Meteors, Orbits, and Gravity

DEVELOPER: OpenSciEd

GRADE: HS | **DATE OF REVIEW:** June 2024

Educators Evaluating Quality Instructional Products

NextGen Science WestEd

Meteors, Orbits, and Gravity

EQuIP RUBRIC FOR SCIENCE EVALUATION

OVERALL RATING: E
TOTAL SCORE: 8

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

Click here to see the scoring guidelines.

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

CATEGORY I CRITERIA RATINGS			CATEGORY II CRITERIA RATINGS			CATEGORY III CRITERIA RATINGS		
A.	Explaining Phenomena/ Designing Solutions	Adequate	**A.**	Relevance and Authenticity	Extensive	**A.**	Monitoring 3D Student Performances	Extensive
B.	Three Dimensions	Extensive	**B.**	Student Ideas	Extensive	**B.**	Formative	Extensive
C.	Integrating the Three Dimensions	Extensive	**C.**	Building Progressions	Adequate	**C.**	Scoring Guidance	Extensive
D.	Unit Coherence	Adequate	**D.**	Scientific Accuracy	Extensive	**D.**	Unbiased Tasks/Items	Extensive
E.	Multiple Science Domains	Adequate	**E.**	Differentiated Instruction	Adequate	**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 has many strengths. For example:

- The overall primary phenomenon of the Chelyabinsk meteor event is interesting and engaging for students, allowing for clear connections to both physical science and Earth and space science ideas.
- The unit contains a strong comprehensive assessment system, including the following:
  - Elements from all three dimensions are integrated in numerous assessment tasks and student performances throughout the unit.
  - There are numerous opportunities to see evidence of student progress in the targeted learning.
  - Guidance for what to look for and what to do for students that are not meeting the target are provided throughout the materials.
- English language arts (ELA) and mathematics standards are clearly integrated throughout the unit and used in a meaningful way while making sense of phenomenon.

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

- Consider providing additional opportunities for students to ask new questions, add to the Driving Questions Board (DQB), and revisit previously asked questions throughout the unit.
- Consider making more explicit connections with the primary phenomenon for some lessons, making it clear to students how their learning is helping to make sense of the unit phenomenon.
- Consider providing additional feedback opportunities where students are supported in using the feedback to improve their next performance, such as through an iterative process.

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

All page numbers refer to the Teacher Edition of the indicated individual lesson unless otherwise noted.

CATEGORY I

NGSS 3D DESIGN

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	Adequate *(None, Inadequate, Adequate, Extensive)*

The reviewers found adequate evidence that learning is driven by students making sense of phenomena or designing solutions to a problem because student learning is focused on making sense of the central phenomenon of the Chelyabinsk event or other meteor collisions in the first section of the unit. However, in the second section of the unit, student learning is often focused on the central science topic of meteor collisions and not on a specific phenomenon or problem. Additionally, in the second section of the unit, learning is often driven by teacher-directed questions rather than students' questions.

Student questions and prior experiences often create a need to engage in the learning. For example:

- Lesson 1: "Brainstorm related phenomena. Present slide H. Ask students to Turn and Talk using the slide prompts: What other examples have you seen or heard about that: looked like this happening in the sky; included something from space that fell to Earth; could help us understand what happened with the Chelyabinsk event. Give students 2 minutes to discuss these with a partner. Say, We will share some of our ideas next time" (page 19).
- Lesson 1: "Record questions about related phenomena. Say, Sorting these cards may have raised different questions, let's record these on a piece of paper. We will come back to these questions and explore how we can answer them. Present slide M. Distribute a blank piece of paper and give students a couple of minutes to record their questions. Collect these before students leave the room" (page 24).
- Lesson 1: "Give students back the models of the Chelyabinsk event they developed during day 1 and their exit ticket. Read the slide prompts out loud to guide students through this task: Look back at the questions you included in: your initial model of the Chelyabinsk event; your initial model of the motion of space objects; your questions about Related Phenomena. Identify the questions that you think will help us understand and explain: the Chelyabinsk event and related phenomena; why some objects remain in orbit and why some hit Earth. Record initial questions. Present slide T. Distribute a few sticky notes and 1 marker to each student. Give students this time to record 1 question per sticky note in marker (with initial on back in pencil). Give students a few minutes to complete this activity. Build the Driving Question Board. Display slide U Review the protocol for sharing, calling on, linking in, and clustering questions on the Driving Question Board (DQB). Continue until everyone has shared at least one question" (page 29).

- Lesson 3: Students create the unit Progress Tracker where they record: "What questions did these help us answer or establish in these lessons?" and "How does what we did in the last few lessons help us further our models or answer our questions on the DQB?" (page 23).
- Lesson 5: "Point out some of the questions that students had related to the energy of a space object as it goes around its orbit. Suggest we start our next lesson by trying to make progress on that series of questions" (page 14).
- Lesson 9: "Present slide B. Say, It seems like we still have a lot of questions about the history of these impacts. Let's spend some time today recording new questions to add to our DQB and brainstorming additional sources of data/investigations that could help us make progress on those questions. Give each student four different colored sticky notes and ask them to arrange the sticky notes on their desk as shown on the slide. Read the text on the slide and cue students to use the pink sticky note to record a question they now have" (page 8).
- Lesson 10: "Reference the Driving Question Board, noting that we developed a whole series of new questions and ideas for investigations from the mathematical model we developed over the last two lessons. Revisit the mathematical model for the prior lesson. Display slide A. Discuss the question on the slide as a class: What new questions or ideas for investigation/data did we have that were related to the amount of damage meteors can cause?" (page 8).
- Lesson 14: "Instruct students to focus on the part of the graph that corresponds to the impactor collision that occurred 65 million years ago. Give students a couple of minutes to record their thinking and then share with partners. Suggested prompt: What does this data from the fossil record tell us about what might have happened around the time of the meteor impact? What new questions does it raise?... Before we look at this evidence, let's define our lesson driving question. Remind students that thinking of the question we are trying to answer helps us establish a purpose for our learning. Ask students to record one question we can answer with fossil data from 65 million years ago at the top of Extinction Evidence Organizer. Student generated questions may vary slightly, but are key to the navigation into the rest of the lesson and should be a variation of the following question: How can a meteor impact cause the extinction of some organisms but not others?" (pages 11–12).
- Lesson 14: "Navigate. Display slide Y. Reach the text on the top of the slide. We explained the effects of 10 km wide object colliding with Earth 65 million years ago. Earth's[sic] is currently about 7,900 km in diameter. Scientists believe that a 6,000 km wide object collided with Earth 4.5 billion years ago. Discuss the question on slide: What new questions does this raise for you? Accept all responses. Emphasize that we will plan to investigate and answer some of these questions as part of a final transfer task/assessment to wrap up the unit in the next lesson" (pages 23–24).

The focus of the first section of the unit is to support students in making sense of phenomena. For example:

- Lesson 1: "Present slide A. Say, A few years ago in Siberia, something puzzling happened. A rock fell from the sky with no warning. Some of you may have seen videos of this event, or heard of something similar happening somewhere else. I will show you two videos from this. The first are from various cameras that recorded the event from different angles. The second is a brief news report related to the event" (page 11).
- Lesson1: "Now that we saw a couple of videos and collected additional information, let's see if we can use our science ideas to try to explain our observations from the Chelyabinsk event. Mention that you want them to explain what they think was happening in the system that helps explain some of our observations. This is not about drawing what we saw, but using drawings and words to try to explain what could have led to the things we observed. Present

slide D. Distribute students a blank piece of paper to show what was happening to the rock: after the rock has entered Earth's atmosphere; when a part of it (meteor) hit the Earth's surface. Encourage them to use pictures, symbols and/or words to both explain what happened over the time of the videos we saw, and why it happened" (page 15).

- Lesson 3: "Chelyabinsk was a meteor that orbited the sun. Could knowing how long it will take similar objects to go around their orbits help us predict their potential for a collision with Earth?" (page 17).
- Lesson 5: "Tell students that scientists know that the Chelyabinsk meteor had an eccentric orbit with an eccentricity of .6. For extra support you may draw an orbit with eccentricity of .6 on a poster or whiteboard. Use the prompts on the slide to get students to think about the motion of the Chelyabinsk meteor" (pages 9–10).
- Lesson 6: "Last time, you made predictions about what the orbit of the Chelyabinsk meteor might have looked like before its collision with Earth. I looked up what scientists have predicted, and the leading theory is that Chelyabinsk had a close to circular orbit, and was in the asteroid belt. Turn and talk to a partner about how this compares to your prediction. Does it surprise you? After a minute, ask students to share. Look for students to say that they had expected the Chelyabinsk meteor to be in a much more eccentric orbit. Then ask the second and third questions on the slide: What are the limitations of our model? What are we not including that could explain why it failed to predict where Chelyabinsk was?" (page 6).

Some lessons in the second set of the unit (such as 12, 13, 14) are not clearly linked with student questions concerning the primary phenomenon of the Chelyabinsk meteor or any secondary phenomena or problems. In this part of the unit, the learning is teacher driven and not based on questions students have about phenomenon. For example:

- Lesson 9: "Our planet is over 4.5 million years old. So what has happened to all the objects many factors of 10 bigger than Chelyabinsk that reached Earth over that time? All the objects that were many factors of 10 smaller? Give students 3 minutes to discuss with a partner. Share and record initial explanations. Write the following question at the top of a piece of chart paper: 'What happened (effects) to all the objects that reached Earth over the last 4.5 billion years?' Under this write 'Effects different scales:' Divide the rest of the chart paper into 3 columns. Say Let's come together and brainstorm the potential effects of different sized impactors. Let's start by thinking about what we know happened with the Chelyabinsk meteor... So what happened to all the meteors that reached Earth over that time that were much smaller than the Chelyabinsk meteor? Then ask, What about the ones that were many factors 10 bigger than the Chelyabinsk meteor?" (pages 6–7). While this lesson connects to the overall topic of meteor impacts and the primary unit phenomenon is mentioned to the students, the lesson is driven by teacher questions; student questions about phenomena are not elicited.
- Lesson 9: "Ask questions about meteor impacts. Present slide B. Say, It seems like we still have a lot of questions about the history of these impacts. Let's spend some time today recording new questions to add to our DQB and brainstorming additional sources of data/investigations that could help us make progress on those questions. Give each student four different colored sticky notes and ask them to arrange the sticky notes on their desk as shown on the slide. Read the text on the slide and cue students to use the pink sticky note to record a question they now have" (page 7). Students ask questions about the general topic of meteor impacts but are not provided the opportunity to ask questions about a specific phenomenon that they want to make sense of.
- Lesson 10: "Display slide A. Discuss the question on the slide as a class: What new questions or ideas for investigation/data did we have that were related to the amount of damage meteors

can cause? Accept all answers. Say, Let's start by reminding ourselves of the damage the Chelyabinsk meteor caused. Link to the anchoring phenomenon. Display slide B. Say, The largest fragment of the Chelyabinsk asteroid left an 8-meter (26-foot) diameter hole in the ice of the lake it hit. Discuss the question on the slide as the class: What do we think the outcome would have been if it had hit the land? Do we think the mass or the speed of the meteor has a bigger impact on the damage it causes when it hits the surface?" (page 8). In this lesson, student learning is more clearly connected to the primary phenomenon of the Chelyabinsk asteroid and students investigate questions that would naturally arise about that event.

- Lesson 12: "Say, We know that rocks burn up when they move through Earth's atmosphere. But not every planet has an atmosphere. What would happen in a place like that? Do events like this still happen in those places? Present slide A. Use the slide prompt to elicit 1-2 ideas: What other objects in our solar system might we be able to look at that have little or no atmosphere? Give students a couple minutes to discuss with someone near them and then solicit ideas. Students will likely say the moon. They might not say anything else, and this is ok. Validate all students' ideas" (page 8). The learning in this lesson focuses on meteor impacts when there is no atmosphere. This is driven by a teacher-made question; this question would not arise naturally from the primary phenomenon. No new phenomenon or problem that would lead to this question from the students' perspectives is provided.
- Lesson 14: "Present slide C. Distribute Mass Extinctions Data Analysis to each pair of students, which shows a graph of the fluctuation of extinction events in the fossil record. Instruct students to focus on the part of the graph that corresponds to the impactor collision that occurred 65 million years ago. Give students a couple of minutes to record their thinking and then share with partners. What does this data from the fossil record tell us about what might have happened around the time of the meteor impact? What new questions does it raise?" (page 11). This lesson is driven by a teacher-made question and would not arise naturally from student questions about phenomena previously presented.

Suggestions for Improvement

- All lessons relate to the topic of meteors, orbits, and collisions. However, some lessons do not currently link directly to an observable phenomenon such as the Chelyabinsk meteor. Linking the student learning to making sense of a specific phenomenon, rather than just studying meteors and collisions in general, would help drive student learning and motivate sense-making. For example, starting Lesson 12 by having students observe pictures of craters on planets and moons in order to elicit the driving question, rather than viewing them later in the lesson, could be more effective at creating a need for sense-making from the student perspective.
- Consider providing additional opportunities for students to ask and record questions. Students rarely add questions to the DQB and have few supports for asking new questions throughout the unit as they learn new ideas.

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	Extensive *(None, Inadequate, Adequate, Extensive)*

The reviewers found extensive evidence that the materials give students opportunities to build understanding of grade-appropriate elements of the three dimensions because students regularly develop and use high school level elements of all three dimensions to make sense of phenomena. There is a reasonable match between most of the claimed elements of the dimensions and the student learning activities, and a reasonable amount of time is spent on most elements for students to develop a deep understanding. There are some targeted elements identified in the Unit Overview and Elements of NGSS Dimensions documents for which students do not have time to develop understanding in the unit or students only engage with part of an element.

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

The reviewers found adequate evidence that students have the opportunity to use or develop the SEPs in this unit because students regularly engage with high school level elements of the targeted SEPs and there is a clear, direct match between the claimed elements and the learning activities.

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 8: "Predict Frequency of an Event. Present slide F. Distribute Frequency vs. Size and a ruler to each student. Ask students what patterns they notice in all of this data. Students will say that the data appears to fall along (or very close to) a straight line (or linear relationship). Draw a line of best fit. Suggest that we develop a line of best fit to represent the trend we think the data is showing us in order to help us make predictions for areas of the graph where we don't have data. Remind students that in the past, we have used CODAP to estimate a line of best fit. Ask students what we could do to create this line ourselves. Listen for ideas about using a ruler to try to follow the trend of the data points. Have students draw a line of best fit with their ruler" (page 10).
  - Lesson 12: "Create a timeline of cratering frequency in the moon. Present slide N. Use the Number of moon craters over time poster with the blank timeline you created. Ask students to use Moon Timeline to take notes during this discussion. Identify a student volunteer to accurately label the divisions of lunar geologic time on the poster timeline. Ask the rest of the class to check their timelines for agreement. Say, let's add a little more information to this timeline. Where should we label the present day? Add a

'present day' label at the far right of the timeline, where 0 billion years ago is indicated. Invite students to share their findings, starting with those who analyzed the frequency data of the small craters, then those who analyzed the frequency data of the medium craters, and finally, those who analyzed the frequency data of the large craters. Use the timeline you prepared ahead of time to keep a record of students' ideas" (pages 15–16). Students use a timeline model/tool to analyze their data about crater frequency and then make claims based on the data on the timeline.

