boundaries based on patterns of movement. Divergent and convergent plate boundaries are the focus of this lesson. They relate to the motion and properties of mantle material more directly than transform boundaries do" (Teacher Edition, page 232).

- Lesson 11: "ATTENDING TO EQUITY Students with physical disabilities may have a hard time pulling the books at a constant velocity. For these students, consider supplying them with the low speed car and the box from the demo. If the student is investigating mass, give them things to place inside the box. If they are investigating surface area, suggest that they rotate the box to a smaller side. This method of measuring friction with the car will be used again in the Vehicle Collisions Unit" (Teacher Edition, page 272).
- Lesson 12: "ATTENDING TO EQUITY Universal Design for Learning: The representation used by students in free body diagrams do not need to match any specific convention. What is important is to have a shared understanding of what each piece means. Allow students agency over these representation [sic] and do not try to force them into any specific convention without an expressed need that the students understand" (Teacher Edition, page 283).
- Lesson 12: "ATTENDING TO EQUITY Students with physical disabilities may have a hard time holding the platform at a steady, specific angle while also reading the scales. For students who struggle with this task, provide additional books or blocks for them to set the platform at an angle. They may need an extra book to keep the platform from sliding as well" (Teacher Edition, page 289).

The materials include some specific support suggestions for students who struggle to meet the targeted standards or have not mastered assumed prerequisite knowledge and skills. For example:

- Lesson 1: "ATTENDING TO EQUITY Emerging Multilingual Learners: If some of your students have not had the chance to learn about components, mechanisms, and interactions, take a moment to introduce these terms now. Until students are comfortable with these terms, consider moving interchangeably between student-friendly language (such as parts to describe components) to allow students to develop meaning of these new terms" (Teacher Edition, page 44).
- Lesson 5: "What to do: If students have successfully recognized the anomaly, but are struggling to interpret it, give them more time to read. Have students specifically look for information that could explain why P-waves might travel more slowly, and/or S-waves might not travel at all. Have students record these questions at the top of their handout to refer back to. Then come back together and try again" (Teacher Edition, page 141).
- Lesson 6: "ADDITIONAL GUIDANCE Students may need a refresher on what temperature measures from middle school. If students do not remember that temperature is the average kinetic energy of a sample, consider pulling up a simulation that allows you to change the temperature of a sample from a particle view. Many such simulations exist, such as http://bit.ly/heating-and-cooling utilized in the Middle School OpenSciEd unit OpenSciEd Unit 6.2: How can containers keep stuff from warming up or cooling down? (Cup Design Unit). Oscillate between different temperatures and ask students to make observations about the behavior of the particles in the sample. This simulation could also be used to consider the differences in density of the mantle parcels as well" (Teacher Edition, page 158).
- Lesson 6: "What to do: If students struggle with explaining the parts of the mantle tank that changed, encourage them to look back at the observations they recorded from the video investigation. Some students who choose the matter perspective might focus on describing the observed motion in the matter. Encourage them to use particle level interactions in their models. Use the M-E-F poster to support students in using one of the perspectives to explain the movement of matter in the mantle tank. Point students to the questions about matter, energy or forces we should be asking ourselves when we try to explain a phenomenon from these perspectives. Consider asking students more focused questions such as the following to help

them consider how matter, energy, or forces can be used to explain the movement of the items in the tank, and the corresponding blob movement in the mantle" (Teacher Edition, page 164)

- Lesson 8: "An alternative approach to modifying instruction in support of students engaging in math and computational thinking is to ask them to describe in words the mathematical relationship they are attempting to represent. This parallels similar cognitive processes while making their thinking visible. This will allow you to identify areas where students might be struggling and provide targeted support and guidance" (Teacher Edition, page 196).
- Lesson 10: There is an alternate activity present for those students who might benefit from a more tactile understanding of plate movement. "Since this is a 3D representation of a planet with multiple interactions happening all at once, some students might struggle with connecting the changes happening on different parts of the planet. If you notice expressions of confusion, you can help them using their hands to make sense of the motion of the plates and the forces acting on them…" (Teacher Edition, page 236).
- Lesson 11: "If students are struggling with distinguishing between the independent and dependent variables, remind students that the independent variable is the one they are actually modifying/changing directly, while the dependent variable is the one they will measure because they think it will be affected by the independent variable. Also, discuss with them what they will control, and why it is important to control those variables" (Teacher Edition, page 270).

The unit materials provide suggestions for extension opportunities for students with particular interest in the unit topics or who have already mastered the targeted standards. For example:

- Lesson 2: "Extension Opportunity: For students who are interested in these mathematical extensions or are exploring vectors in their current math class, you can show (or ask them to show) how one can do the following: CCSS.MATH.CONTENT.HS.N-V.2 Represent and model with vector quantities. Finding the components of a vector by subtracting the coordinates of an initial point from the coordinates of a terminal point. CCSS.MATH.CONTENT.HS.N-V.4a. Perform operations on vectors. Add vectors end-to-end, component-wise, and by the parallelogram rule" (Teacher Edition, page 79).
- Lesson 3: "Extension Opportunity: This is designed to serve as an optional extension opportunity for planning and carrying out an investigation and developing a mathematical relationship from the data collected. Have students look back at their response to question 2 on Forces Acting on Rocks. Ask students to take a moment to consider if any of them would have an interest in designing and carrying out an investigation to support or refute their claim. Have students who are interested in that extension opportunity circle question 2 now before handing in Forces Acting on Rocks. Such an opportunity was developed as a differentiation option for students who either have demonstrated prior fluency or high interest in the related science and engineering practices it would require, particularly related to developing mathematical models from experimental data. While such work was a focus of the first unit of the prior chemistry course OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit), it has not yet been a focus of the prior unit of this course (material.pe). Such mathematical modeling approaches will be introduced for the first time in this course in lesson 8, and will become a larger focus of students' work in the next two units: [material:pm] and [material.pg]" (Teacher Edition, page 106).
- Lesson 4: "ALTERNATE ACTIVITY Extension Opportunity 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. No attempt is made to explain the underlying code of the simulation, which emulates the effect of electric forces between particles using an equation that calculates the combined effect of repulsive

forces (e.g.[sic] positive nuclei) and attractive force (between nuclei and shared electrons). The code uses a twelfth order potential energy equation known as the Lennard-Jones potential (LJP) to derive the net force vs. distance relationships. Understanding that relationship is not a target disciplinary core idea for high school" (Teacher Edition, page 119).