- *Apply concepts of statistics and probability (including determining ~~function fits to data, slope, intercept~~, and correlation coefficient for linear fits) to scientific and engineering questions and problems, using digital tools when feasible.*
    - Lesson 10: "Say, I think we can see that increasing the mass and velocity of the impactor results in larger craters. No surprise here. But which of these variables better explains the size of the crater? To answer this question, it is better if we use a mathematical tool we have used in the past, the coefficient of correlation. Introduce the coefficient of correlation. Present slide M. Read aloud the description of the coefficient of correlation at the top of the slide: The coefficient of correlation (R2) is a measure of the strength of the relationship between two variables. The closer R2 is to 1, the stronger the relationship between the independent and dependent variables" (page 16).
- *Evaluate the impact of new data on a working explanation and/or model of a proposed process or system.*
    - Lesson 10: "Revise explanation of meteor collision. Present slide S. Remind students that we have seen evidence of fragments from mid-sized meteors that hit Earth (10,000,000 kg), but as we have seen before, scientists rarely find large fragments of big meteors that hit Earth. Give students a minute of individual thinking time to consider the prompt: How can you explain why it is easier to find large fragments of smaller meteors than large fragments of large meteors? Present slide T, and have students read the prompt: Use words, mathematical symbols, and/or drawings to explain why finding large fragments of smaller meteors is easier than finding large fragments of larger meteors. Include: Use ideas related to M-E-F to account for this difference. Ask students to write these explanations on a separate piece of paper. Collect these as a formative assessment" (page 19). Students revise their previous explanation in this lesson based on the new information they learned about kinetic energy and their lab investigation data about impact craters.
    - Lesson 15: "Question 1. Models of the impact between Theia and Earth result in Theia being destroyed, and the Earth melting into liquid rock. Use M-E-F thinking to explain why the models might produce this result (use a combination of words, drawings, and symbols)" (Lesson 15 Assessment – Moon Formation). Students use new information about a theory about Earth and Theia colliding in order to revise their model of the formation of the early earth.

Using Mathematics and Computational Thinking

- *Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations.*
    - Lesson 2: "Use the universal law of gravitation to make predictions for different conditions. Present slide FF. Say, We started this lesson wondering about how gravity could act differently on different space objects. Let's see if we can use some of our ideas to see if this can help us explain why some objects remain in orbit while others

collide with Earth. Organize the class in groups of 4 students. Distribute Calculating Gravitational Forces to every student. Point to the space objects students are calculating, and the data used for their calculations. Assign each member of the group a condition to solve for" (page 32).
    - Lesson 5: In the Lesson 5 Handout – Energy Transfer Investigation, students use mathematical representations of gravitational potential and kinetic energy to explain the motion and changing speeds of an asteroid's orbit.
    - Lesson 7: "Question 5: The spacecraft crashed into Dimorphos at roughly 6,258 m/s. Compared with Dimorphos, which has a mass of about five billion kilograms (5 * 109 kg), the DART spacecraft weighed just 550 kilograms (5.5 * 102 kg) at the time of impact. So how did such a light spacecraft affect the orbit of a relatively massive asteroid? Use an energy transfer perspective and the equation below to support your answer: Kinetic energy = m*V^2/2" (Lesson 7 Assessment, page 6).
- *Apply techniques of algebra and functions to represent and solve scientific and engineering problems.*
    - Lesson 2: "Make predictions using the equation. Display slide EE. Say, Let's think about what this equation would predict would happen when we change some of these variables by one order of magnitude (a factor of ten). Give students a minute and a half to discuss the related predictions on the slide with a partner and then quickly share these out with the class" (page 31),
    - This element is claimed as being intentionally developed in this unit but is only encountered in one lesson.
- *Use simple limit cases to test mathematical expressions, computer programs, algorithms, or simulations of a process or system to see if a model "makes sense" by comparing the outcomes with what is known about the real world.*
    - Lesson 2: "Display slide II. Say, now that we have figured out how the magnitude of these forces change over distances, let's add a sketch of the non-linear trends of both of these as distances get bigger and bigger" (page 34).
    - This element is claimed as being intentionally developed in this unit but is only encountered in one lesson.

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 4: "Model a planet's orbit. Give students a couple of minutes to construct a model of the circular orbit assigned to them and label the important parts, in accordance with the prompts on their handout and the slide. Towards the end of the time limit, remind students to calculate the eccentricity of the orbit they created using the steps in the handout… Have students compare their models with the other members of their groups. Then invite a few volunteers to share some of their findings using the prompts: What do your orbits have in common? Where is the semimajor axis, and what other name do we have for it when the shape is a circle? What happened to the shape of the orbit when the semimajor axis increased? What is the value of the eccentricity we calculated?" (page 12). This lesson does not provide evidence for illustrating or predicting relationships between systems or components of a system.
    - Lesson 5: "Annotate and create a model for an object orbiting the Sun with a high eccentricity. Color code and label the orbit path to show when the orbiting object is moving closer to the Sun and show the direction of its motion on the orbit path. Color

code and label the orbit path to show when the orbiting object is getting farther from the Sun and show the direction of motion on the orbit path… Where does energy transfer to when the orbiting object slows down (its kinetic decreases)? Where does energy transfer from when the orbiting object speeds up (its kinetic energy increases)? Describe using words, drawings, and symbols what is happening to the direction and magnitude of the force of gravity on both the Sun and the object as the object moves along its path. How could these forces be playing a role in transferring energy to and from the asteroid to explain our changes in kinetic energy?" (Lesson 5 Handout – Orbital Energy Transfer, pages 1, 2).

- Lesson 6: "Consider the Chelyabinsk meteor and the Sun system are in their stable orbit in the asteroid belt and we introduce another very large massed planet (Jupiter) into our sun-meteor system. Use words, drawings, and symbols to show how the introduction of another planet into our system could have led to the redirection of the Chelyabinsk meteor towards earth" (Lesson 6 Handout – Redirection of Asteroids).
- Lesson 7: Students use data collected by scientists and some of the mathematical models developed in this unit to explain two strategies to deflect asteroids. "Record student ideas on chart paper and categorize them based on the changes they could cause to the Earth-meteor system: Changes in meteor's orbit, Changes in meteor's velocity, and Changes in meteor's mass" (page 135). "According to this strategy, the gravity tractor can change the motion of an asteroid. As we have seen in this and other units, changes in motion are related with energy transfer in the system. Use the image and words to explain how the energy from the gravity tractor transfers to the asteroid without touching it" (Lesson 7 Assessment – Changing Asteroid Orbits).
- Lesson 13: "Use a model to test ideas. Present slide J. Say, I have some materials that will help us test some of our ideas about the mechanisms that we think help explain why it is hard to find craters on Earth's surface. Distribute materials to every pair of students. Instruct them to use these materials to test their ideas. Read the slide instruction aloud: Use the physical model to test your ideas about how Earth processes can affect surface features of craters over time? Use your observations to answer the following questions in your notebook: Which of the changes you observed in the craters using this physical model do you think could be observed in real craters on Earth? Why? How much time would it take to observe similar changes in the surface features of real craters on Earth?" (page 13).
- Lesson 14: "Draw an initial model to explain the dinosaur extinction. Present slide H. Say, This was not just one instantaneous event. Let's create a model to show the chain of causes and effects that led certain types of organisms to become extinct. Distribute Timeline, a blank timeline to help students use ideas they have learned thus far in the unit to create their initial models. Generate new questions about the K-Pg layer. Present slide I. Say, Scientists have used a variety of methods to study the K-Pg layer, including gravimetry and seismic imaging, and we now have a lot more information about what is in this layer. What additional evidence do we need to refine our initial models?" (page 14).
- Lesson 14: "Say, now, we will take on the force interactions and energy transfer lens. In particular, think about what other Earth systems might have experienced a transfer of energy to/through them as a result of this impact that we haven't considered yet" (page 17).
- Lesson 14: "Revise initial models. Display slide U. Have students look at their initial model from day 1 as you review the questions for them to consider in their revisions to the model on the slide. Emphasize that their revisions should include annotations to

help make their thinking visible to others in an upcoming gallery walk. Give students the remaining time to complete this individual assessment" (page 22).
  - Lesson 15: "Question 1. Models of the impact between Theia and Earth result in Theia being destroyed, and the Earth melting into liquid rock. Use M-E-F thinking to explain why the models might produce this result (use a combination of words, drawings, and symbols)" (Lesson 15 Assessment – Moon Formation). Students develop a model concerning the effect of a collision between early Earth and Theia on the formation of the Moon.
- *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 3: "Based on your results and your ideas about the relationship between gravity and the velocity of orbiting objects, develop an explanation for: how space objects can remain in stable orbits and how their orbits can change. In your explanation, describe how the distance between objects affects this relationship" (Lesson 3 Handout – Investigating Circular Motion, page 3). Students use the results from their physical model exploration to develop an explanation of how objects can remain in stable or changing orbits.

Planning and Carrying Out Investigations

- *Plan an investigation or test a design individually and collaboratively to produce data to serve as the basis for evidence as part of building and revising models, supporting explanations for phenomena, or testing solutions to problems. Consider possible confounding variables or effects and evaluate the investigation's design to ensure variables are controlled.*
  - Lesson 10: Students plan and carry out an investigation to determine whether the velocity or the mass of a meteor better predicts the size of the crater it forms. "Ask students to work with a partner to define in their notebook a protocol to change the mass and a protocol to change the velocity of the impactor, using some of the materials for this investigation. Instruct them to indicate the variables that they will control, manipulate, and measure" (page 10).

Constructing Explanations and Designing Solutions

- *Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects.*
  - Lesson 11: "Construct individual explanations. Display slide K. Read the text at the top of slide and the related prompt: Scientists estimate that the Chelyabinsk meteor had a mass of 12 tons (12,000 kg) when it first reached Earth's atmosphere. But, they only recovered 1 ton of solid fragments. How can you explain what happened to the 11 tons of missing matter? Emphasizing that students should use ideas related to M-E-F to account for this discrepancy. Ask students to write these individual explanations on a separate piece of paper. Collect these as a formative assessment" (page 14). In this formative assessment task, students apply scientific ideas, principles, and evidence to provide an explanation of a phenomenon but do not take into account possible unanticipated effects.

Engaging in Argument from Evidence

- *Compare and evaluate competing arguments or design solutions in light of currently accepted explanations, new evidence, limitations (e.g., trade-offs), constraints, and ethical issues.*

- Lesson 14: Students read different articles that provide competing arguments for the Chicxulub event that is believed to cause the extinction of the dinosaurs. Students share their argument with their group and answer this question: "Develop an argument on Evaluate Alternate Mechanisms. Compare and evaluate at least two alternate mechanisms. Which alternate mechanism is most probable? Support your thinking with evidence from the K-Pg layer" (page 19).

Obtaining, Evaluating, and Communicating Information

- *Critically read scientific literature adapted for classroom use to determine the central ideas or conclusions and/or to obtain scientific and/or technical information to summarize complex evidence, concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.*
  - Lesson 13: Students read one of four articles about an Earth process to determine when this process likely happened during Earth's history as represented by the timelines. It is unlikely that the readings came from scientific literature as there are no methods described or citations on any of the readings.
  - Lesson 14: Students read two articles about the Chicxulub Crater and then in a jigsaw, "Give students 8 minutes to share the key ideas from their article and how this relates to the changes in matter related to the Chicxulub crater" (page 17). It is unlikely that the readings came from scientific literature as there are no methods described or citations on any of the readings.

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

The reviewers found adequate evidence that students have the opportunity to use or develop the DCIs in this unit because students regularly engage with elements of the targeted DCIs at the high school level. There is a reasonable match between claimed elements and student activities and sufficient time is spent developing most of the claimed elements. In some cases, the claimed learning does not match the student activities and there were some inconsistencies regarding strikethrough portions of DCI elements.

ESS1.B Earth and the Solar System

- *Kepler's laws describe common features of the motions of orbiting objects, including their elliptical paths around the sun. ~~Orbits may change due to the gravitational effects from, or collisions with, other objects in the solar system~~.*
  - Lesson 3: "Based on your results and your ideas about the relationship between gravity and the velocity of orbiting objects, develop an explanation for: how space objects can remain in stable orbits and how their orbits can change. In your explanation, describe how the distance between objects affects this relationship" (page 3).
  - Lesson 3: "Scientists call the relationship between the radius and period that you identified in questions c and d as Kepler's third law. What does this law tell us about the motion of planets around the sun? Suppose NASA discovers a new asteroid at a distance of 3.5 AU from the Sun. Use the relationship between T and a that you just discovered to determine how long it would take that asteroid to complete one orbit, in years?" (Lesson 3 Handout – Kepler's Third Law, page 4).
  - Lesson 4: "After this time, say, Now that we are more familiar with some of the terms used by scientists to describe orbits, let's see if we can use these terms to describe more accurately the differences between circular and elliptical orbits. Motivate using a physical model to explore circular and elliptical orbits. Present slide G. Use the slide

prompt to elicit 1-2 student ideas: How do you think the shape of the orbit will change if we double: the length of the semimajor axis? the distance between the foci?" (page 11).

- Lesson 5: "Annotate and create a model for an object orbiting the Sun with a high eccentricity. Color code and label the orbit path to show when the orbiting object is moving closer to the Sun and show the direction of its motion on the orbit path. Color code and label the orbit path to show when the orbiting object is getting farther from the Sun and show the direction of motion on the orbit path. Label the point along the orbit path where the object will be moving the fastest (highest kinetic energy). Label the point along the orbit path where the object will be moving the slowest (lowest kinetic energy)" (Lesson 5 Handout — Orbital Energy Transfer).
- Lesson 6: "Consider the Chelyabinsk meteor and the Sun system are in their stable orbit in the asteroid belt and we introduce another very large massed planet (Jupiter) into our sun-meteor system. Use words, drawings, and symbols to show how the introduction of another planet into our system could have led to the redirection of the Chelyabinsk meteor towards earth. How do you predict the force will affect the speed and direction of the Chelyabinsk meteor and why? How do you predict this force will affect the direction that Jupiter will move and why? Consider the possibility that the Chelyabinsk meteor experienced a collision with another asteroid in the asteroid belt. Use words, drawings, and symbols to show a collision with another asteroid could have led the Chelyabinsk meteor towards earth" (Lesson 6 Handout – Redirection of Asteroids).
- Lesson 7: "Question 5: The spacecraft crashed into Dimorphos at roughly 6,258 m/s. Compared with Dimorphos, which has a mass of about five billion kilograms (5 * 109 kg), the DART spacecraft weighed just 550 kilograms (5.5 * 102 kg) at the time of impact. So how did such a light spacecraft affect the orbit of a relatively massive asteroid? Use an energy transfer perspective and the equation below to support your answer: Kinetic energy = m*V^2/2" (Lesson 7 Assessment, page 6).

ESS1.C The History of Planet Earth

- *Although active geologic processes, such as plate tectonics and erosion, have destroyed or altered most of the very early rock record on Earth, other objects in the solar system, such as lunar rocks, asteroids, and meteorites, ~~have changed little over billions of years. Studying these objects~~ can provide information about Earth's formation and early history.*
  - Lesson 9: "Turn and talk. Does the mathematical model we used to make these predictions hold for the 4.5-billion-year history of Earth? Why or why not? Do you think our model holds for our Moon or other planets? Consider the sorts of data we would need to answer these two new questions below. Add your ideas to your blue sticky note" (Slides F–G). Students discuss and ask questions about whether their predictions match the data for earth's history for craters and impacts. The students then plan investigations and determine what information they would need to make sense of this data.
  - Lesson 12: "Create a timeline of cratering frequency in the moon. Present slide N. Use the Number of moon craters over time poster with the blank timeline you created. Ask students to use Moon Timeline to take notes during this discussion. Identify a student volunteer to accurately label the divisions of lunar geologic time on the poster timeline. Ask the rest of the class to check their timelines for agreement. Say, let's add a little more information to this timeline. Where should we label the present day? Add a

‘present day’ label at the far right of the timeline, where 0 billion years ago is indicated. Invite students to share their findings, starting with those who analyzed the frequency data of the small craters, then those who analyzed the frequency data of the medium craters, and finally, those who analyzed the frequency data of the large craters. Use the timeline you prepared ahead of time to keep a record of students' ideas” (pages 15–16).

- Lesson 13: “Distribute materials to every pair of students. Instruct them to use these materials to test their ideas. Read the slide instruction aloud: Use the physical model to test your ideas about how Earth processes can affect surface features of craters over time? Use your observations to answer the following questions in your notebook: Which of the changes you observed in the craters using this physical model do you think could be observed in real craters on Earth? Why? How much time would it take to observe similar changes in the surface features of real craters on Earth?” (page 13).
- Lesson 14: “Revise initial models. Display slide U. Have students look at their initial model from day 1 as you review the questions for them to consider in their revisions to the model on the slide. Emphasize that their revisions should include annotations to help make their thinking visible to others in an upcoming gallery walk. Give students the remaining time to complete this individual assessment” (page 22). Students develop a model of how changes to the Earth caused by meteor impact may have caused a mass extinction.
- Lesson 15: “Question 1. Models of the impact between Theia and Earth result in Theia being destroyed, and the Earth melting into liquid rock. Use M-E-F thinking to explain why the models might produce this result (use a combination of words, drawings, and symbols)” (Lesson 15 Assessment – Moon Formation). Students use information about the formation of the Moon to make a model of how the early earth might have been impacted.

PS2.B Types of Interactions

- *Newton’s law of universal gravitation ~~and Coulomb’s law~~ provide the mathematical models to describe and predict the effects of gravitational ~~and electrostatic~~ forces between distant objects.*
  - Lesson 1: This element is claimed for Lesson 1 in the Elements of NGSS Dimensions document. Students think about the role gravity plays in some of the initial phenomena presented but do not learn about Newton’s law of universal gravitation or mathematical models in this lesson.
  - Lesson 2: “Use the universal law of gravitation to make predictions for different conditions. Present slide FF. Say, We started this lesson wondering about how gravity could act differently on different space objects. Let’s see if we can use some of our ideas to see if this can help us explain why some objects remain in orbit while others collide with Earth. Organize the class in groups of 4 students. Distribute Calculating Gravitational Forces to every student. Point to the space objects students are calculating, and the data used for their calculations. Assign each member of the group a condition to solve for. …Point out that earlier we said that gravity acts on all matter, and now we figured out that all matter produces gravity. Add ‘all matter’ to the corresponding cell on the next row of the Comparing Forces from Gravitational vs. Magnetic Field poster” (pages 32, 34).
  - Lesson 5: “The amount of energy stored in the field relative to Earth’s surface can actually be calculated by simply multiplying the height of the object times the force of

gravity on it. For earth the force of gravity is just mass times our Earth's gravity of 9.81 m/s2 because the change in distance is not significant, but for asteroids it is a bit more complicated because the force of gravity changes as its distance changes from the sun" (page 16).
    - Lesson 6: "Consider the Chelyabinsk meteor and the Sun system are in their stable orbit in the asteroid belt and we introduce another very large massed planet (Jupiter) into our sun-meteor system. Use words, drawings, and symbols to show how the introduction of another planet into our system could have led to the redirection of the Chelyabinsk meteor towards earth. How do you predict the force will affect the speed and direction of the Chelyabinsk meteor and why?" (Lesson 6 Handout – Redirection of Asteroids).
    - Lesson 7: "Question 1: Use the equation below and the information provided to calculate the force of gravity between the asteroid and the spacecraft. Show the steps you followed to find the value for Fg" (Lesson 7 Assessment – Changing Asteroid Orbits, page 1).
- *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 2: "Compare Earth's magnetic field and gravitational field. Say, It sounds like the logistics of investigating gravity will be tricky. What other forces do we know about that act at a distance like gravity, without the two objects having to touch? Look for students to suggest electricity and/or magnetism. If they do not, ask, Have any of you ever tried holding a magnet near another magnet? It acts at a distance, right without the magnets having to touch" (page 15).
    - Lesson 7: Students are told, "Use the equation below and the information provided to calculate the force of gravity between the asteroid and the spacecraft. Show the steps you followed to find the value for Fg" on the Changing Asteroid Orbits Assessment.

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 1: The class develops a consensus model that labels the energy transfer associated with a meteor entering Earth's atmosphere. Motion, light, and thermal energy are included.
    - Lesson 5: In Lesson 5 students use mathematical models to see how energy can convert from gravitational potential energy to kinetic energy (motion). Sound, light, and thermal energy are not discussed.
    - Lesson 11: "Connect to prior experiences. Reference the energy corner of the M-E-F poster. Remind students that earlier in the course we explained many other phenomena in terms of energy transfers that we could observe occurring as light or heat given off by matter in the system, such as when a light bulb goes on, a wire heats up, or even when radioactive materials decay to cause convection deep within the Earth's mantle. Suggest that we consider these two ways that we know energy can be transferred to the surroundings a bit further - light and heat" (page 9).
    - Lesson 14: "The impactor likely caused a high degree of heat transfer to Earth or a blockage of sunlight, which directly affected the survivability of species in Earth's biosphere" (page 21). In this lesson students discuss the energy involved in a meteor impact but do not discuss how energy manifests itself in multiple ways.

- *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 11: "Connect to particle-level interactions in the atmosphere. Display slide J. Have students discuss the related question on the slide with a partner for two minutes: What particle-level interactions in the atmosphere could cause some of the matter from the meteor to form into these shapes?" (page 14).
    - This element is minimally developed in this unit. In Lesson 11, most of the text of the element is struck through but the entire element is claimed in the Elements of NGSS Dimensions document.

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 5: "Where does energy transfer to when the orbiting object slows down (its kinetic [sic] decreases)? Where does energy transfer from when the orbiting object speeds up (its kinetic energy increases)? Describe using words, drawings, and symbols what is happening to the direction and magnitude of the force of gravity on both the Sun and the object as the object moves along its path. How could these forces be playing a role in transferring energy to and from the asteroid to explain our changes in kinetic energy?" (Lesson 5 Handout – Orbital Energy Transfer).
    - Lesson 7: "Question 5: The spacecraft crashed into Dimorphos at roughly 6,258 m/s. Compared with Dimorphos, which has a mass of about five billion kilograms (5 * 109 kg), the DART spacecraft weighed just 550 kilograms (5.5 * 102 kg) at the time of impact. So how did such a light spacecraft affect the orbit of a relatively massive asteroid? Use an energy transfer perspective and the equation below to support your answer: Kinetic energy = m*V^2/2" (Lesson 7 Assessment, page 6).
- *Mathematical expressions, which quantify how the stored energy in a system depends on its configuration (e.g. relative positions of charged particles, compression of a spring) and how kinetic energy depends on mass and speed, ~~allow the concept of conservation of energy to be used to predict and describe system behavior.~~*
    - Lesson 8: "Add two columns for kinetic energy (KE) and destruction and calculate the first row together. Present slide M. Ask students what velocity we should assume. Students may not know, but they may have some ideas of where we could look. Suggest that we go with a worst case[sic] velocity, the speed of the Chicxulub meteor. Ask students to look back to the data cards from Lesson 1 (also found in Student Data Cards). They should settle on about 20 km/s" (page 14).
- *The availability of energy limits what can occur in any system.*
    - Lesson 10: "Give students a few moments to read the text on the slide: Most craters lack evidence of the meteor that created them, but a recent study by Nicholas Timms and coworkers found cubic zirconia in a Canadian crater. This material forms when zircon, a common mineral on Earth, is heated to at least 2370°C (4298 °F). This suggests that intense heat is generated during a meteor collision — enough to vaporize a meteor! Then ask them to Turn and Talk with the prompts: Where does the energy to generate this intense heat come from? When you invite students to share, they should

mention that the energy to generate the high heat comes from the kinetic energy of the meteor" (page 19).

Crosscutting Concepts (CCCs) | **Rating: Extensive**
The reviewers found extensive evidence that students have the opportunity to use or develop the CCCs in this unit because students regularly engage in high school elements of the CCCs. There is a match between most claimed elements and student learning activities and prompts.

Scale, Proportion, and Quantity

- *The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs.*
  - Lesson 1: "Discuss the scale of phenomena. Present slide L. Begin by asking students to consider the spatial scale of the phenomena presented in the cards, and then discuss the time scale of these phenomena. You can ask the following questions: What information presented in the cards can give us ideas about how much distance these objects travel? What information presented in the cards can give us ideas about the duration of each of these phenomena?... Use Chart paper during this discussion. Draw a horizontal line to represent the space scale first. Once students have shared their ideas to sort the cards from this perspective, draw a vertical line to represent the time scale. Use the sticky notes with the names of the phenomena cards and arrange them based on the ideas students share. The objective of this activity is to assist students in recognizing the similarities and differences in the time and space scales among various space objects. Additionally, it will help prompt scale-related questions, such as why some objects remain in orbit for longer periods while others only last a few years. This activity also aims to encourage ideas about the properties of space objects that might explain the differences in scale" (pages 22–23).
  - Lesson 8: "Connect to prior work with testing model limitations across different scales. Emphasize that a recurring practice in science is to test to see if the models that we/scientists build based on data collected at one scale hold over a much larger or much smaller scale. Refer to the scale chart developed in OpenSciEd Unit P.4: Meteors, Orbits, and Gravity (Meteors Unit) and ask students to recall an example of similar thinking/wonderings we had from this unit. Listen for students to recall one or more of these examples: From lesson 2: Whether the trend in gravitational force vs. height at a smaller scale (seemingly constant at the scale of the dimensions of our room) holds over a larger scale (thousands of miles away from Earth's surface). From lesson 5: Whether the trend in energy stored in a gravitational field vs. height from Earth'(sic) surface at a smaller scale (a seemingly linear relationship near Earth'(sic) surface) holds over a larger scale (ends up being non-linear when viewed thousands of miles away from Earth's surface)" (page 12).
  - Lesson 9: "Under this write 'Effects different scales:' Divide the rest of the chart paper into 3 columns. Say Let's come together and brainstorm the potential effects of different sized impactors. Let's start by thinking about what we know happened with the Chelyabinsk meteor. Ask students to share what they remember happened as a result of the Chelyabinsk meteor impact. As students share, record their ideas in the middle column of the chart paper under the heading 'Chelyabinsk sized.'" (page 6). The class makes a chart to classify effects on earth from different sized scales of meteors.
  - Lesson 11: This element is claimed in the Teacher Guide document for this lesson, but student prompts and questions make no mention of scale or proportion in this lesson.

- *Some systems can only be studied indirectly as they are too small, too large, too fast, or too slow to observe directly.*
    - Lesson 2: "Use scale thinking. Present slide G. Consider the limitations of our current setup to investigate the role of distance on gravity with the prompt: Why might it be challenging to study the effect of distance on gravity at the scale we are investigating in the classroom? Look for students to say that we would need to go really high, which is very difficult and even dangerous. Say, The scale we believe we need to investigate this question is too large. Let's consider another non-contact force that can help us explore this question on a smaller scale" (page 15). "Motivate collecting some data. Say, We are interested in investigating how gravity affects space objects, but we know we cannot study it directly because the scale required for that is too large. Instead, we will use magnets to collect data on a smaller scale—the scale of our classroom—and compare it to data collected by others for gravitational forces at a larger scale, where we are unable to collect the data ourselves" (page 17).
    - Lesson 13: "Which of the changes you observed in the craters using this physical model do you think could be observed in real craters on Earth? Why? How much time would it take to observe similar changes in the surface features of real craters on Earth? What sort of data do scientists use to study changes in Earth's systems over this time scale? Look for the following ideas: We saw the features (shape, size) of the craters changing. This should happen to the real craters. It would take millions of years for real craters to change in the same way the craters in our physical model did" (page 15).
- *Algebraic thinking is used to examine scientific data and predict the effect of a change in one variable on another (e.g., linear growth vs. exponential growth).*
    - Lesson 2: "Display slide Y. Give students three minutes to discuss the questions on the slide with a partner: How would the graph for a 3 times larger mass (60 g) compare? How would a graph of the force of gravity on either object (20g or 60 g) compare if we measured it as we moved it away from the center of the moon?... Ask them to compare their annotated graphs with a partner, and discuss the prompt: How does the distance (r) between an object and center of the planet/moon affect the strength of the gravitational force (Fg) on it?... How does the mass of the object (m1) affect this force (Fg)? How does the mass of the planet or moon (m2) affect this force (Fg)?" (pages 28, 30).
    - Lesson 3: "Based on your results and your ideas about the relationship between gravity and the velocity of orbiting objects, develop an explanation for: how space objects can remain in stable orbits and how their orbits can change. In your explanation, describe how the distance between objects affects this relationship" (Lesson 3 Handout – Investigating Circular Motion, page 3).
    - Lesson 3: "Describe the effect of a change in radius, a, on the period, T. What type of mathematical relationship is this? Choose one: Linear; Exponential; It is quadratic; There is no clear relationship. Justify your choice based on the graph" (Lesson 3 Handout – Kepler's Third Law, page 3).
    - Lesson 7: "Question 5: The spacecraft crashed into Dimorphos at roughly 6,258 m/s. Compared with Dimorphos, which has a mass of about five billion kilograms (5 * 109 kg), the DART spacecraft weighed just 550 kilograms (5.5 * 102 kg) at the time of impact. So how did such a light spacecraft affect the orbit of a relatively massive asteroid? Use an energy transfer perspective and the equation below to support your answer: Kinetic energy = m*V^2/2" (Lesson 7 Assessment, page 6).

Patterns

- *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 7: While reviewing different methods to change the path of an asteroid, students are asked, "This is an example of making predictions and then comparing patterns in the system at one scale (time differences) to patterns at a different scale (size differences). What are other systems where you would expect to observe different patterns when observed at various scales?" (Assessment Changing Asteroid Orbits).
- *Mathematical representations are needed to identify some patterns.*
    - Lesson 2: "Turn and Talk: How would the graph for a 3 times larger mass (60 g) compare? How would a graph of the force of gravity on either object (20g or 60 g) compare if we measured it as we moved it away from the center of the moon?... Based on the patterns you noticed in the data, does the force of gravity on an object become zero when its distance from Earth is sufficiently large?... This equation is one that scientists have developed to predict the relationships we identified. It is referred to as the Universal Law of Gravitation... Use the Universal Law of Gravitation to find what the strength of the gravitational force would be on both objects in your system." (Lesson 2 Slides, slides Y–FF)
    - Lesson 10: Students calculate potential and kinetic energies in order to identify patterns in the effect of energy on the size of impact craters. "Highlight the difficulty of measuring the velocity of an object on free fall, as it happens too fast to measure it accurately. Use the equation on the board to help the class see how we can find the velocity of the object: m*g*h = ½(m*v2). Use the slide prompt during this discussion: How is this relationship similar to one we used to predict changes in the pendulum and orbiting objects?... Say, This means we don't need to measure the velocity ourselves, but we need to measure the height very accurately. Let's see how we can double the velocity by changing the height of the drop..." (pages 10–11).