- Lesson 4: "Extension opportunity: Introduce Home Learning. Present slide DD if you want to provide additional practice to students to engage with Developing and using models, suggest they identify the advantages and limitations of the simulation by filling the last row of Evaluating Models" (Teacher Edition, page 129).
- Lesson 8: "ALTERNATE ACTIVITY Differentiation Opportunity: For students who are interested, you can encourage them to bring in a sample of rocks they may have collected that have such crystals in them or you can encourage students to take photos of any rocks they find around where they live or around the school that show evidence of this" (Teacher Edition, page 195).
- Lesson 8: "Extension Opportunity: This is suggested as an optional extension opportunity for students who have either demonstrated prior fluency or a high interest in the science practice of planning and conducting investigations. Such an opportunity can function as a differentiation opportunity. Instead of providing students with the spreadsheet, encourage them to develop their own spreadsheet. This approach will prompt students to consider how they will record, analyze, and evaluate their data" (Teacher Edition, page 197).
- Lesson 9: "Students might also suggest rigidity, or temperature, or composition. If students suggest temperature, this would also be an easy thing to measure in the classroom. Tell students rigidity and composition require equipment that we don't have, but encourage them to look it up later and report back" (Teacher Edition, page 221).
- Lesson 9: "Extension Opportunity: The standards do not require students to investigate the composition of various types of rock, and how that affects their density. For students who are eager to learn more, consider offering those students the optional extension reading: Composition of Continental and Oceanic Rocks. You may also choose to ask these students to research the composition of other types of rocks in Earth's crust, and come prepared to share some of this information with their peers" (Teacher Edition, page 221).

Suggestions for Improvement

Consider including additional suggestions for how to respond to students coming in below proficiency to meet targeted elements of the NGSS.

II.F. TEACHER SUPPORT FOR UNIT COHERENCE

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

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

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

Rating for Criterion II.F. Teacher Support for Unit Coherence	Extensive *(None, Inadequate, Adequate, Extensive)*

The reviewers found extensive evidence that the materials support teachers in facilitating coherent student learning experiences over time because guidance and tools are provided for teachers throughout the lessons to ensure student learning is coherently linked across the unit and student sense-making is linked to their three-dimensional learning.

Several tools and strategies are provided in the unit to support teachers in linking student engagement across lessons.

- The class initial consensus model helps students keep track of what the class has learned in relationship to the anchoring phenomenon. The initial consensus model is developed in Lesson 1 (Teacher Edition, pages 46–48), and referenced, added to, revised, or new models developed in Lesson 5 (Teacher Edition, page 136), Lesson 6 (Teacher Edition, pages 159, 165–170, 180–181), Lesson 9 (Teacher Edition, pages 218 and 225), Lesson 10 (Teacher Edition, pages 242–255), Lesson 11 (Teacher Edition, pages 263 and 273), Lesson 12 (Teacher Edition, pages 293 and 299).
- The DQB is set up in Lesson 1 (Teacher Edition, page 48), and revisited in Lesson 2 (Teacher Edition, page 68), Lesson 3 (Teacher Edition, page 105), Lesson 5 (Teacher Edition, page 150), Lesson 6 (Teacher Edition, page 170), Lesson 8 (Teacher Edition, page 193), Lesson 9 (Teacher Edition, page 224), and Lesson 13 (Teacher Edition, pages 300–301).

Student sense-making of phenomena is clearly linked with their learning in the three dimensions.

- The scale chart helps students compare the temporal and spatial scales of various phenomena they interact with throughout the unit. The chart is set up in Lesson 1 (Teacher Edition, pages 46–47), and referenced, added to, or revised in Lesson 2 (Teacher Edition, pages 64–65), Lesson 4 (Teacher Edition, pages 114–115, 118, 121, 126–128), Lesson 5 (Teacher Edition, page 150), Lesson 7 (Teacher Edition, page 183), Lesson 8 (Teacher Edition, page 205), Lesson 9 (Teacher Edition, pages 222–223), and Lesson 13 (Teacher Edition, pages 299–300).
- The Matter-Energy-Forces triangle model is started in Lesson 2 (Teacher Edition, pages 69–70), and referenced, added to, or revised in Lesson 2 (Teacher Edition, pages 79–81, 84 and 86), Lesson 3 (Teacher Edition, pages 96, 98–105), Lesson 4 (Teacher Edition, pages 114–116, 118, 121–125, 127–128), Lesson 6 (Teacher Edition, pages 163–164 and 167), Lesson 7 (Teacher Edition, pages 178–179, 181 and 183), and Lesson 11 (Teacher Edition, page 267).

Suggestions for Improvement

None

II.G. SCAFFOLDED DIFFERENTIATION OVER TIME

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

Rating for Criterion II.G. Scaffolded Differentiation Over Time	Adequate *(None, Inadequate, Adequate, Extensive)*

The reviewers found adequate evidence that the materials support teachers in helping students engage in the practices as needed and gradually adjusts supports over time because there is evidence for reduced scaffolding over time for some targeted SEP elements. However, for some SEP elements, students are not provided with the opportunity to become increasingly independent and in some cases, scaffolds are introduced after students have increased independence in the practice.

Related evidence include:

Constructing Explanations and Designing Solutions

- *Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.*
    - Over the course of the unit, this element has some level of scaffolded differentiation over time. However, not all parts of this element are developed in the unit. The final transfer task aligns to some, but not all, parts of the element and some scaffolding is re-introduced.
    - Lesson 7: Students construct explanations based on their readings in the "cause and effect model" worksheet. Not all aspects of this element are developed, see criterion I.B. The only source students refer to is the reading and the last part of the element, "*the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future,*" is not addressed.
    - Lesson 10: Students write out an explanation on how the surface of East Africa will look like in the future. This leads to further independence in this element as students move from a graphic organizer used in Lesson 7 to a box for explanations in this lesson. In addition, students also engage in the process of revising their explanations in this lesson.
    - Lesson 13: Students reflect on their DQBs on what they have explanations for by revising their previous explanations. In this lesson, there are fewer scaffolds as students are required to use all of their knowledge from the previous lessons in order to complete the task. However, the laws and theories are not explicitly developed.
    - Lesson 13: In the final Midcontinent Rift assessment students answer questions about a new phenomenon in a transfer task. They are asked to pull from specific things they learned throughout the unit. The transfer does not have increased independence as students do not revise their explanations and their explanations are not based on a variety of sources. This task better aligns with the middle school element: *Apply scientific ideas, principles, and/or evidence to construct, revise and/or use an explanation for real-world phenomena, examples, or events.*
- *Make a quantitative and/or qualitative claim regarding the relationship between dependent and independent variables.*
    - This element is only used once in the unit, and therefore differentiated scaffolding is not present over time.