Systems and System Models

- *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 the models.*
    - Lesson 4: "Part 4: Develop a model. Use words and drawings to show the shape, or eccentricity of the orbits of objects in our solar system influences the likelihood of objects colliding in our solar system. What additional information would you need to create a model that predicts the potential of a collision between a comet and Earth with high accuracy?" (Lesson 4 Handout – Orbital Shapes, page 5).
    - Lesson 4: "Consider the limitations of the model. Present slide W. Ask students to answer the following questions in their notebook: Is the shape of orbits enough to predict a future collision between Earth and a space object? Why or why not? What additional information would you need to predict where and/or when a collision could occur?" (page 21).
    - Lesson 6: "Consider the possibility that the Chelyabinsk meteor experienced a collision with another asteroid in the asteroid belt. Use words, drawings, and symbols to show a collision with another asteroid could have led the Chelyabinsk meteor towards earth. What type of force will affect the speed and direction of the Chelyabinsk meteor, and why? 3. What limitations might your models have in being able to predict how the orbit

of the Chelyabinsk Meteor was changed?" (Lesson 6 Handout – Redirection of Asteroids).

Energy and Matter

- *The total amount of energy and matter in closed systems is conserved.*
  - Lesson 5: Students use visual and mathematical models to determine the energies found in a pendulum system and an orbiting asteroid system. After analyzing data from their models, the class shows that energy was conserved in both systems. "Share Findings. Present slide V. Invite some volunteers to share their findings about the energy of the pendulum and orbit. Use the slide prompts to elicit findings: Say, Right, we can clearly see how our changes in energy are consistent throughout the stages. That means we can say the energy is conserved. We just proved that the energy does flow in and out of the system and is not being created or destroyed as our Kinetic energy levels change" (page 21).
- *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 10: This is a targeted CCC element for Lesson 10, but student prompts and instructions do not engage them with the idea of energy and matter flows into, out of, and within a system.
  - Lesson 11: "Construct individual explanations. Display slide K. Read the text at the top of slide and the related prompt: Scientists estimate that the Chelyabinsk meteor had a mass of 12 tons (12,000 kg) when it first reached Earth's atmosphere. But, they only recovered 1 ton of solid fragments. How can you explain what happened to the 11 tons of missing matter? Emphasizing that students should use ideas related to M-E-F to account for this discrepancy. Ask students to write these individual explanations on a separate piece of paper. Collect these as a formative assessment" (page 14).
  - Lesson 14: "Prompt students to consider other M-E-F perspectives. Present slide N. Prompt 2-3 student responses to the questions on the slide. Say, now, we will take on the force interactions and energy transfer lens. In particular, think about what other Earth systems might have experienced a transfer of energy to/through them as a result of this impact that we haven't considered yet" (page 17).
  - Lesson 15: "Question 1. Models of the impact between Theia and Earth result in Theia being destroyed, and the Earth melting into liquid rock. Use M-E-F thinking to explain why the models might produce this result (use a combination of words, drawings, and symbols)" (Lesson 15 Assessment – Moon Formation).

Stability and Change

- *Much of science deals with constructing explanations of how things change and how they remain stable.*
  - Lesson 3: Students develop an explanation for the interactions between space objects to account for the stability and change of orbits. The Investigating Circular Motion Handout instructs, "Based on your results and your ideas about the relationship between gravity and the velocity of orbiting objects, develop an explanation for: how space objects can remain in stable orbits and how their orbits can change."
  - Lesson 13: Students will write an explanation about why the Moon's surface has remained relatively stable while Earth's surface has changed in the last 4.5 billion years.
  - Lesson 14: Students investigate how the Chicxulub impactor could have led to the extinction of some species (change) but not others (stability), based on fossil evidence.

"Elicit students' thinking about Earth's systems. Present slide R. Motivate students to connect the mass extinctions that occurred 65 million years ago to a shift in one or more of Earth's systems. Read the slide instructions aloud: Based on the readings, which Earth systems do scientists think were affected by the meteor impact? How could some of these changes in Earth systems have led to the extinction of some organisms but not others? Look for students to articulate potential ways that Earth's systems were affected by a massive impactor collision" (page 20).

- Lesson 15: "Much of science deals with constructing explanations of how things change, and how they remain stable. Let's use some of the ideas we developed during this unit to explain how the sudden collision of Theia and early Earth could have led to the stable system we see today. Question 1. Models of the impact between Theia and Earth result in Theia being destroyed, and the Earth melting into liquid rock. Use M-E-F thinking to explain why the models might produce this result (use a combination of words, drawings, and symbols)" (Lesson 15 Assessment – Moon Formation).

Suggestions for Improvement

Science and Engineering Practices

Consider ensuring that student activities match all the claimed elements and not just the practice categories (e.g., **Developing and Using Models**), which often represent an early elementary level of the SEP. Consider modifying claims of targeted SEP elements to match the student activities in the unit.

Disciplinary Core Ideas

- Some of the targeted elements have only one lesson or one part of a lesson in which students engage and learn about the idea. Providing more opportunities throughout the unit for students to engage with the same ideas more than once could help deepen student understanding of these core ideas.
- For the missing parts of the DCI elements, consider either providing an opportunity for students to use and develop the entire element, or clearly documenting what part of the element is not developed. Consider matching which part of the elements are claimed in the front matter and what is claimed in unit lessons.

Crosscutting Concepts

In major assessments, such as the transfer task in Lesson 15, consider ensuring that the student prompts contain language from or similar to the CCC elements to encourage students to respond to the prompt using the lens of the CCC at the high school level. Using specific language from the element could help guide students to include these ideas in their responses.

Meteors, Orbits, and Gravity
EQuIP RUBRIC FOR SCIENCE EVALUATION

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 or designing solutions to problems because there are numerous learning events and assessments where students use targeted elements of all three dimensions to make sense of phenomenon. While some learning tasks may integrate only two dimensions, most involve all three dimensions working together.

Examples of student learning tasks that integrate elements from all three dimensions:

- Lesson 3 Handout – Investigating Circular Motion: "Based on your results and your ideas about the relationship between gravity and the velocity of orbiting objects, develop an explanation for: how space objects can remain in stable orbits and how their orbits can change. In your explanation, describe how the distance between objects affects this relationship" (page 3). This assessment prompt requires students to integrate the following elements:
  - SEP: *Develop and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems*,
  - DCI: *Kepler's laws describe common features of the motions of orbiting objects, including their elliptical paths around the sun. Orbits may change due to the gravitational effects from, or collisions with, other objects in the solar system*.
  - CCC: *Algebraic thinking is used to examine scientific data and predict the effect of a change in one variable on another (e.g., linear growth vs. exponential growth).*
- Lesson 4 Handout – Orbital Shapes: "Part 4: Develop a model. Use words and drawings to show the shape, or eccentricity of the orbits of objects in our solar system influences the likelihood of objects colliding in our solar system. What additional information would you need to create a model that predicts the potential of a collision between a comet and Earth with high accuracy?" (page 5). This formative assessment task integrates the following elements:
  - 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: *Kepler's laws describe common features of the motions of orbiting objects, including their elliptical paths around the sun. Orbits may change due to the gravitational effects from, or collisions with, other objects in the solar system*.
  - 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 the models.*
- Lesson 6 Handout – Redirection of Asteroids: "Consider the possibility that the Chelyabinsk meteor experienced a collision with another asteroid in the asteroid belt. Use words, drawings, and symbols to show a collision with another asteroid could have led the Chelyabinsk meteor

towards earth. What type of force will affect the speed and direction of the Chelyabinsk meteor, and why? What limitations might your models have in being able to predict how the orbit of the Chelyabinsk Meteor was changed?" In this activity, students integrate the following elements:
   - 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: *Kepler's laws describe common features of the motions of orbiting objects, including their elliptical paths around the sun. Orbits may change due to the gravitational effects from, or collisions with, other objects in the solar system* and *Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational ~~and electrostatic~~ forces between distant objects.*
   - 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 the models.*
- Lesson 10: Students investigate if a meteor's velocity or mass better predicts its crater size. They analyze the results using the coefficient of correlation to establish that the velocity of an impactor better predicts the crater's size. They model the changes in matter and energy within the meteor-Earth system. The activity integrates the following elements:
   - SEP: *Evaluate the impact of new data on a working explanation and/or model of a proposed process or system*.
   - DCI: *The availability of energy limits what can occur in any system.*
   - CCC: *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 15 Assessment – Moon Formation: "Question 1. Models of the impact between Theia and Earth result in Theia being destroyed, and the Earth melting into liquid rock. Use M-E-F thinking to explain why the models might produce this result (use a combination of words, drawings, and symbols)." In this assessment task, students integrate the following elements:
   - SEP: *Develop and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems.*
   - DCI: *Although active geologic processes, such as plate tectonics and erosion, have destroyed or altered most of the very early rock record on Earth, other objects in the solar system, such as lunar rocks, asteroids, and meteorites, have changed little over billions of years. Studying these objects can provide information about Earth's formation and early history*.
   - CCC: *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*.

Suggestions for Improvement

Consider ensuring that student prompts and teacher questions integrate language from the targeted CCC element in order for students to better integrate the CCCs into their sense-making.

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	Adequate *(None, Inadequate, Adequate, Extensive)*

The reviewers found adequate evidence that lessons fit together coherently to target a set of Performance Expectations (PEs) because lessons connect logically across the unit and are sequenced coherently from the student perspective. Some opportunities to address student questions and cultivate new questions are found throughout the unit. There are sufficient opportunities for students to build proficiency in most, but not all, of the targeted learning for all three dimensions.

Lessons are logically and coherently sequenced from the student perspective. The "Navigation" section at the start and end of each lesson supports students in seeing these connections between lessons. Some examples:

- Lesson 5: "Review findings about space collisions. Present slide A. Remind students that we decided that the shape of an orbit can help us predict future collision with the Earth. Use slide prompts to elicit some ideas about needed additional information: How could the shape of an orbit help us predict if it will collide with Earth? What additional information about the Earth-object system did we want to collect to help us predict?" (page 7).
- Lesson 8: "Discuss DART technology. Present slide A. Say, Last time we explored some technology that could prevent Earth from a future impact. Give students a half minute to read the two questions on the slide on their own and then discuss them as a class. Suggested prompts: We have technology to deflect potential incoming objects, but how often do we think something like this will be needed? What kind of data could help us figure this out?" (page 7).
- Lesson 9: "Present slide A. Say, We started considering these questions last time. Let's revisit them again to develop our initial ideas further. Our planet is over 4.5 million years old. So what has happened to all the objects many factors of 10 bigger than Chelyabinsk that reached Earth over that time? All the objects that were many factors of 10 smaller? Give students 3 minutes to discuss with a partner" (page 6).
- Lesson 11: "Display slide A. Say, Last time we investigated how mass and velocity of a meteor help explain the damage it can cause. Discuss the question on the slide as the class: What ideas did we have in our last lesson about what happens to all of these objects that enter Earth's atmosphere every year? Point to the Initial Consensus Model: Observed Phenomena During the Chelyabinsk Event poster during this conversation to elicit additional ideas. Sample student responses include: They burn up in the atmosphere; They do not make it to the surface; They melt; They disappear" (page 8).

All lessons build directly on prior lessons. However, most lessons are connected by the teacher telling students what they will be figuring out next based on their learning in the previous lesson. A few lessons build on prior lessons by addressing questions and cultivating new questions based on what students figured out. For example:

- Lesson 3: "Present slide A. Use the slide prompts to motivate investigating the role of gravity on the motion of space objects: What did we figure out last time about the interaction between two objects in space? What would our models predict should happen to all matter in space?" (page 10).
- Lesson 3: "Introduce this unit's progress tracker. Remind students that we use a progress tracker to make a record of our sense making(sic) and ideas throughout each unit. Distribute Progress Tracker and colored pencils. Display slide U. Introduce the format for this unit's progress tracker and its focus on our models and questions. This unit's progress tracker will have three columns: What patterns, results, or data have we seen or experienced? What questions did these help us answer or establish in these lessons? How does what we did in the last few lessons help us further our models or answer our questions on the DQB?" (page 23).
- Lesson 9: "Review the protocol for sharing, calling on, linking in, and clustering questions on the Driving Question Board (DQB). Continue until everyone has shared at least one question. If students still have additional questions, shift to giving them an additional minute to add them silently to the DQB, sorted into clusters if they know where they go, or simply putting them on the edge for now, which the class can work on clustering later. Label any new DQB categories that come up" (page 11).
- Lesson 15: "Return to the Driving Question Board. Present slide A. Say, This is the last lesson of this unit. In the past, we have looked at the progress we have made by looking at the questions we can answer from the Driving Question Board.✱ Mark patterns in questions answered using the sticky dots. Facilitate identifying patterns in the 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 sticky dots to mark each of these categories. Distribute a set of sticky dots to each student, and have them come up to the DQB and add their dots to the posted questions" (page 5).

Targeted learning for the unit is identified in the "Unit Overview Materials" document and the "Elements of NGSS Dimensions" document. These documents identify the targeted PEs as well as the elements for all three dimensions for the unit and on the lesson level. As stated in Criterion I.B, students are given sufficient time to develop most of the targeted elements, but not all. Through the course of the unit, students build proficiency toward most of the following PEs:

- **HS-ESS1-4** *Use mathematical or computational representations to predict the motion of orbiting objects in the solar system.*
- **HS-ESS1-6** *Apply scientific reasoning and evidence from ancient Earth materials, meteorites, and other planetary surfaces to construct an account of Earth's formation and early history.*
- **HS-PS2-4** *Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.*
- **HS-PS3-1** *Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.*
- **HS-PS3-2** *Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motion of particles (objects) and energy associated with the relative positions of particles (objects).*

Suggestions for Improvement

Currently, many lessons do not revisit student questions or provide students with opportunities to develop new questions. Evidence for this criterion would be stronger if students regularly engaged in asking questions based on what they have learned so that each lesson built off of what they have learned and still need to answer.

I.E. MULTIPLE SCIENCE DOMAINS

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

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

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

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

The reviewers found adequate evidence that links are made across the science domains when appropriate because the phenomena used in the unit can be clearly explained using the physical science and Earth science domains. However, CCC use across science domains is not explicitly pointed out to students and some parts of the unit do not make it clear how different domains work together to explain phenomena.

Students develop understanding of DCIs from both the Earth science domain (such as **ESSS 1.B** and **1.C**) and physical science domain (such as **PS2.B** and **PS3A**) and use these ideas from both domains to explain phenomena in the unit.

Opportunities for students to explicitly use CCCs to make connections across science domains to make sense of the unit phenomena are rarely provided. Related evidence include:

- Lesson 2: "The image used on the slide represents the same Scale Chart used in OpenSciEd Unit P.2: How forces in Earth's interior determine what will happen to its surface? (Earth's Interior Unit). This is a tool to help students consider the scales at which different phenomena occur, and to see how patterns of data at one scale compare and relate to phenomena at other scales" (page 26). While the usefulness of the CCC in explaining phenomena is highlighted, its usefulness *across* science domains is not highlighted.
- Lesson 11: "SUPPORTING STUDENTS IN DEVELOPING AND USING SCALE, PROPORTION, AND QUANTITY Here is an opportunity to make an explicit reference to this element of this crosscutting concept…" (page 16). Several similar statements are made throughout the unit teacher materials highlighting the use or importance of CCCs, but not making connections across science domains.

Suggestions for Improvement

- Consider providing guidance for teachers to support students to see how CCCs can be used across science domains when the opportunity arises. Referencing previous units or other courses like Life Science can allow students to see CCC usefulness across all science domains. In Lesson 14, student learning clearly is connected to life science. This would also be an excellent opportunity to highlight for students the usefulness of CCCs across science domains.
- Consider providing opportunities for students to see more clearly how DCI elements from Lesson Set 1 and Lesson Set 2 work together to explain the unit phenomenon.

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, ELA, history, social studies, or technical standards. Standards are listed in the lessons and students are supported to see how mathematics supports their science sense-making. Students have multiple opportunities to use reading, writing, and speaking standards.