Developing and Using Models:

- *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.*
  Over the course of the unit, this element has appropriate scaffolds removed over time. Progress towards proficiency of this element is described below.
  - Lesson 1: Students develop an initial model using a handout with provided variables to predict how changes can occur in Afar.
  - Lesson 4: Students use a computational model to predict how different variables can affect relationships between forces, matter and energy. A consensus model is created through class discussions. There are less scaffolds as students now choose which variables to investigate and make conclusions on how these variables affect the system.
  - Lesson 6: Students develop and revise their models. They start off with predictive models on the role of temperature and matter and are asked to explain why matter is moving in a certain way within the model tank system. They then explore a pellet model to explore the matter, energy, and force components in the system. Finally, students compare this to the Afar model and revise their initial Afar model to determine if their explanations on how the mantle is moving under Afar still holds. In this lesson, students are now using multiple models and making revisions independently, thereby increasing their proficiency in developing this element.
  - Lesson 11: Students continue to develop and revise models in this lesson, this time exploring the effect of force on plates to cause motion. Students engage in an investigation, then use their results in order to determine the relationships within this system. In groups, students then convert their predictive models to explanatory models. Students are increasing their proficiency in this element because they are now generating their own investigations to collect evidence in order to determine relationships within a system. However, since students worked independently in Lesson 6, having students work in groups in Lesson 11 is not supporting continued student independence in this element.
  - Lesson 12: Students carry out another investigation to collect data in order to predict how gravity can affect plate motion. Students develop their own models independently to showcase their findings. After a class discussion, students independently connect this understanding to explain how plate motion in Afar might occur.

- *Develop and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems.*
  - There's some evidence of scaffolding for this element in the unit. However, because students develop this element in Lesson 2 and then don't return to it until Lesson 10, students may not have sufficient opportunity to effectively develop this element.
  - Lesson 2: Students use a mathematical model to generate data to determine the relationships of magnitude in a right triangle. Students do not engage with the second part of this element "*support explanations, predict phenomena, analyze systems, and/or solve problems.*"
  - Lesson 10: All aspects of this element are used. Students develop a model and utilize data from investigations to support predictions.

- *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.*
    - This element is only used partially once in the unit, and therefore scaffolding is not present over time.
    - Lesson 4: Students evaluate the merits and limitations of two different models but they do not select or revise a model that best fits the evidence or design criteria.

Suggestions for Improvement

- Consider further developing target SEPs so that students have opportunities to gain proficiencies in the focal elements over time.
- Consider adding appropriate scaffolding to the performance of key SEP elements early on in the unit, so that they can be gradually removed over time for target SEP elements.

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

CATEGORY III

MONITORING NGSS STUDENT PROGRESS

III.A. MONITORING 3D STUDENT PERFORMANCES

III.B. FORMATIVE

III.C. SCORING GUIDANCE

III.D. UNBIASED TASK/ITEMS

III.E. COHERENT ASSESSMENT SYSTEM

III.F. OPPORTUNITY TO LEARN

III.A. MONITORING 3D STUDENT PERFORMANCES

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

Rating for Criterion III.A. Monitoring 3D Student Performances	Extensive *(None, Inadequate, Adequate, Extensive)*

The reviewers found extensive evidence that the materials elicit direct, observable evidence of students using practices with DCIs and CCCs to make sense of phenomena and/or design solutions because students routinely produce artifacts with evidence of using targeted elements of all three dimensions. Most student tasks are three-dimensional and require high school elements. Tasks connect with the primary phenomenon of the Afar region or center around making sense of related geological phenomena.

Most student tasks require students to use the three dimensions together to make sense of phenomena. For example:

- Lesson 1: Students develop initial models to predict how Afar changed before, during, and after a central event. In the handout "Initial Afar Models'' students use the following elements of the three dimensions:
  - SEP: *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.*
  - DCI: *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.*
  - CCC: *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.*
- Lesson 2: Students carry out an investigation to determine how forces affect stability and motion using a piece of foam and spring scales. Students use the following elements of the three dimensions:
  - SEP: *Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly.*
  - DCI: *Earth's systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes.*
  - CCC: *When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models.*
- Lesson 3: Students explore what happens to matter and energy when balanced forces increase by a reading passage with follow up questions. "Question 1) If an engineer tested similar sized samples of two different materials from the data table shown here, which one of those

materials would require application of higher magnitude forces on it, to produce the same amount of elastic deformation as the other material? Write an evidence-based claim that answers this question. Make sure your claim references the variables in question and two materials in the data table: Question 2) How would doubling the external force applied to elastically deform a solid, affect the amount of energy that could be transferred back out of it when the force is removed? Write an evidence-based claim to answer this question. Make sure your claim references the variables in question and two materials in the data table. Use the ideas in the M-E-F poster your class developed, to support your claim" (P.2 Lesson 3 Handout Forces Acting on, pages 1–2). Students use the following elements of the three dimensions:
  - SEP: *Make a quantitative and/or qualitative claim regarding the relationship between dependent and independent variables.*
  - DCI: *Earth's systems, being dynamic and interacting, cause feedback effects that can*
  - *increase or decrease the original changes.*
  - CCC: *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.*
- Lesson 5: Students update their model of the Earth's interior after reading about the mantle. "Give students about five minutes on their own to revise their models following the directions on the slide: Add labels, symbols, drawings, and/or annotations to your model of Earth's interior to reflect our new understandings about the mantle and its matter" (Teacher Edition, page 149). Students use the following elements of the three dimensions:
  - SEP: *Evaluate the impact of new data on a working explanation and/or model of a proposed process or system.*
  - DCI: *Evidence from deep probes and seismic waves, reconstructions of historical changes in Earth's surface and 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.*
  - CCC: *Classifications or explanations used at one scale may fail or need revision when information from smaller or larger scales is introduced; thus requiring improved investigations and experiments.*
- Lesson 6: "Use your knowledge about the particle nature of matter at different temperatures to create a model for why the parcels in the mantle move on the tomography data below. Use a combination of words and drawings to explain the mechanisms behind the movement in the mantle" (Afar Mantle Model). Students use the following elements of the three dimensions in this task:
  - SEP: *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.*
  - DCI: *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).*
  - CCC: *Energy drives the cycling of matter within and between systems.*
- Lesson 8: "What do the patterns across your graphs tell us about the rate of decay of the different radioactive element(s) you tested? How do these patterns compare to your predictions?" (Analyzing Decay Trends Handout). Students use the following elements of the three dimensions in this task:

  - SEP: *Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution.*
  - DCI: *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.*
  - CCC: *Empirical evidence is needed to identify patterns.*
- Lesson 12: "Section 4: Connecting Gravity and Plate Motion What do our lab results tell us about the more complex plate systems? Use free body diagrams, words, and/or drawings to connect our lab findings with the stability and change of plate motion over long time[sic] scales" (P.2 Lesson 12 Handout Measuring Forces on, page 3). Students use the following elements of the three dimensions in this task:
  - SEP: *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.*
  - CCC: *Some systems can only be studied indirectly as they are too small, too large, too fast, or too slow to observe directly.*
  - DCI: *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.*

Formal tasks center around making sense of related geological phenomena. For example:

- Lesson 4: "Anak Krakatau is a volcano off the coast of Indonesia. It lies near the boundary between the Indo-Australian Plate, and the Eurasian Plate. Interactions between these two plates transfer energy into the rock near the boundary. This causes pockets of rock to melt and become magma. Gases in the hot magma put pressure on the solid rock above as a result of particle collisions. The upward force from this pressure can cause the crust to deform over time, and eventually break, allowing magma to reach the surface" (Lesson 4, Exit Ticket).
- Lesson 7: "The planet Jupiter has many moons. One of the most interesting to planetary scientists is Europa. Europa is covered in a crust made of water ice, floating over a layer of liquid water that scientists say may be hundreds of miles thick. Where there is water, there is the possibility of life. Could there be creatures lurking at the bottom of Europa's ocean? Underwater volcanoes could power hydrothermal systems like those that fuel life at the bottom of Earth's oceans. On Earth, when seawater comes into contact with hot magma, the interaction results in chemical energy. And it is chemical energy from these hydrothermal systems, rather than sunlight, that helps support life deep in our own oceans. 'The prospect for a hot, rocky interior, and volcanoes on Europa's seafloor, increases the chance that Europa's ocean could be a habitable environment,' said Robert Pappalardo, a scientist with NASA's upcoming Europa Clipper Mission. To figure out if there could be life on Europa, we need to know more about if there is volcanic activity on its seabed" (Lesson 7, Exit Ticket).
- Lesson 13: Assessment: "Over millions and billions of years, tectonic plates can move apart, stretching the matter in the Earth's crust between them. This causes deep cracks in the Earth's crust where mantle material is able to rise to the surface. Where the land has been stretched, new oceans may form, breaking land that was once continuous into new, separate continents. This process is known as rifting. Many scientists predict that rifting in the Afar region, evidenced by frequent volcanic and seismic activity, could someday result in a new ocean that will split the continent of Africa in two. But rifting can slow down over time, and even stop altogether, as evidence from a history buried deep beneath the United States shows. The Midcontinent Rift. We don't usually think of the American Midwest as a place where there is a lot of volcanic or

seismic activity. But over 1.1 billion years ago, evidence points to an active rift valley that stretched from what is now Ontario, Canada, perhaps as far south as Oklahoma. Basalt seeped from cracks in the Earth's crust as the land stretched over time, and frequent volcanic eruptions filled lakes of lava hundreds of feet thick. The weight of this dense rock caused the rift valley to sink further, much like in the Afar region. Scientists call the 2,000 km (1,200 mi) long region of dense basalt that marks the location of this ancient valley the Midcontinent Rift."

Suggestions for Improvement

None.

III.B. FORMATIVE

Embeds formative assessment processes throughout that evaluate student learning to inform instruction.

Rating for Criterion III.B. Formative	Extensive *(None, Inadequate, Adequate, Extensive)*

The reviewers found extensive evidence that the materials embed formative assessment processes throughout that evaluate student learning and inform instruction because there are frequent three-dimensional formative assessments throughout the unit. Some formative assessments include instruction for how to respond to the class or to individual students who are not meeting expectations.

Every lesson has a three-dimensional lesson-level PE, and some have up to four formative assessments aligned with it. Related evidence includes:

- The "Lesson-by-Lesson Assessment Opportunities" table lists lesson-level performance expectations, associated assessments, and "what to look/listen for in the moment" guidance. (Teacher Edition, pages 309–319).
- There are several answer keys provided for the teacher, so that the teacher can analyze student work. Some examples are listed below:
  - Lesson 5 "evaluating models" handout has an answer key.
  - Lesson 7 "cause and effect" handout has an answer key.

Each lesson has a "what to do /what to look for" to support teachers on modifying their instruction. However, there are few opportunities for teachers to address the needs of individual students in any of the three dimensions.

- Lesson 1: "What to look/listen for in the moment: Indication of movement, force, and/or energy transfer between components of the model (e.g. arrows) (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, gradual vs sudden change, either in models or in written responses. (DCI: ESS2.B) A cause and effect relationship between something happening inside the earth and something happening at the surface. (CCC: 2.2). What to do: If students' initial models are lacking information about the earth's interior, point or refer back to surface effects (e.g. cracking, shaking, crumpling, tearing). Ask students what happened in their models to create those effects. Then ask how the earth could do something similar. Verbally prompt students to show which direction(s) model components are moving. Ask students to be specific about what timescales they are thinking about changes occurring over. When they predict the future, are they thinking ten years in the future, or more? Why? Do all of the changes happen at the same pace?" (Teacher Edition, page 42).