Common Core mathematics standards used in the unit are referenced in the Unit Overview Materials document along with which units the standards are used. Side boxes throughout the teacher edition notes and "Additional Teacher Guidance" boxes at the end of each lesson in the Teacher Edition also highlight connections to the ELA and mathematics CCSSs. For example:

- **CCSS.MATH.CONTENT.HS.N-Q.1 Quantities:** *Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.*
    - Lesson 2: "Students will use the Universal Law of Gravitation equation to calculate the force of gravity acting on objects that have fallen on Earth and objects that remain in orbit. This requires them to choose and interpret units consistently" (page 36).
- **CCSS.MATH.CONTENT.HS.N-Q.2 Quantities:** *Define appropriate quantities for the purpose of descriptive modeling.*
    - Lesson 2: "As students use the Universal Law of Gravitation equation to calculate the force of gravity acting on objects at different distances from Earth, they need to define the units for the constant G" (page 36).

    - Lesson 5: "Students define the parts of a Sun-Asteroid system and a pendulum-Earth system. They define different quantities to calculate energy conservation in these systems" (page 22).
- **CCSS.MATH.CONTENT.HS.A-SSE.1a Seeing Structure in Expressions:** *Interpret parts of an expression, such as terms, factors, and coefficients.*
    - Lesson 2: "As students use the Universal Law of Gravitation equation, they need to interpret what the terms mean in a two object system" (page 36).
    - Lesson 5: "Students interpret what the parts of the equations of kinetic energy and energy stored in fields mean in the real world" (page 22).
- **CCSS.MATH.CONTENT.HS.A-REI.2 Reasoning with Equations and Inequalities:** *Solve simple rational and radical equations in one variable, ~~and give examples showing how extraneous solutions may arise~~.*
    - Lesson 2: As students use the Universal Law of Gravitation equation to calculate the force of gravity acting on objects that have fallen on Earth and objects that remain in orbit, they will need to solve radical equations in one variable" (page 36).
- **CCSS.MATH.CONTENT.HS.A-SSE.2 Seeing Structure in Expressions:** *Use the structure of an expression to identify ways to rewrite it.* And **CCSS.MATH.CONTENT.HS.A-CED.4 Creating Equations:** *Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations.*
    - Lesson 7: "Students will calculate the kinetic energy of an object due [sic] its mass and velocity. They will also use the T2/a3 relationship to find the semimajor axis of an orbit. Students might come with different strategies to rearrange these formulas to highlight a quantity of interest. Some students might be tempted to skip steps for rearranging the formulas, which can lead to algebraic errors. Encourage students to write every step they follow to solve an equation. You can ask students to compare their solutions with an elbow partner in order to expose them to additional ways to rearrange an equation" (page 9).
- **CSS.ELA-ELA/Literacy -RST.11-12.1** *Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.*
    - Lesson 4: "Students will use Objects in Space to distinguish between comets, asteroids, and meteor showers, clarifying gaps in their understanding from lesson 1 that are connected to related phenomena they analyzed in that lesson" (page 24).
    - Lesson 6: "Students will read and analyze what scientists predict caused the redirection of the Chelyabinsk meteor. There[sic] are to highlight specific evidence scientists used to develop their argument and will cite that evidence verbally when they share with the class their ideas about what evidence scientists used" (page 11).
- **CCSS.ELA-LITERACY.RST.11-12.2:** *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 12: "Students will read about the different time periods of the moon, and use a timeline to summarize these ideas" (page 20).

- **CCSS.ELA-LITERACY.RST.9-10.7** *Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words.*
    - Lesson 4: "Students represent one of the types of objects and their orbital paths on chart paper, translating technical information about the eccentricity and semimajor

axis of Earth's and the Peekskill meteor's orbit to create their models. The representation they create serves the purpose of predicting why or whether something collides with Earth and not others, addressing questions that emerged in lesson 1" (page 24).

- **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 13: "Students will integrate ideas from different readings to explain how Earth processes have changed the evidence of craters from Earth's surface" (pages 21–22).

Students have numerous opportunities to use reading, writing, speaking, and listening skills throughout the unit. Some examples are provided below:

- Lesson 3: Students make a written explanation. "Based on your results and your ideas about the relationship between gravity and the velocity of orbiting objects, develop an explanation for: how space objects can remain in stable orbits and how their orbits can change. In your explanation, describe how the distance between objects affects this relationship" (Lesson 3 Handout – Investigating Circular Motion).
- Lesson 4: "Distribute Objects in Space. Present slide Q. Remind students that our goal of the reading is to know about how these objects move in space and if they have the potential to collide with Earth and cause damage. Give them about 10 minutes to complete this reading. Turn and talk about the potential to collide with Earth. Present slide R. Ask students to Turn and Talk with the prompt: What in the reading helps us consider if these things have the potential to collide with Earth and cause damage? Allow students a couple of minutes to discuss before inviting them to share their ideas with the class" (page 19).
- Lesson 5: "Say, Let's set up a data table to keep track of what we notice about objects with various eccentricities. Take a moment to go into your personal glossaries and Turn and Talk with a partner about what eccentricity describes, and how it is related to the shape of an orbit" (page 8).
- Lesson 6: "Present slide F. Explain that we will read about what scientists think caused the redirection of the Chelyabinsk meteor from the asteroid belt so they can find out which possibility is predicted to be the most probable. With your class: Use the slide prompt to generate ideas about what evidence scientists used to make their predictions: What evidence did scientists argue with to determine what redirected the meteor? Listen for the following ideas: The observed trajectory and speed to support the idea of gravitational perturbation; Fragmentation of the meteor supports the idea of a collision based redirection" (page 10).
- Lesson 8: "Present slide G. Distribute Moon Timeline and Lunar Time Periods to each student. Say, the moon's history is divided into different time periods. Understanding these lunar time periods will help us make sense of the crater data. Instruct students to use the information in the reading to mark and label the duration of each time period on their timeline. Give students 8 - 10 minutes to complete this task" (page 12).
- Lesson 11: "Display slide D. Give students a minute to discuss the question on the slide with a partner and then discuss it as a class to elicit some examples" (page 9).
- Lesson 13: Students do a jigsaw reading with some articles and share what they learned in a small group.

Suggestions for Improvement

None

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

CATEGORY II

NGSS INSTRUCTIONAL SUPPORTS

II.A. RELEVANCE AND AUTHENTICITY

II.B. STUDENT IDEAS

II.C. BUILDING PROGRESSIONS

II.D. SCIENTIFIC ACCURACY

II.E. DIFFERENTIATED INSTRUCTION

II.F. TEACHER SUPPORT FOR UNIT COHERENCE

II.G. SCAFFOLDED DIFFERENTIATION OVER TIME

II.A. RELEVANCE AND AUTHENTICITY

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

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

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

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

Rating for Criterion II.A. Relevance and Authenticity	Extensive *(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 students engage with the phenomena through video and pictures. Students have opportunities to connect the phenomena in the unit to their own prior experiences, communities, and cultures.

The phenomena and classroom activities used in the unit are interesting to students and are connected to the real world. Related evidence include:

- Lesson 1: The primary phenomenon for the unit is a rock from space that hit Siberia in 2013. It glowed brightly as it traveled through the air for a few seconds, then exploded and damaged windows in buildings for many miles. This phenomenon can be engaging and compelling for high school students.
- Lesson 7: The assessment task guides students to read about real-world strategies for dealing with a possible asteroid strike on earth.
- Students regularly use real world data as part of the data analyses and investigations. For example, in Lesson 8, students use real-world data about frequency and size of meteor impacts. In Lesson 12 students use real-world data about moon craters from different time periods.

Students experience phenomena as directly as possible, mostly through videos and pictures. Related evidence includes:

- Lesson 1: “Present slide A. Say, A few years ago in Siberia, something puzzling happened. A rock fell from the sky with no warning. Some of you may have seen videos of this event, or heard of something similar happening somewhere else. I will show you two videos from this. The first are from various cameras that recorded the event from different angles. The second is a brief news report related to the event” (page 11).
- Lesson 11: “Describe what happens in the high speed[sic] wind tunnel. Say, Let’s orient ourselves to the views you will see in a video where scientists are testing a satellite in it to what will happen to it when it re-enters the earth’s atmosphere. Point out the different camera views that students will see in the next video in the still image on this slide…Analyze data. Present slide F. Say, The video below shows the results of testing a satellite in the high speed[sic] wind

tunnel. As you watch the video, consider what changes you see happening as well as what interactions might be causing this. Play the video" (page 11).

Students are supported in connecting learning with their communities, cultures, or personal lives as well as their prior experiences. For example:

- Lesson 1: "What other examples have you seen or heard about that: looked like this happening in the sky, included something from space that fell to Earth, could help us understand what happened with the Chelyabinsk event?" (page 19).
- Lesson 1: "Say, I bet there is a lot we can learn from your stories and the stories of those in your families and communities. Let's gather some of these stories for next time. Ask students to spend time describing what happened in Chelyabinsk with friends, family, or a trusted adult, and then discussing the prompts on the handout: What examples have you seen or heard about that looked like this happening in the sky? Included something from space that fell to Earth? Could help us understand what happened with the Chelyabinsk event?" (page 17).
- Lesson 3: "Present slide V. Say, We saw that some space objects, like planets, orbit in stable circular paths around the sun. Do you think that all objects in the solar system have orbits that look like this? What evidence or experiences do you have that could support your claim? Distribute a piece of paper to every student, and give students a few minutes to complete this as an exit ticket. Then say, Let's explore these questions next time" (page 24).
- Lesson 7: "How many of you have seen science fiction movies or TV shows, or read a book where something like this happens? Open up the space for a minute or two for students to share connections to movies and books from pop culture that they enjoy or have connected with. Then say, Usually they come up with a solution though, right? Let's think for a moment about what those could look like" (page 5).
- Lesson 8: "Motivate choosing a real-life equivalent that will help us quantify danger. Present slide L. Ask students the prompts on the slide: How can we quantify how dangerous each of these impactors are? What Earth-bound events can we use [sic] a comparison to understand the effects they might have on a city, for example? You can help students understand these questions by pointing to our table and asking, Where is the line where this becomes very dangerous? Like the level of destroying an entire city? What have we used to quantify the danger of a collision before? Students may suggest forces, or maximum force. Validate these ideas, and ask, What is something you have heard of on Earth that can wipe out an entire city?" (page 14).
- Lesson 11: "Reference prior experiences. Say, You may also recall examples of where air also glows when it is heated above a certain temperature. Some examples of this include the air that produces the flash during lightning and the light given off by the gasses in the flame of a fire" (page 180).
- Lesson 12: "Ask students to Turn and Talk with the prompt: We figured out that there is a connection between what we see on the Moon and what we see on Earth. What from our own experience or from the stories of our communities tells us that the Moon is connected to Earth?...There is no right or wrong answer to this question...Say, it sounds like helping us understand Earth's history is just one way that the Moon is connected to life on Earth. Some of these ideas may be backed by evidence and others may not, but clearly the connections we feel with the Moon is[sic] universal" (page 19).

Suggestions for Improvement
None

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 students often express, clarify, and justify their thinking. Students receive feedback from the teacher and peers but there are very few opportunities to respond to the feedback.

Students are given opportunities to express, clarify, justify, interpret, and represent their ideas in small group and whole class discussions as well as individual written form. For example:

- There are many examples where students do a "turn and talk" with a partner to share their ideas. These opportunities for partner talk occur in nearly every lesson.
- Lesson 3: "Describe the effect of a change in radius, a, on the period, T. What type of mathematical relationship is this? Choose one: Linear; Exponential; It is quadratic; There is no clear relationship; Justify your choice based on the graph" (Lesson 3 Handout – Kepler's Third Law).
- Lesson 6: "Ask the students in the circle to look for places of agreement or disagreement with their own models, such as: Use of arrows; Direction of arrows; Labeling of forces. Ask students to justify their ideas if they disagree with a representation. Encourage students to respond to one another as you come to consensus. After you have come to a consensus, facilitate a discussion using the slide prompts: How do we know which possibility would have a bigger impact on the path of a meteor? How do we know which possibility is more likely? What changes in our initial consensus model do we need to make to reflect this new information about what could have caused the Chelyabinsk meteor to crash into Earth?" (page 9).
- Lesson 8: "Scaffolding Analyzing and Interpreting Data SEP: During the second lesson set of this unit, students will analyze graphs displaying data at different scales. The prompts on slide C are intended as scaffolding to guide students' analysis[sic] of graphs. The goal of this scaffolding is to prompt students to pay attention to the scale shown on the x-axis and y-axis of a graph. Remove this scaffolding in subsequent lessons (10, 12) by not asking these prompts explicitly to give students more responsibility in the way they engage with this practice" (page 8).

Students are supported to reflect on their own learning and reasoning throughout the unit by using the Progress Tracker to show changes in thinking over time. For example:

- Lesson 3: "Introduce this unit's progress tracker. Remind students that we use a progress tracker to make a record of our sense making[sic] and ideas throughout each unit. Distribute Progress Tracker and colored pencils. Display slide U. Introduce the format for this unit's progress tracker and its focus on our models and questions. This unit's progress tracker will have three columns: 1. What patterns, results, or data have we seen or experienced? 2. What questions did these help us answer or establish in these lessons? 3. How does what we did in the last few lessons help us further our models or answer our questions on the DQB? Students should add their Progress Tracker in their science notebook. If students need more space in later lessons, have additional copies of the second page of Progress Tracker" (page 23).

- Lesson 4: "Update Progress Trackers. Present slide Y. Ask students to get out their Progress Tracker and review what they have recorded so far. Then, using the slide, ask them to think about what they have to add to their progress tracker and take a couple minutes to discuss with a partner near them. Distribute or have students collect colored pencils to continue their progress trackers. Have students individually add to their progress trackers considering the prompt: Use words and representations that have helped you make sense of the motion and interactions of space objects" (page 23).
- Lesson 12: "Add to progress tracker. Present slide T. Give students five minutes to use the ideas developed in the last lessons to update their progress trackers. Distribute colored pencils or have them collect colored pencils. Remind students that they should be using their coding system and updating it or adding to it as they need to" (page 20).

Students are given peer and teacher feedback but rarely given the opportunity to respond to it and use the feedback to show growth. For example:

- Lesson 1: "Ask students to use these different perspectives to talk with a partner for 3 minutes about places where they picture the matter is changing in some way, energy is being transferred, and forces are acting on objects in the system… Update individual models. Present slide F. Give students 4 minutes to update their model using some of the ideas they discussed with their partner. Encourage students to use arrows, words, and colored pencils to express their thoughts. Encourage them to use their model to identify any questions they have about this phenomenon, and record those questions at the bottom of their models" (page 15).
- Lesson 2: "Collect their work and provide feedback that can help students identify areas of strength and growth on the use of this mathematical model. Consider providing additional copies of the Calculating Gravitational Forces handout to all students to practice using this mathematical model to calculate the force of gravity acting on other space objects. Both feedback and additional practices will help students prepare for carrying out similar calculations on the mid unit transfer task" (page 33). Student support for utilizing the feedback to improve their performances is not provided.
- Lesson 4: "Prepare for a gallery walk. Present slide U. Let students know that they will be interacting with some of their peers' models through a gallery walk. Ask them to prepare a T-chart in their science notebooks to record similarities and differences between models. Facilitate a gallery walk. Students should stay with the groups where they developed their initial models, rotating to see models from three other groups for 1 minute each. During that time, they should discuss and write down similarities and differences between models in their science notebooks. Return to small groups to reflect on initial models. Present slide V. Ask students to return to their initial models with their partner and discuss what revisions they might want to make. Give them a few more minutes to revise their models" (page 21). Students do a gallery walk to see similarities and differences with other students' models to revise their own model. However, they are not giving feedback to each other in order to improve their models.
- Lesson 5: "During the mid unit transfer task, students will consider how a gravity tractor can transfer energy to an asteroid to change its orbit. See how students describe energy transfer

between the object and the gravitational field. If students only mention the values of kinetic energy and energy stored in fields, provide feedback that prompts them to describe whether and how energy is transferred in the system" (Lesson 5 Handout – Energy Investigation Key).