- Lesson 3: "What to do: If students need additional practice, give Evaluating Models back to them toward the end of the next period and ask them to use row 3 to evaluate the advantages (merits) and limitations of the simulation they used that day" (Teacher Edition, page 119). This recommendation provides a possible intervention for students who are struggling with modeling.
- Lesson 4: Electronic Exit Ticket: "What to look for/listen for in the moment: Use L4 EET Key to assess student work. What to do: This assessment is designed to make it easy to gather information about where students are still struggling to put the pieces together. It assesses one of the lesson-level performance expectations from Lesson, which brings together DCIs, CCCs, and SEPs from the previous three lessons" (Teacher Edition, page 129). "What to look for: The correct answer is: The repulsion due to electric forces (bonds) between the particles of rock will weaken when the particles are forced apart by the upward forces. What to do: Encourage students to look back in their Progress Tracker to find the particle level models they made over Lessons 2-3. If you identify a large number of students selecting other answers, consider discussing this question as a class, exploring the force interactions described in each option… What to look for: The correct answer is: The forces on each cube of matter are roughly balanced at this scale, so the system will be stable. What to do: Encourage students to estimate the net force acting on the blocks according to this model. Then encourage students to look for ideas related to stability and change in the M-E-F poster" (Answer Key L4 EET Key).
- Lesson 6: "What look/listen for in the moment: Look for all models to predict the relationship between the particle nature of the parcels of different temperatures and their movement in the mantle. (SEP: 2.3; DCI: PS3.A.4) Models should include particle level interactions at different locations in the mantle system. (DCI: PS3.A.4) Models should include changes in the matter related to the energy transferred in the mantle parcels. (CCC: 5.4) What to do: At this point in the lesson, the model does not need to be accurate. This model is meant for formative assessment purposes and can inform instruction for future steps in this lesson, including the consensus model at the beginning of Day 2. Students will also have one more chance to revisit this model at the end of Day 1. Do not press for specific right answers at this point. Instead, use the following sections as guidelines for helping students consider a new perspective or idea. If particle differences are missing or limited: If students do not show particle differences in their parcels, direct students to consider what differences exist between particles of the same matter sample in the same state at two different temperatures. Have students consider this movement and how it would affect the density of the sample. If the movement of the sample or changes in matter due to energy transfer is missing or limited: Direct students to consider how that density difference would affect it if it were two vastly different differences, such as a more or less dense pool toy in water. Ask students to consider how these differences might affect the movement of the parcels in the mantle, and how those blobs interact with blobs of different densities. Some students may include the core as an energy source. While this is an important component of the model of Earth's interior, it is not necessary to include the core at this time. By the end of the lesson, students will converge on the idea that thermal convection occurs in the mantle, but they do not have evidence of the mechanism. This will provide a segue into the next lesson" (Teacher Edition, page 159).

- Lesson 10: "What to look/listen for in the moment: 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 students to describe the motion of plates vertically and horizontally. This evidence will be central for the investigation in the next lesson. (SEP: 2.6) Row 4: Use ideas about density to explain how plate interactions at plate boundaries shape a planet's surface features. (ESS2.B.3) Row 5: Use the simulation to describe the interactions between the following components of the system's matter: moving plates, mantle material, magma, and surface features. (CCC: 4.3) What to do: Walk through the classroom as students complete their investigation, asking groups to briefly describe to you the changes they are seeing at plate boundaries. Look for students to mention the following observations of Convergent boundaries: The densest plate is moving underneath the other one. The sinking plate is melting, creating magma The upward flow of magma when the subducting zone reaches a certain depth. The formation of continental crust from magma over the less dense plate. Formation of mountains where the continental crustal matter is being crumpled Formation of volcanoes where the magma is erupting Look for students to mention the following observations of Divergent boundaries: Magma is coming from the mantle into the point of divergence Magma is turning into the oceanic crust The oceanic crust is spreading out to each side The boundary moves over time Magma reaches the crust at a higher point of elevation, over time it moves downward Formation of volcanoes where the magma is erupting" (Teacher Edition, page 239)

Some assessments in the unit promote equity by offering additional support or multiple ways that students can demonstrate what they know or are able to do, but this type of support is not frequent throughout the unit.

- Lesson 5: "What to do: •If you think your students will be intimidated by this math, consider letting them discuss and work out the math in pairs before responding. •Consider encouraging students to work through the mathematical reasoning without doing the math. •Move around the classroom and provide support for students who are having trouble organizing the resources available to them. Point to the graph on How do scientists explore Earth's interior? and ask them to choose a dot that corresponds to a P-wave moving slower than expected. Then ask them how they could figure out the speed of that P-wave from the information on the graph. They should recognize that speed in distance over time, or the x-value over the y-value" (Teacher Edition, page 142).
- Lesson 4: Particle Investigations: "Universal Design for Learning: Provide multiple means of representing these findings. In Investigation 1, students can record both qualitative and quantitative data. They can also use tables or graphs. If they record only quantitative data, encourage them to write a conclusion summarizing their findings. If they include only qualitative data, encourage them to support their ideas with a couple of data points. For Investigations 2-4, which are brief, encourage students to record several observations at the very least. Adjust the simulation speed using the setting located at the top. Some students with disabilities might benefit from using a lower speed to more easily track changes in the system" (Teacher Edition, page 120).
- Lesson 7: "Supporting emergent multilingual students: Encourage students to record their ideas using linguistic (e.g., written words) and nonlinguistic modes (e.g., drawings) in the space provided in the readings. This is especially important for emerging multilingual students because making connections between written words and nonlinguistic representations helps students generate richer explanations of scientific phenomena" (Teacher Edition, page 178).
- Lesson 7: "Cause-Effect Model A and Cause-Effect Model B are two versions of the same handout. They vary in the level of scaffolding they provide to students. Cause-Effect Model A

provides a more scaffolded version with suggestions for building the causal chain, while Cause-Effect Model B only provides sentence frames. We recommend starting with the less scaffolded version of the handout, but having the more scaffolded version on hand. If a student needs extra support, offer them the scaffolded version in the moment as needed. If you have a class with a lot of students who are multilingual, or who need additional literacy support, consider starting with the more scaffolded version for all students" (Teacher Edition, page 180).
- Lesson 8: "What to do: •Collect Predicting composition trends at the end of the period. •Reach out to math colleagues to find out how they are scaffolding graphing for their high school students. •Ask students clarifying questions if they are struggling, about why they are making specific decisions. This will help students articulate their reasoning, a metacognitive exercise that can be powerful in helping students figure out what to do in order to achieve a purpose, rather than just to follow directions. •An alternative approach to modifying instruction in support of students engaging in math and computational thinking is to ask them to describe in words the mathematical relationship they are attempting to represent. This parallels similar cognitive processes while making their thinking visible. This will allow you to identify areas where students might be struggling and provide targeted support and guidance" (Teacher Edition, page 196).

Suggestions for Improvement
- Consider including additional targeted support for individuals or small groups of students who struggle to meet targeted learning goals throughout the unit.
- While many aspects of supporting student equity in instruction are provided, more support for teachers in ensuring student equity in formative assessment could strengthen the unit.
- Consider providing more ways to differentiate for individual students based on formative data.

III.C. SCORING GUIDANCE

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

Rating for Criterion III.C. Scoring Guidance	Adequate *(None, Inadequate, Adequate, Extensive)*

The reviewers found adequate evidence that the included aligned rubrics and scoring guidelines help the teacher interpret student performance for all three dimensions because the materials provide a variety of different supports for interpreting student performance, but there are few resources to support students to interpret their own three-dimensional performance and most assessments only provide exemplary student responses rather than a range of responses at different levels.

Assessment targets are clearly stated (Teacher Edition, pages 13 and 19). All major assessment opportunities have an answer key showcasing the three-dimensional learning targets. The answer keys have a few discrepancies in the chart and color coded questions. Related evidence include:

- Lesson 4*:* Question 3 claims the **Stability and Change** CCC element: *Much of science deals with constructing explanations of how things change and how they remain stable* (Teacher Edition, page 355). Question 2 assesses this CCC but it is not included in the chart. The reviewers believe this was a typographical error and question 2 rather than question 3 should have an "x" next to this CCC. Similarly, Question 2 claims the DCI as: **PS2.B.3** *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*. This DCI is not covered in the question as it asks: Using this model Question 2, which of the following do you predict about stability and change in the system at this scale. (SEP: **2.3**; CCC: **7.1**). The reviewers believe that this was a typographical error and only question 1 should have an "x" next to this DCI.
- Lesson 7*:* Question 4 has color coded answers which covers both a DCI and CCC. However, there is no "x" placed for any dimension in the answer key chart. Similarly, Question #3 has a CCC claimed in the chart, when in fact it is not utilized. The reviewers believe this is a typographical error and that question 4 should be checked off.

The materials provide guidance to teachers in a variety of formats including, "what to do" descriptions for embedded formative assessments, answer keys for key learning activities and major assessments that include rubrics, exemplar responses, a range of possible student responses at different proficiency levels, and/or suggestions for providing feedback. Rubrics and scoring guidance are teacher facing, without student-facing equivalents.

- Lesson 2 "P.2 Lesson 2 Answer Key Investigations A&B KEY" includes guidance on what teachers should look for and how they should respond. For example,: "For both investigations, look for students to record different force combinations acting on the object. **What to do:** Make sure that students are following the calibration protocols. If the recorded forces acting on the same axis are not similar, ask students to show you how they are calibrating their setup. Provide suggestions for how to improve data accuracy" (P.2 Lesson 2 Answer Key Investigations A&B KEY, page 1). However, equivalent student-facing guidance is not provided in order for students to monitor their own progress.
- Lesson 4: "P.2 Lesson 4 Answer Key Evaluating Models Key" includes exemplar responses. However, a range of student responses is not provided.
- Lesson 7: The "Cause-Effect Model Key" provides teachers with a rubric with three proficiency levels, suggestions for feedback, and an exemplar response. "The table below shows what a completed cause-effect table might look like for students. If students use the more highly scaffolded version of the handout, the responses in blue will be provided for them. For all students, the text in black is provided. Students do not need to have every detail in every box. Students may use different words, or a different combination of frames (energy, forces, matter) to fill in the boxes" (P.2 Lesson 7 Answer Key Cause-Effect Model Key). However, a range of student responses is not provided.
- Lesson 10: The answer key for "Predicting the Future" includes sample student responses at two levels, for example: "Sample prediction focused at a local level. It considers the rifting African plate as its own system" and "Sample prediction that takes into account the plates surrounding the African Plate and how this can affect its future. This is just one of many possible predictions. Students may predict the formation of mountains AND a new ocean, for example" (P.2 Lesson 10 Answer Key Predicting the Future, page 1). However, a range of student responses is not provided.

Suggestions for Improvement

Consider providing three-dimensional student-facing assessment rubrics for key assessments, or other methods to help students track their own performance.

III.D. UNBIASED TASK/ITEMS

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

Rating for Criterion III.D. Unbiased Task/Items	Adequate *(None, Inadequate, Adequate, Extensive)*

The reviewers found adequate evidence that the materials assess student proficiency using accessible and unbiased methods, vocabulary, representations, and examples because students are provided with multiple modalities to engage in some assessments and are sometimes provided with a choice of modality to demonstrate their performance. However, many assessments in the unit do not provide students with a choice of demonstrating their performance. Additionally, some assessments do not include on-ramping guidance in order for all students to be able to successfully complete the task.