- Lesson 7: "This assessment will take students the remainder of the class period to complete. Once completed, students should turn in their assessment to you for feedback" (page 8). Guidance for student feedback is provided but students do not have an opportunity to respond to the feedback or revise their thinking/product.
- Lesson 10: "Students will use these ideas about how the amount of energy in a system can determine the observed changes in matter during the summative end-of-unit transfer task in Lesson 15. Provide prompt feedback on these explanations to give students enough time to identify areas where they may need support before the assessment" (page 20).
- Lesson 14: "Prepare for and carry out a silent gallery walk. Display slide V. Distribute 5 sticky notes to each student as they review the directions on the slide. Have students lay out their models on their desk so others can see them. Have students carry out a silent gallery walk… Review and respond to questions. Display slide W. Give students the remaining time to review the directions on the slide and respond to the questions other students left for them" (page 23).
- Lesson 15: "This assessment will take students the remainder of the class period to complete. Once completed, students should turn in their assessment to you for feedback" (page 7). Guidance for student feedback is provided but students do not have an opportunity to respond to the feedback or revise their thinking/product.

Suggestions for Improvement

In many cases, students receive feedback from the teacher or from peers, but they are not provided the opportunity or instruction to revise their work or improve their work, incorporating the feedback they receive. Consider providing teachers guidance and supports for ensuring students use the feedback they receive to show growth in their learning.

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. The Teacher Edition resources and the Unit Materials Overview document identify prior learning in all three dimensions, but not at the element level. Additionally, the guidance in the Teacher Edition describes how prior learning will be built upon in the lessons.

Related evidence include:

- In the Unit Overview Materials document, prior student learning that the unit builds upon is identified and linked to previous units and middle school elements that students should already be familiar with. This prior learning is identified for all three dimensions at the general category level and not at the element level.
- A list of common ideas that students may have going into the unit is provided in the Unit Overview Materials document. For example, "Some relevant ideas that students may come into the unit with include the following: A continuous force is needed for continuous orbital motion. Direction of motion in an orbit implies direction of force. Rest is the natural state of objects in space" (Unit Overview Materials, page 27). Guidance for teachers to address these potential alternate understandings is not provided here.
- Each lesson identifies how prior learning will be built upon in all three dimensions in the "Where We Are Going" section of the Teacher Edition. The materials often make connections with previous OpenSciEd units and lessons that students may have encountered. Some examples are provided below:
    - Lesson 1: "Students first developed ideas about how energy transfers are accompanied by changes in matter in OpenSciEd Unit P.1: How can we design more reliable systems to meet our communities' energy needs? (Electricity Unit) and extended this idea in OpenSciEd Unit P.2: How forces in Earth's interior determine what will happen to its surface? (Earth's Interior Unit). Students considered how forces cause changes in matter, including non-elastic, permanent deformation in the later unit as well as in OpenSciEd Unit P.3: What can we do to make driving safer for everyone? (Vehicle Collisions Unit)" (page 9).
    - Lesson 4: "This lesson is designed to continue to target SEP 2.3, 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. Students evaluate the impact of new data on developing the overarching models of objects colliding with Earth. This is supported in this lesson through the use of the progress tracker as well as within the modeling task. In the next lesson, students will continue using this practice through the use of shape models and the addition of speed. Both lessons connect specifically to the system of Earth, the Sun, and other objects in space that have the potential to collide with Earth. This is a direct tie to the anchoring phenomenon and DQB. This lesson continues to develop student understanding of Kepler's laws covered in this DCI element: DCI ESS1.B.1 Kepler's laws describe common features of the motions of orbiting objects, including their elliptical paths around the sun (HS-ESS1-4). The previous lesson establishes the relationship between orbit period and orbital radius. In this lesson we explore elliptical shapes and motivate the need to explore the motion of objects along their orbit. This lesson is designed to support understanding of the following crosscutting concept: Systems and System Models: 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" (page 7).
    - Lesson 8: "Connect to prior work with testing model limitations across different scales. Emphasize that a recurring practice in science is to test to see if the models that we/scientists build based on data collected at one scale hold over a much larger or much smaller scale. Refer to the scale chart developed in OpenSciEd Unit P.4: Meteors,

Orbits, and Gravity (Meteors Unit) and ask students to recall an example of similar thinking/wonderings we had from this unit" (page 12).

- Lesson 9: "This lesson is designed to coherently build ideas related to the following disciplinary core idea, which students used in the prior lesson: ESS1.C.2 Although active geologic processes, such as plate tectonics and erosion, have destroyed or altered most of the very early rock record on Earth, other objects in the solar system, such as lunar rocks, asteroids, and meteorites, have changed little over billions of years. Studying these objects can provide information about Earth's formation and early history. (HS-ESS1-6) This lesson extends students' use of the crosscutting concept from the previous lesson that the significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs, considering different size scales of meteor again and different time scales (a single year) vs. the entire history of Earth. This cross-cutting concept will be used again in the next lesson" (page 5).
- Lesson 14: "Students develop and use these elements of this CCC across this lesson: Changes in systems may have various causes that may not have equal effects. 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. Much of science deals with constructing explanations of how things change and how they remain stable. Students have developed these two ideas in the context of explaining what is happening to meteors moving through the atmosphere in lesson 1. In this lesson, students will be applying these ideas to explain matter changes after the moment of impact. Students develop and use this element of this DCI across this lesson: PS3.A.2 At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. Students developed these ideas in the context of explaining what is happening to meteors moving through the atmosphere in lesson 10. In this lesson, students will be applying those ideas to explain matter changes occurring in the crust, ejecta, and sediments and energy transfers related to tsunamis, seismic waves, and heat emitted from debris traveling through the atmosphere" (page 8).

Suggestions for Improvement

- Consider identifying prior learning necessary for students to access the unit materials at the element level in all three dimensions.
- Consider providing supports for teachers to recognize common preconceptions students may have coming into the unit and how to address those preconceptions.

Meteors, Orbits, and Gravity

EQuIP RUBRIC FOR SCIENCE EVALUATION

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 because all science ideas and representations in the materials are accurate and real-world data are used extensively throughout the unit.

Related evidence includes:

- Teachers are supplied with a variety of supports to help them facilitate scientifically accurate learning, including references to scientific studies and articles on the topics explored in the unit. For example:
  - The unit provides a Teacher Background Knowledge section in the Unit Overview Materials document with information about lab safety and how the DCIs are used in the context of this unit (page 16).
  - The teacher materials provide a list of common ideas students may have that are prior conceptions that may need to be addressed to ensure scientific accuracy (Unit Overview Materials, page 27).
  - The Unit Overview Materials document contains a section titled "What are recommended adult-level learning resources for the science concepts in this unit?" (page 30).
  - "Additional Guidance" sections throughout the Teacher Edition provide background information for the teacher that is scientifically accurate.
  - Throughout the unit, students read scientific texts. These articles are written at a grade-appropriate level, although the source of these articles is not always clear.
- Lesson 9: "We started considering these questions last time. Let's revisit them again to develop our initial ideas further. Our planet is over 4.5 million years old. So what has happened to all the objects many factors of 10 bigger than Chelyabinsk that reached Earth over that time?" (page 6). Scientists estimate the age of the Earth as over 4.5 billion years old. While the reviewers believe this was simply a typo, it is a very significant typo that may promote student misunderstandings about the age of the Earth. At later points in the same lesson and other lessons 4.5 billion is cited as the age of Earth.

Suggestions for Improvement

Consider citing credible and reliable sources for text and data provided in handouts and reading materials.

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	Adequate *(None, Inadequate, Adequate, Extensive)*

The reviewers found adequate evidence that the materials provide guidance for teachers to support differentiated instruction because some support for students with disabilities or multilingual learners is provided. However, these supports are infrequent and diverse learners may not be able to successfully engage in the learning throughout the unit. Additionally, support for students who may begin the unit with significantly higher or lower proficiency is not provided. Extensions for students who have already met the PEs and support for struggling students is provided.

Some strategies to support and address the needs of various learner groups are provided. However, supports for multilingual learners and students with disabilities are infrequently provided in the materials. Some of the supports provided include:

- Very general guidance for supporting multilingual learners is provided in the Unit Overview Materials document. “It is especially important for emergent multilingual students to have a reference for this important vocabulary, which includes an accessible definition and visual support. Sometimes defining a word is a challenge. The Teacher Guide provides a suggested definition for each term to support you in helping your class develop a student-friendly definition that is also scientifically accurate” (Unit Overview Materials, page 32).
- Lesson 3: “This PhET simulation includes sound and sonification features. These are non-speech sounds, such as musical tones, that correspond to changing values in the simulation. This feature is intended to create a more immersive simulation environment, and can help reinforce concepts such as the relationship(s) between distance, gravitational force, and velocity of the moving object. The sounds can increase accessibility for students with visual impairments” (pages 18–19).
- Lesson 3: “Encourage students’ action[sic] and expression[sic] in using different representation systems and categories. Allowing students to express their ideas using multiple modalities supports student ownership of their learning by giving students choice, access, and control in navigating their own understanding around the science ideas” (page 23).
- Lesson 3: “English learners language students might benefit from sentence stems that can help them organize their ideas. Provide them with the following sentence stems:
  The relationship between gravitational force and velocity is a key factor in determining…
  When _____________ of an orbiting object is balanced with ______________, it results in __________________.

Changes in _____________ of an orbiting object can impact the stability orbit stability by _________________.
When the distance of the orbiting object increases, its ________________ has to ______________ in order to remain in a stable orbit" (page 16).

- Lesson 13: "The articles in these handouts were written at different reading levels: Accretion (A) and Accretion (B) are written at different levels. Accretion (A) is more challenging, with longer sentences and more complex vocabulary. Accretion (B) contains the same content, but is more accessible for readers. Plate Tectonics, Weathering, Erosion and Deposition and Glaciation should be accessible for readers at this grade level" (page 16).
- Lesson 14: "The articles in these handouts were written at different reading levels: Chicxulub #2: Seafloor is more accessible for readers, while the other readings are more challenging, with longer sentences and more complex vocabulary" (page 15).
- Lesson 15: "Universal Design for Learning: Consider allowing students to express their understandings of the Moon formation in various ways. Some students may benefit from orally responding to the prompts, or by using drawings to make their thinking visible. Online tools such as Flip can assist students in showing and explaining their ideas in more than just writing" (pages 6–7).

Extra support for students who are struggling to meet targeted learning goals is provided. Related evidence includes:

- Every Assessment Opportunity call out box contains a "What to do" section that describes how to support students who are not reaching the learning targets in the three dimensions for that assessment. Some examples include:
  - Lesson 4: "What to do: If students are struggling to create a predictive model, suggest that they create two simple models—one with a space object moving along a low eccentric orbit and one with a space object moving along a high eccentric orbit, including Earth's orbit in each. Ask them to explain how the potential for a collision might increase or decrease based on the shape of the object's orbit. See Orbital Shapes Key for sample responses" (page 17).
  - Lesson 5: "What to do: This is not a moment to judge the accuracy of students' ideas about energy transfer. Instead, keep track of them as you walk around the classroom. If a majority of students don't really know where energy transfers to and from the orbiting objects, highlight that as a question we need to continue exploring, because energy is neither created nor destroyed. You will explore these ideas during the discussion on slide S. Use the Orbital Energy Key to assess students. If students are struggling, use the guidance provided in the included rubric. For questions #2 and #3, if students are struggling to answer those questions, revisit these ideas during the pendulum demonstration on slide S when developing the energy transfer model. For questions[sic] #3, if students struggle to think about what transferred energy into the object, ask students, What sped the object up?" (page 11).
  - Lesson 10: "What to do: Use the following prompts to support groups in discussing each of their protocols: What specific question about the mass and velocity of the impactor are we trying to address with this protocol? Are there any potential confounding variables that could impact your results? How can you control for them? How can you measure how much larger the crater is when you change your independent variable? If your students feel comfortable designing investigations, ask them to make a directional hypothesis that predicts the relationship between the independent and dependent variables" (page 10).

Extensions for students with high interest or who have already met the PEs are provided.

- Lesson 5: "In this extension opportunity, students will further prove that energy is conserved, the sun-asteroid system is closed, and that energy transfers between the gravitational field and the objects by calculating the total amount of energy in the sun-asteroid system… This extension opportunity is recommended as a differentiation option for students who have demonstrated either prior mastery or high interest in the related science and engineering practices it entails. It is not recommended as a required extension for all students" (Lesson 5 Teacher Reference – Extension Opportunity).
- Lesson 8: "If students ask how the mass of a meteor can be derived from a photograph you could offer them an opportunity to explore the data collection method a bit further outside of class. Provide access/copies of [sic] Canadian camera network to interested students who want to investigate this further. It will describe the methodology behind the derivation of estimated mass from the photographs taken" (page 8).
- Lesson 11: "If questions come up about why some planets have atmospheres and others do not you could offer this optional reading to interested students: Magnetosphere. If questions do not come up now, you could offer this as an extension opportunity at the end of lesson 12" (page 18).

Suggestions for Improvement

- Consider providing additional supports for multilingual learners in the lesson materials. Additional assessments with student choice in modality would better serve all learners.
- While some guidance is provided for teachers about the reading level of provided texts, offering alternative versions of these articles at a lower reading level could make the lessons more accessible for students who are well below grade level in reading.

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 support for teachers to link lessons together throughout the unit are provided along with strategies for linking student sense-making to all three dimensions.

Strategies are provided for teachers to link student engagement across lessons through the Progress Tracker, the DQB, and Navigation sections of each lesson's Teacher Guide.

- Navigate Section examples:
  - Lesson 2: "Navigate. Present slide A. Say, Last time we figured out that some space objects can fall from the sky while others remain in space. Then ask students to Turn and Talk with the prompts:" (page 12).
  - Lesson 3: "Present slide A. Use the slide prompts to motivate investigating the role of gravity on the motion of space objects: What did we figure out last time about the interaction between two objects in space? What would our models predict should happen to all matter in space?" (page 10).
  - Lesson 4: "Review evidence about the motion of space objects. Present slide A. Give students a chance to pull out and review their exit tickets from last class. If students were absent or do not have their exit tickets, ask them to simply consider the prompts again: Do you think that all objects in the solar system have orbits that look like this? What evidence or experiences do you have that could support your claim? Present slide B. Ask students to turn and talk about the prompts on the slide, and then use the prompts to elicit 1-2 student ideas" (page 8).
  - Lesson 9: "Compare initial explanations. Present slide A. Say, We started considering these questions last time. Let's revisit them again to develop our initial ideas further" (page 6).
- Lesson 3: "Introduce this unit's progress tracker. Remind students that we use a progress tracker to make a record of our sense making and ideas throughout each unit. Distribute Progress Tracker and colored pencils. Display slide U. Introduce the format for this unit's progress tracker and its focus on our models and questions. This unit's progress tracker will have three columns: What patterns, results, or data have we seen or experienced? What questions did these help us answer or establish in these lessons? How does what we did in the last few lessons help us further our models or answer our questions on the DQB?" (page 23).
- Lesson 15: "Discuss the DQB questions we can answer. Present slide B. Gather the class in a Scientists Circle for a discussion of the questions we can now answer. Display the Takeaways poster to record the 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" (page 5).
- Students use a Science Notebook throughout the unit.
  - Lesson 2: "Give students a few minutes to consider the slide prompts and record their ideas in their science notebook" (page 25).
  - Lesson 3: "In your notebook, use words and drawings to describe the resulting motion of the satellite" (page 11).
  - Lesson 3: "As students set up their progress tracker [sic] is a good opportunity to have them check in on the organization of their science notebook binder. Have students make sure that they have their personal glossary easily accessible and have a section in the notebook set up for this unit with flags, sticky notes, etc. to separate parts of the unit. This will allow them to easily access their personal glossaries and progress trackers throughout the unit" (page 23).
  - Lesson 4: "Let students know that they will be interacting with some of their peers' models through a gallery walk. Ask them to prepare a T-chart in their science notebooks to record similarities and differences between models" (page 21).