Representations, scenarios, and phenomena in assessments are fair and mostly unbiased. Vocabulary and text volume are appropriate for high school level. Appropriate on-ramping is provided for students to engage with the assessment tasks for most, but not all, assessments. Related evidence includes:

- Lesson 4: The assessment includes a scenario along with an image, and several questions that students answer related to it. "Anak Krakatau is a volcano off the coast of Indonesia. It lies near the boundary between the Indo-Australian Plate, and the Eurasian Plate. Interactions between these two plates transfer energy into the rock near the boundary. This causes pockets of rock to melt and become magma. Gases in the hot magma put pressure on the solid rock above as a result of particle collisions. The upward force from this pressure can cause the crust to deform over time, and eventually break, allowing magma to reach the surface" (Exit Ticket). Other than brief guidance on administering the task to students, the teacher is not provided with any additional guidance on the limitation of the task and how to best support students who may not be familiar with the scenario. The student-facing Exit Ticket has some on-ramping with a brief textual introduction of the geographical area of focus, along with a picture to showcase the plate boundary. The task is presented with multiple modalities including text, a map, and images (Afar – Lesson 4 Electronic Exit Ticket). However, some drawings are a bit faint and might be hard for students who have visual difficulty to read.
- Lesson 7: The assessment includes a scenario along with two images, and several questions that students answer related to it. "The planet Jupiter has many moons. One of the most interesting to planetary scientists is Europa. Europa is covered in a crust made of water ice, floating over a layer of liquid water that scientists say may be hundreds of miles thick" (Exit Ticket). Other than brief guidance on administering the task to students, the teacher is not provided with any additional guidance on the limitation of the task and how to best support students who may not

be familiar with the scenario. Because the task includes unfamiliar words such as "hydrothermal" and guidance is not provided for the teacher to provide on-ramping for students who are not familiar with these words, the task may be biased for some students.

- Lesson 13: There is support for the teacher to conduct this assessment: "Administer the assessment individually to students. Present slide E. Say, In this unit, we've figured out not only why the crack in Afar happened, but also why different surface features happen as well. Did you know that we have a rift system that was similar to Afar in the middle of the United States? Scientists have said that this rift system, the Midcontinent Rift, began creating a new ocean like we see at the Afar region, but instead of the rift system opening into a new ocean, it failed. Let's see if we can use our knowledge of Afar and more information about the Midcontinent Rift to explain what might have happened" (Teacher Edition, page 302). On-ramping includes text, maps, images, verbal discussion (P.2 Lesson 13 Assessment Midcontinent Ridge Transfer).

Over the course of the unit, there are a few examples of students having a choice on how they engage with an assessment task or use multiple modalities to express their understanding. Related evidence includes:

- Lesson 4: "Geysers, landslides , and ice chunks breaking off of a glacier are all processes on Earth's surface that happen very suddenly, like volcanoes do. Choose one of these processes that you think you could explain using ideas from the M-E-F triangle. •Geysers that erupt every few hours •Landslides right after a rainstorm •Ice chunks breaking off a glacier a few days after the warmest month on record Which lens(es) would be the most useful to explain why the process you chose could occur so suddenly after a long period of no change? •Stability and change over time or space •Cause and effect •Thinking at/across different scales How could the lens(es) you chose help you explain the process you chose?" (P.2 Lesson 4 Answer Key L4 EET Key, page 4).
- Lesson 5: "What to do: •If you think your students will be intimidated by this math, consider letting them discuss and work out the math in pairs before responding. •Consider encouraging students to work through the mathematical reasoning without doing the math. •Move around the classroom and provide support for students who are having trouble organizing the resources available to them. Point to the graph on How do scientists explore Earth's interior? And ask them to choose a dot that corresponds to a P-wave moving slower than expected. Then ask them how they could figure out the speed of that P-wave from the information on the graph. They should recognize that speed in distance over time, or the x-value over the y-value" (Teacher Edition, page 142).
- Lesson 8: "What to do: •Collect Predicting composition trends at the end of the period. •Reach out to math colleagues to find out how they are scaffolding graphing for their high school students. •Ask students clarifying questions if they are struggling, about why they are making specific decisions. This will help students articulate their reasoning, a metacognitive exercise that can be powerful in helping students figure out what to do in order to achieve a purpose, rather than just to follow directions. •An alternative approach to modifying instruction in support of students engaging in math and computational thinking is to ask them to describe in words the mathematical relationship they are attempting to represent. This parallels similar cognitive processes while making their thinking visible. This will allow you to identify areas where students might be struggling and provide targeted support and guidance."
- Lesson 13: "Attending to Equity: Universal Design for Learning: Consider allowing students to express their understandings of the Midcontinent Rift in various ways for this assessment. Some students may benefit from orally responding to the prompts, or by using manipulatives such as the foam pieces to physically represent what they believe happened in North America

1.1 billion years ago. Online tools such as flipgrid can assist students in showing and explaining their ideas in more than just writing" (Teacher Edition, page 302).

Suggestions for Improvement

- Consider providing students with additional opportunities to make choices about how they will express their learning.
- Consider providing the teacher with additional support to understand the limitations of each assessment scenario for reaching all students.
- Ensure that all visuals and text are accessible to students. For example, the drawings in the Lesson 4 Exit Ticket could be larger.

III.E. COHERENT ASSESSMENT SYSTEM

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

Rating for Criterion III.E. Coherent Assessment System	Extensive *(None, Inadequate, Adequate, Extensive)*

The reviewers found extensive evidence that the materials include pre-, formative, summative, and self-assessment measures that assess three-dimensional learning because all four types of assessment are used throughout the unit and most of the assessments connect to the learning goals of the unit in all three dimensions. Assessment system rationale is explained in the Assessment System Overview document.

Pre Assessment:

- Lesson 1: "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 and to post to the board. However, any questions students 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 your students practice turning these questions into open-ended questions when they relate to the investigations underway" (Teacher Edition, page 306).

Self-assessment:

- "Self-Assessment Discussion Rubric" (Teacher Edition, page 308) does not support students to evaluate their learning in the three dimensions.

- The Progress Tracker is called out as a form of self-assessment of learning progress for students that is revisited throughout the unit. However, clear guidance for students to assess their own progress in relation to the three dimensions on this artifact is not provided.

Formative Assessment

- In Lesson 6, students develop a model of the mantle under the Afar region. This is a formative assessment of their learning.
- In Lesson 10, students predict what will happen in the future in the Afar region. This task is used as a formative assessment.
- See further evidence of formative assessments in Criterion III.B.

Summative Assessment

- The Electronic Exit Tickets in Lessons 4 and 7 are used as summative assessment opportunities in the unit.
- The transfer task in Lesson 13 is used as an end-of-unit summative assessment.

Suggestions for Improvement

Consider providing additional opportunities for students to self-assess with guidance for determining their level of mastery of the learning objectives.

III.F. OPPORTUNITY TO LEARN

Provides multiple opportunities for students to demonstrate performance of practices connected with their understanding of disciplinary core ideas and crosscutting concepts and receive feedback.

Rating for Criterion III.F. Opportunity to Learn	Adequate *(None, Inadequate, Adequate, Extensive)*

The reviewers found adequate evidence that the materials provide multiple opportunities for students to demonstrate performance of practices connected with their understanding of DCIs and CCCs. There are opportunities for teachers and peers to provide feedback throughout the unit. However, students have limited opportunities in utilizing this feedback to revise and improve their understanding to improve a performance or future assessment.

For the claimed learning in the unit, there are multiple opportunities for students to demonstrate their growth in proficiency over time. Related evidence includes:

- For key claimed learning in the targeted elements of **ESS2.B** DCI, **Developing and Using Models** SEP, and **Cause and Effect** and **Scale, Proportion, and Quantity** CCC:
  - Lesson 1: Students create initial models to showcase what causes a land to crack, break, or move. Students are asked to explain how the land might change in the future, taking into account what might be causing such a change over time. Students are asked to think about how quickly changes might happen.

- Lesson 11: Students create initial models to predict how forces might act on plates to cause motion. They carry out an investigation to explore these relationships, then revise their models to showcase how friction, mass, surface area, and texture may affect movement. The Exit Ticket question asks students to reflect how these results might cause some plates to move differently than others.
- Lesson 12: Students conduct an investigation to determine how forces on an incline can affect movement. They create mathematical models by drawing out force diagrams when mass is on an incline. At the end of the investigation students are asked to think about how their investigation results can be applied to plate motion over time.

- For key claimed learning in the targeted elements of **ESS2.A** DCI, **Using Math and Computational Thinking** SEP**,** and **Patterns** and **Scale, Proportion, and Quantity** CCC:
  - Lesson 5: Students look for patterns in the data of seismic velocities anomalies in order to determine the composition of the Earth's interior.
  - Lesson 8: Students use Excel sheets to create graphs of exponential decay in order to compare patterns in crystal sizes and decay of parent elements. Students then use this understanding to determine the rock composition of the Afar region.
  - Lesson 12: Because it would be hard to observe plate movement, students utilize bottles and put them on an incline to determine how gravity might affect movement. Students create force diagrams in order to determine forces acting up on it. They use the data from this investigation to "connect our lab findings with the stability and change of plate motion over long time[sic] scales" (Handout: Measuring forces on incline investigation, section 4).

There are also opportunities for students to use feedback. However, it is not always to revise learning or to improve performance.

- Front Matter: "Peer Feedback: 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 from others. We suggest that peer review happen at least two times per unit. This document is designed to give you options for how to support this in your classroom. It also includes student-facing materials to support giving and receiving feedback along with self-assessment rubrics where students can reflect on their experience with the process. 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 times 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 peer feedback. It should be a formative, not summative type of assessment. It is also necessary for students to have experience with past investigations, observations, and activities where they can use these experiences as evidence for their feedback" (page 309). This resource provides general guidance on providing peer feedback and using feedback to revise student work. No specific examples in the Teacher Edition are provided for when students can utilize peer feedback to revise their work in an iterative process.
- Lesson 2: "What to do: If you collect Investigation A&B, you can provide written feedback on this assessment opportunity, otherwise you can visit groups and provide verbal feedback/guidance. If you do the latter, and a group seems to be done with their data collection, ask them to share with you their ideas about the last prompt on the slide. Accept all answers, but prime a few groups who have different ideas about this. Invite these groups to share their ideas tomorrow during the whole group discussion. See Investigations A&B KEY for sample responses" (Teacher Edition, page 73).

- Lesson 5: "5.B.1 When to check for understanding: After the Building Understanding Discussion on Day 3 when students add to their models. Collect Earth's Interior Model to provide feedback before the next class" (Teacher Edition, page 313). The feedback from this lesson can be applied for further student understanding in order to explore the role of temperature in convection.
- Lesson 7: "What to do: Provide feedback for students using the suggestions in the key. This feedback will be useful for students as they join their jigsaw groups later to compare and integrate their ideas with those obtained by their peers" (Teacher Edition, page 178). The ideas from this activity are directly used for the next performance task which is the Exit Ticket at the conclusion of the lesson.
- Lesson 10: "2. Use drawings and/or words to explain how the interactions between the plates and the mantle will cause the surface changes in Afar and Africa that you are predicting. Include any relevant source(s) of evidence from our investigations and your progress trackers to support your prediction… Revise your prediction and explanation on the front of this page before you continue" (Predicting the Future of Afar Handout). "Present slide O. Say, We can use models to explain data, and we can use models to make predictions about events in the future. We have used so many different types of evidence during this work. Let's see if we can use this evidence, and the model we made, to improve our predictions and explanations about what will happen to Afar in the future. You can change or add on to the predictions and explanation you developed at the beginning of the class. Give students the rest of the class period to complete this task. They should revise their responses to questions 1 and 2 on Predicting the Future of Africa and Afar, and then respond to all parts of question 3 on the back" (Teacher Edition, page 255). Students revise their previous predictions/explanations. However, their revisions are based on new information/concepts they learned rather than revising based on feedback.
- Lesson 11: "Compare and discuss revised models. Present slide F. Have students participate in a gallery walk to compare their models with their peers, looking for similarities and differences among models. After a few minutes, ask students to return to their seats" (Teacher Edition, page 265). Students have a chance to show their learning to their peers through their revised models but do not receive peer feedback.
- Lesson 13: "What to do: Use the key to assess students, and for suggestions on how to provide productive feedback for students who are working with foundational ideas but not yet linking them, students who are linking ideas but not yet organizing them, and for students who are organizing their ideas, and need an additional challenge" (Teacher Edition, page 302). While feedback is provided, it is not in service of improving performance or to apply for the next assessment.

Suggestions for Improvement

- Consider providing additional protocols to support peer feedback of student work.
- Consider providing opportunities for students to provide written feedback to their peers.
- Consider providing additional structures to support students to use peer feedback to construct new learning and improve their performance.

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

SCORING GUIDES FOR EACH CATEGORY

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

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

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

OVERALL SCORING GUIDE

Scoring Guides for Each Category

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

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

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

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