- Lesson 6: "Let students know that they will be interacting with some of their peers' models through a gallery walk. Ask them to prepare a T-chart in their science notebooks to record similarities and differences between models" (page 9).
- Lesson 10: "Ask students to work with a partner to define in their notebook a protocol to change the mass and a protocol to change the velocity of the impactor, using some of the materials for this investigation" (page 10).

Throughout the unit, students see that their learning in the three dimensions is linked to the progress they make toward explaining phenomena. Support for teachers to highlight this can be found in the Teacher Edition instructions and call-out boxes. For example:

- Lesson 2: "Reference the crosscutting concept of scale. Present slide W. Use the slide prompt to consider the influence of scale: Do we think the pattern between magnetism and distance at this scale is similar to that of gravity at a larger scale? If so, how would the force of gravity vs. distance graph look?✱ The image used on the slide represents the same Scale Chart used in OpenSciEd Unit P.2: How forces in Earth's interior determine what will happen to its surface? (Earth's Interior Unit). This is a tool to help students consider the scales at which different phenomena occur, and to see how patterns of data at one scale compare and relate to phenomena at other scales" (pages 26–27).
- Lesson 4: "Present slide O. Say, Last time we got to investigate objects moving in orbits with different shapes. Revise some of these orbital shapes by asking students to Turn and Talk with the prompts: What new orbit shapes did we see last time? How does knowing the shape of orbits help us consider the risk of Earth colliding with another space object?" After students finished developing a model of orbital shapes and variables that affect them, the teacher helps them see how their learning connects with the possibility of a meteor collision with Earth.
- Lesson 8: "The focus of this lesson is primarily on helping students use this element of the cross-cutting concept: The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. But taking a moment here to connect to prior work with scale gives you an opportunity to explicitly foreground how these additional elements of these crosscutting concepts appear to be particularly relevant to explaining and predicting the phenomena in this lesson. You may want to ask students for examples of where we have used ideas like this in our prior two units - OpenSciEd Unit P.2: How forces in Earth's interior determine what will happen to its surface? (Earth's Interior Unit) and OpenSciEd Unit P.3: What can we do to make driving safer for everyone? (Vehicle Collisions Unit): Related to the pattern of decreasing frequency of larger mass meteors but only having a limited amount of data we have directly observed so far: Some systems can only be studied indirectly" (pages 10–11).
- Lesson 10: "Revisit the mathematical model for the prior lesson. Display slide A. Discuss the question on the slide as a class: What new questions or ideas for investigation/data did we have that were related to the amount of damage meteors can cause? Accept all answers. Say, Let's start by reminding ourselves of the damage the Chelyabinsk meteor caused. Link to the anchoring phenomenon. Display slide B. Say, The largest fragment of the Chelyabinsk asteroid left an 8-meter (26-foot) diameter hole in the ice of the lake it hit. Discuss the question on the slide as the class: What do we think the outcome would have been if it had hit the land? Do we think the mass or the speed of the meteor has a bigger impact on the damage it causes when it hits the surface?" (page 8). After developing mathematical models and using mathematical and computational thinking, the teacher helps students connect their learning back to the sense-making of the phenomenon.

Suggestions for Improvement

- Consider providing more frequent support for teachers to utilize the DQB or other methods for cultivating and addressing student questions.
- Consider providing more explicit connections between lessons and the primary phenomenon of the Chelyabinsk event and support for teachers to help students see those connections with the primary phenomenon would support stronger unit coherence.

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 some support for reduced scaffolding over time for some of the targeted SEP elements is provided in the teacher resources.

Using Mathematics and Computational Thinking

- *Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations.*
    - Lesson 2: Students look for patterns between the distance (r) between an object and center of the planet/moon and gravitational force. This is completed as a class. “Analyze a gravitational force vs. distance graph <u>together as a class</u>. Display slide X. Discuss the patterns students notice in this graph for a couple of minutes” (page 67).
    - Lesson 5: Students calculate Kepler’s Law to determine the Kinetic Energy and Stored Energy for both the Chelyabinsk Meteor. “With a Partner: Prompt students to jigsaw the calculations for stages 2 & 3 so that <u>each pair of students</u> only calculates the energy for one more stage and then they can share their findings with one another pair. Prompt them to also complete the questions at the end of the handout” (page 120).
    - Lesson 7: Before students complete a transfer task, “Ask students to brainstorm about possible strategies to change the orbit of a space object and discuss the reasons for investing in such strategies” (page 132). They are allowed to use their notes from the unit, but the task is completed individually.

Analyzing and Interpreting Data

- Lesson 8: “Scaffolding Analyzing and Interpreting Data SEP: During the second lesson set of this unit, students will analyze graphs displaying data at different scales. The prompts on slide C are intended as scaffolding to guide students' analysis[sic] of graphs. The goal of this scaffolding is to prompt students to pay attention to the scale shown on the x-axis and y-axis of a graph. Remove this scaffolding in subsequent lessons (10, 12) by not asking these prompts explicitly to give students more responsibility in the way they engage with this practice. If you feel some students could benefit from additional scaffolding and support to engage in this practice, consider providing them [materialPG.L8.REF]” (page 8).

- *Evaluate the impact of new data on a working explanation and/or model of a proposed process or system.*
    - This element is developed in Lessons 10 and 15. In both lessons, students individually complete the revision of an explanation based on new data. There is no evidence of purposeful scaffolding in the earlier lesson that could be later reduced.

Suggestions for Improvement

Consider providing more support for teachers in reducing scaffolding over time for all targeted SEP elements as students move through the unit.

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

CATEGORY III

MONITORING NGSS STUDENT PROGRESS

III.A. MONITORING 3D STUDENT PERFORMANCES

III.B. FORMATIVE

III.C. SCORING GUIDANCE

III.D. UNBIASED TASK/ITEMS

III.E. COHERENT ASSESSMENT SYSTEM

III.F. OPPORTUNITY TO LEARN

III.A. MONITORING 3D STUDENT PERFORMANCES

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

Rating for Criterion III.A. Monitoring 3D Student Performances	Extensive *(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 or design solutions. Students demonstrate their three-dimensional learning through frequent assessment throughout the unit.

Materials routinely elicit observable evidence that students integrate the three dimensions in sense-making of phenomena. The "Assessment Opportunity" boxes in the Teacher Edition call out places where students are showing evidence of this. Some examples:

- Lesson 1: "Collect these models at the end of this activity. You will give these models back at the end of day three. They will use the questions they included in this handout during the construction of the Driving Question Board (DQB) during day three of this lesson… What to look/listen for in the moment: Look for students' models to: Use evidence about the Chelyabinsk event such as flashes of light, sound, smoke, or anything else they might have observed. Label this evidence in some way to indicate changes in matter and energy in different parts of the system. (SEP: 2.3; CCC: 2.2; DCI: PS3.A.2, PS3.A.2) Represent forces such as gravity, friction, or other contact forces acting on the meteor and the Earth's surface. (SEP: 2.3; DCI: ESS1.B.1, PS2.B.1) Represent two different spatial scales - one where we are zoomed out enough to see the meteor above the Earth, and one where the meteor is close to the surface of the Earth. (SEP: 2.3; CCC: 2.2) What to do: This is a great formative assessment opportunity to identify the ideas students are bringing to this unit to represent their thinking about changes in matter, forces acting on matter, and energy. Collect these models at the end of the activity to identify the focus of students' models to represent these ideas" (page 16).
- Lesson 3: "Develop an explanation. Present slide K. Give students 6 minutes to write their answers to the questions in the Data analysis section of Investigating Circular Motion. If time allows it, invite a couple of volunteers to share their answers… What to look/listen for in the moment: Use evidence about velocity, distance, and gravitational force obtained from the physical and computer simulations to support their explanations. (SEP: 2.6; DCI: ESS1.B.1) Account for the stability and change of orbits by describing the relationship between force and velocity. (CCC: 7.1; DCI: ESS1.B.1) Use evidence to describe how the distance of an orbiting object influences the relationship between gravitational force and velocity. (SEP: 2.6; CCC: 7.1; DCI: ESS1.B.1)" (page 16).
- Lesson 6: "Model redirection of meteor. Present slide C. Direct students to show their thinking about what the two possibilities for the redirection of the Chelyabinsk Meteor might look like. Distribute Redirection of Asteroids. Give students 6 minutes to use the instructions in the handout to develop their models… What to look/listen for: Students are using an arrow facing toward Jupiter to model the gravitational force on the Chelyabinsk meteor from Jupiter. (SEP: 2.3; DCI: PS2.B.1) Students label the force as the force of gravity on the Chelyabinsk meteor

from Jupiter. (SEP: 2.3, DCI: PS2.B.1) Students predict that the force they modeled will result in the Chelyabinsk meteor speeding up or slowing down, and moving slightly more in the direction of Jupiter (a wider orbit than expected). (SEP: 2.3, DCI: ESS1.B.1, PS2.B.1) Students predict that the force they modeled will result in minimal changes in the speed and direction of Jupiter. (SEP: 2.3 DCI: ESS1.B.1, PS2.B.1) Students model a collision with an asteroid that will result in a change of the orbit of Chelyabinsk to be in the direction towards Earth. (SEP: 2.3; DCI: ESS1.B.1) Students identify that the force that results in the change in orbit to be a collision/impact force (DCI: ESS1.B.1) Students identify that our models inherently cannot be entirely accurate due to the limitations of our understanding in scale, our inconsideration of other space objects, and/or the precision in the changes in motion for the Chelyabinsk Meteor (CCC: 4.4)" (page 7).

Formal tasks are driven by students making sense of real-world phenomenon using the three dimensions. Some examples:

- Lesson 7: "Question 4: Scientists predicted a minimum change of 73 seconds in the moonlet's revolution period, yet the observed period (Tf) was nearly 30 minutes shorter at 11.38 hours. Let's explain what this means for the motion of the moonlet and the success of this mission. Compare time and spatial scales: How large of an impact will the observed change in time have on the shape of the orbit? Make an initial prediction and explain your reasoning" (Lesson 7 Assessment, page 4). This assessment elicits evidence of student integrating the following elements:
    - 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: *Kepler's laws describe common features of the motions of orbiting objects, including their elliptical paths around the sun. Orbits may change due to the gravitational effects from, or collisions with, other objects in the solar system.*
    - CCC: *The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs.*
- Lesson 7: "Question 5: The spacecraft crashed into Dimorphos at roughly 6,258 m/s. Compared with Dimorphos, which has a mass of about five billion kilograms (5 * 109 kg), the DART spacecraft weighed just 550 kilograms (5.5 * 102 kg) at the time of impact. So how did such a light spacecraft affect the orbit of a relatively massive asteroid? Use an energy transfer perspective and the equation below to support your answer: Kinetic energy = m*V^2/2" (Lesson 7 Assessment, page 6). This assessment elicits evidence of students integrating the following elements:
    - SEP: *Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations.*
    - DCI: *Kepler's laws describe common features of the motions of orbiting objects, including their elliptical paths around the sun. Orbits may change due to the gravitational effects from, or collisions with, other objects in the solar system.*
    - CCC: *Algebraic thinking is used to examine scientific data and predict the effect of a change in one variable on another (e.g., linear growth vs. exponential growth).*
- Lesson 15: "Question 4. When astronauts visited the Moon during the Apollo missions in the 1960s and 1970s, they collected rocks from the Moon and brought them back to Earth for analysis. Given the great challenges of collecting these samples, astronauts only grabbed samples from a few spots on the Moon, and none from its deeper layers. This table shows the results that scientists have obtained from analyzing the composition of soil and rock samples

from the Moon and Earth:… Explain how the results from radiometric data and composition support the Giant Impact hypothesis using any combination of words, drawings, or symbols" (Lesson 15 Assessment, page 4). This assessment elicits evidence of students integrating the following elements:

- 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: *Although active geologic processes, such as plate tectonics and erosion, have destroyed or altered most of the very early rock record on Earth, other objects in the solar system, such as lunar rocks, asteroids, and meteorites, have changed little over billions of years. Studying these objects can provide information about Earth's formation and early history.*
- CCC*: Much of science deals with constructing explanations of how things change and how they remain stable.*

Suggestions for Improvement

Consider providing tasks that require students to integrate the three dimensions in service of sense-making or problem solving in varied ways. In the current unit, students are typically expected to create artifacts of their initial learning but do not always create artifacts later in the learning process. While there is some evidence that students revise their thinking it is typically updating a pre-existing task rather than producing a new artifact such as a model or explanation.

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 the Assessment Opportunity call out boxes as well as the Unit Overview Materials highlight formative assessment opportunities along with support for how teachers should adjust instruction based on student responses.

Related evidence includes:

- Lesson 1: "Collect these models at the end of this activity. You will give these models back at the end of day three. … What to look/listen for in the moment: Look for students[sic] models to: Use evidence about the Chelyabinsk event such as flashes of light, sound, smoke, or anything else they might have observed. Label this evidence in some way to indicate changes in matter and energy indifferent parts of the system. (SEP: 2.3; CCC: 2.2; DCI: PS3.A.2, PS3.A.2) Represent forces such as gravity, friction, or other contact forces acting on the meteor and the

Earth's surface. (SEP: 2.3; DCI: ESS1.B.1, PS2.B.1) Represent two different spatial scales - one where we are zoomed out enough to see the meteor above the Earth, and one where the meteor is close to the surface of the Earth. (SEP: 2.3; CCC: 2.2) What to do: This is a great formative assessment opportunity to identify the ideas students are bringing to this unit to represent their thinking about changes in matter, forces acting on matter, and energy. Collect these models at the end of the activity to identify the focus of students' models to represent these ideas" (page 16).

- Lesson 2: "Question 6: How did mathematical thinking help you identify patterns that help make sense of gravity acting across space over the last few periods? What to look for in response: Note: These could be different for each student. Students should discuss particular ways in which they used mathematics to identify and make sense of patterns throughout the lesson. Students should say how a particular mathematical activity or tool helped them figure out something about gravity; for example, how strong it is at different distances. What to do: If students are struggling to articulate how they used mathematical thinking in their sensemaking, discuss particular ways as a class. These could be: describing patterns in how force and distance between two magnets compare for different sizes of magnets, which helped us make a claim about how a force at a distance can change as objects move apart comparing patterns in magnetic fields to those in gravitational fields, which helped us understand how the pattern in gravitational fields is similar to that in magnetic fields" (Lesson 2 Answer Key – Electronic Exit Ticket Key).
- Lesson 5: "Present slide I. Direct students to use their findings and the simulation to create a model for an object orbiting the sun with a high eccentricity. Distribute Orbital Energy Transfer to each student. Emphasize that students should first model what is happening with matter and then explain orbital speed in terms of energy. See assessment guidance in the teacher guide for what to look for, and how to support students in the moment… What to look for/listen for in the moment: Students mention where energy is transferred to when the orbiting object slows down. (CCC: 5.3; PS3.B.2) Students mention where energy is transferred from when the orbiting object speeds up. (CCC: 5.3; PS3.B.2) Students considering the forces acting on the orbiting object at different points and how the magnitude of the forces changes with distance (PS2.B.1) Describe how these forces can cause energy transfer in/out of the object according to the direction of the motion of the object. (PS2.B.1, PS3.B.2) What to do: This is not a moment to judge the accuracy of students' ideas about energy transfer. Instead, keep track of them as you walk around the classroom. If a majority of students don't really know where energy transfers to and from the orbiting objects, highlight that as a question we need to continue exploring, because energy is neither created nor destroyed. You will explore these ideas during the discussion on slide S. Use the Orbital Energy Key to assess students. If students are struggling, use the guidance provided in the included rubric. For questions #2 and #3, if students are struggling to answer those questions, revisit these ideas during the pendulum demonstration on slide S when developing the energy transfer model. For questions[sic] #3, if students struggle to think about what transferred energy into the object, ask students, What sped the object up?" (page 11).
- Lesson 10: Students revise their explanation about the presence of meteor fragments on Earth. This is called out as a formative assessment and is followed by teacher instructions for what to look for in their explanations and what to do if those elements are not present: "What to look/listen for in the moment: Look for the revised explanation to include the following elements: Differences in the kinetic energy of a small and large meteor due to their mass (SEP: 4.5; CCC: 1.5, 5.2) Changes in the surface due to the kinetic energy of the meteors (SEP: 4.5; CCC: 1.5, 5.2, DCI: PS3.B.4) Some of the energy is transferred to the surroundings as sound and

heat. (SEP: 4.5; CCC: 5.2) The initial kinetic energy of the large meteor results in more heat in the system upon surface impact, which vaporizes the meteor, while the kinetic energy of a small meteor does not result in enough heat to vaporize it. (SEP: 4.5; DCI: PS3.B.4; CCC: 5.2) Matter from the meteor vaporizes, so it might disperse throughout the surroundings. Some matter from the surface is ejected out to the surroundings. Some matter on the surface is broken down, and maybe vaporized as well. (SEP: 4.5; CCC: 5.2) What to do: Ask students to use the Matter and Energy connection on the M-E-F poster: 'Energy transfers and matter changes happen together.' Instruct them to first track the changes in matter and then describe where the energy related to these changes transferred from and to. Project slide R to support students in making connections between the amount of energy transferred by a meteor and the changes in matter observed in the system. Suggest they include this idea in their Progress tracker, as it will support their sense making in Lessons 14 and 15. Energy loss to the surroundings as heat is an idea that students have explored during OpenSciEd Unit P.1: How can we design more reliable systems to meet our communities' energy needs? (Electricity Unit). This is a good opportunity to see if students can apply this idea in a very different context" (page 20).

- Lesson 11: Students respond to the prompt, "How can you explain what happened to the 11 tons of missing matter? Emphasizing that students should use ideas related to M-E-F to account for this discrepancy. Ask students to write these individual explanations on a separate piece of paper. Collect these as a formative assessment" (page 14).
- Guidance is provided to use the Science Notebook as a formative assessment in Lessons 10, 11, 12, 13, and 14. For example:
    - Lesson 10: "Students design an investigation and collect data to analyze how the mass and velocity of the impactor affect impact crater size (volume). The analysis of the data is focused on (1) using the correlation coefficient to identify whether the velocity or the mass of the impactor better explains the damage an asteroid can cause, and (2) drawing connections between the limitations of the experimental setup and the conclusions that can be made about the relationships that were investigated. This is an opportunity to identify areas where students may need support before they apply the ideas about how the amount of energy in a system can determine the changes in matter that are observed during the final transfer task (Lesson 15)" (Unit Overview Materials, page 36).
    - Lesson 13: "Students will develop an explanation about how different geological processes on Earth help explain the patterns in the age distribution of terrestrial craters, which differ vastly from the record of lunar craters. This is an opportunity to identify areas where students may need support before they apply the ideas about how geological processes can alter surface features in Moon Formation in Lesson 15" (Unit Overview Materials, page 37).

Suggestions for Improvement

Consider modifying the formative assessments to attend to issues of student equity and access regularly by including culturally- and linguistically-responsive strategies to help elicit, interpret, and respond to student thinking related to the learning targets.

III.C. SCORING GUIDANCE

Includes aligned rubrics and scoring guidelines that provide guidance for interpreting student performance along the three dimensions to support teachers in (a) planning instruction and (b) providing ongoing feedback to students.	
Rating for Criterion III.C. Scoring Guidance	Extensive *(None, Inadequate, Adequate, Extensive)*

The reviewers found extensive evidence that the included aligned rubrics and scoring guidelines help the teacher interpret student performance for all three dimensions because all formative and summative assessments include scoring guides that include sample student responses and guidance in planning instruction and providing feedback to students. These guidelines are found both in the Unit Overview Materials in the Assessment Overview section and in the "KEY" documents found in individual lesson folders for each assessment.

Assessment targets for elements in all three dimensions are clearly stated and incorporated into the scoring guides and rubrics. For example:

- Lesson 2 Exit Ticket: Scoring Guide indicates which elements of all three dimensions are being assessed in each question of the Exit Ticket. Most questions incorporate two dimensions at once. For example, "Question 6: How did mathematical thinking help you identify patterns that help make sense of gravity acting across space over the last few periods? What to look for in response: Note: These could be different for each student. Students should discuss particular ways in which they used mathematics to identify and make sense of patterns throughout the lesson. Students should say how a particular mathematical activity or tool helped them figure out something about gravity; for example, how strong it is at different distances. What to do: If students are struggling to articulate how they used mathematical thinking in their sensemaking, discuss particular ways as a class. These could be: describing patterns in how force and distance between two magnets compare for different sizes of magnets, which helped us make a claim about how a force at a distance can change as objects move apart comparing patterns in magnetic fields to those in gravitational fields, which helped us understand how the pattern in gravitational fields is similar to that in magnetic fields."
- Lesson 5 Orbital Energy Assessment: Scoring Guide indicates which elements of all three dimensions are being assessed in each question of the formative assessment. Most questions incorporate two dimensions at once. For example, "Question 1: Look for: A model/drawing of an elliptical orbit path around the Sun. (SEP, 2.3; ESS1.B.1, PS3.A.2) The model describes the speed of the orbiting object at multiple points. (SEP, 2.3; PS3.A.2) The model describes the changes in distance at multiple points. (SEP, 2.3; ESS1.B.1) The model shows the Sun at one of the foci, not at the center. (SEP: 2.3; ESS1.B.1)."
- Lesson 7 Changing Asteroid Orbits Assessment: Scoring Guide indicates which elements of all three dimensions are being assessed in each question of the summative assessment. Most questions incorporate two or more dimensions at once. For example, "Question 5: Foundational Pieces Look for: Students include ideas about energy transfer in the system. (PS3.B.2) Linked Understanding Look for: Students use algebraic thinking to include the role of mass and velocity in their energy transfer explanations. (DCI: PS3.B.2; CCC: 5) Organized Understanding Look for: Students use algebraic thinking to include the role of mass and velocity in their energy transfer explanations. (DCI: PS3.B.2; CCC: 5) AND Students use the mathematical model of kinetic energy

to calculate the energy of the spacecraft at the moment of collision to generate and use their answer to support their explanation. (SEP: 2.3; DCI: PS3.B.2)."

All major assessments include scoring and assessment guidance for teachers. Some examples include:

- Lesson 1: "Students showing Foundational Pieces will focus on descriptions of visible (macroscopic) changes in the system. For instance, they might indicate observable evidence of energy in the system, such as the meteor moving fast, fire and heat coming out of the rock, or the blast causing damage on the surface. It is likely at this point in the unit that most students will have this level of understanding. Students with a Linked Understanding might represent force interactions between parts of the system to describe energy transfer, such as the friction between the rock and the atmosphere, or the contact force between the meteor and the surface. Students with an Organized Understanding will display particle-level interactions to account for the energy transfer in the system, such as bonds breaking at the surface, or rock and air particles vibrating very fast. It is unlikely that you will have many students at this level this early in the unit. If many students have an organized understanding, be ready to challenge their ideas about matter, energy and forces in subsequent lessons so that the class does not feel bored. Keep note of the student distribution in each level of understanding. The goal of this unit is to get all students to use ideas at all levels to make sense of this phenomenon" (page 16).
- Lesson 2: "Question 6: How did mathematical thinking help you identify patterns that help make sense of gravity acting across space over the last few periods? What to look for in response: Note: These could be different for each student. Students should discuss particular ways in which they used mathematics to identify and make sense of patterns throughout the lesson. Students should say how a particular mathematical activity or tool helped them figure out something about gravity; for example, how strong it is at different distances" (Lesson 2 Answer Key – Electronic Exit Ticket Key).
- Lesson 2: For the Calculating Gravitational Forces assessment, exemplar student responses are provided. However, a full range of student answers considering different levels of proficiency is not included.
- Lesson 3: For the Kepler's Third assessment exemplar responses are provided. However, a full range of student answers considering different levels of proficiency is not included.
- Lesson 4: For the Orbital Shapes Key assessment, exemplar responses are provided. Two sample student answers are included for the last question, but they do not represent different levels of proficiency.
- Lesson 4: For the Example Collision Model assessment, an exemplar response is provided. However, a full range of student answers considering different levels of proficiency is not included.
- Lesson 5: The Orbital Energy Key provides sample student responses and descriptions of what to look for in student responses at the Foundational, Linked Understanding, and Organized Understanding levels. Suggestions on how to support students at the foundational and linked understanding level are provided in the key as well.
- Lesson 7: The Changing Asteroid Orbits Key provides exemplar student responses for all questions as well as "what to look for" suggestions for each question. For the final question sample student responses are provided at the Foundational, Linked Understanding, and Organized Understanding levels.
- Lesson 14: For the Extinction Organizer assessment, exemplar responses are provided. However, a full range of student answers considering different levels of proficiency is not included.

- Lesson 14: For the Mass Extinction assessment, exemplar responses are provided. However, a full range of student answers considering different levels of proficiency is not included.
- Lesson 15: The Summative Task (Moon Formation) Key has exemplar responses for all questions as well as sample responses at the Foundational, Linked Understanding, and Organized Understanding levels.

Assessment rubrics and scoring guides also provide teachers with guidance for planning instruction and modifying lessons.

- Lesson 2: "What to do: If students are struggling to articulate how they used mathematical thinking in their sensemaking, discuss particular ways as a class. These could be: describing patterns in how force and distance between two magnets compare for different sizes of magnets, which helped us make a claim about how a force at a distance can change as objects move apart comparing patterns in magnetic fields to those in gravitational fields, which helped us understand how the pattern in gravitational fields is similar to that in magnetic fields" (Lesson 2 Answer Key – Electronic Exit Ticket Key).
- Lesson 5: "Feedback/What to Do: Linking: Invite students to revisit their models from lesson 4. What shape are highly eccentric orbits, and are they like circles or more squished? Where is the sun always located for orbits? Organizing: Ask students to use the model to show where energy is being transferred from and to the orbiting object." (Lesson 5 Answer Key Orbital Energy Key, page 3)
- Lesson 7: "How to modify instruction: Encourage these students to use drawings and or mathematical symbols in these explanations to provide additional evidence about students' use of SEP2 and SEP5, and their ideas about ESS1.B.1." (Lesson 7 Answer Key Changing Asteroid Orbits, page 7).
- Lesson 7: "Linking: Encourage students to use ideas about the mass and the energy of the spacecraft to elaborate [sic] their answer. Organizing: Encourage students to be more accurate in their explanations by using the equation. Extending: Challenge students by asking them about what happened with the energy of the spacecraft once it crashed with the moonlet. While the original question is not targeting that part of this DCI element, this extension opportunity will provide evidence about students' ideas about energy conservation in the system." (Lesson 7 Answer Key Changing Asteroid Orbits, page 9).

Suggestions for Improvement

- Consider providing more ways for students to consider their own progress on assessments during the unit. Students could show how their thinking changed over time with evidence from the Progress Tracker.
- Consider adding student responses on some keys for student products that show what different levels of proficiency could look like and what resources from the unit would help with interventions.

III.D. UNBIASED TASK/ITEMS

Meteors, Orbits, and Gravity

EQuIP RUBRIC FOR SCIENCE EVALUATION

Assesses student proficiency using methods, vocabulary, representations, and examples that are accessible and unbiased for all students.	
Rating for Criterion III.D. Unbiased Task/Items	Extensive *(None, Inadequate, Adequate, Extensive)*

The reviewers found extensive evidence that the materials assess student proficiency using accessible and unbiased methods, vocabulary, representations, and examples because representations and scenarios are fair and unbiased. Sufficient on-ramping and scaffolding is provided for each assessment task. Vocabulary and text used for assessment are grade appropriate and frequently accompanied by graphs, diagrams, and pictures.

On-ramping and scaffolding is provided for students to access assessment tasks.

- Lesson 7: "Have students prepare for the assessment. Distribute one copy of Changing Asteroid Orbits to each student, and a calculator. Tell students they will be allowed to use the notes they recorded in their science notebook throughout the unit. This assessment will take students the remainder of the class period to complete. Once completed, students should turn in their assessment to you for feedback" (page 8). Prior to completing the summative mid-unit assessment task, the class brainstorms asteroid deflection ideas and watches a video about one strategy scientists have come up with. This leads up to allowing students to use their notes on the summative assessment task about asteroid deflection strategies.
- Lesson 14: "Administer the assessment individually to students. Present slide D. Say, In this unit, we've figured out how scientists use evidence from Earth and other space objects to predict the future and understand the past. To wrap up our unit you will be asked to apply your understanding of everything we figured out to a new situation, and to consider whether the available evidence supports a theory about the formation of the Moon. This is our final individual assessment for the unit. Project https://youtu.be/vAorgMubH0I to present a supercomputer simulation that NASA scientists carried out to test this theory. Have students prepare for the assessment. Distribute one copy of the [materialPG:L15.SA] Transfer Task to each student, and a calculator. Tell students they will be allowed to use the notes they recorded in their science notebook throughout the unit. This assessment will take students the remainder of the class period to complete. Once completed, students should turn in their assessment to you for feedback" (pages 6–7).

Multiple modalities are used to present information. For example:

- Lesson 4: The Orbital Shapes Handout uses diagrams and text to help students understand relationships between variables they need to create their physical models.
- Lesson 7: "These videos are intended as supports for students to understand the strategies and prompts in the Transfer Task, by providing a pictorial modality to access these ideas" (page 7).
- Lesson 12: Students are given bar graphs, photographs of the moon, texts, and crater images for students to make sense of crater impacts on the moon.
- Lesson 15: The final summative assessment presents information in pictures and in a data table.

Students are provided with opportunities to share their thinking in multiple modalities, and they are sometimes given a choice of modality to respond in. For example:

- Lesson 3: "Encourage students' action[sic] and expression[sic] in using different representation systems and categories. Allowing students to express their ideas using multiple modalities supports student ownership of their learning by giving students choice, access, and control in navigating their own understanding around the science ideas" (page 23).
- Lesson 4: "1. Use drawings and/or descriptions to compare the two orbital shapes" (Lesson 4 Handout – Orbital Shapes). Students are able to show the results of their investigation with their physical model using words or drawings.
- Lesson 10: To answer the prompt, students are encouraged to, "Use words, mathematical symbols, and/or drawings to explain why finding large fragments of smaller meteors is easier than finding large fragments of larger meteors" (page 20).
- Lesson 15: "Universal Design for Learning: Consider allowing students to express their understandings of the Moon formation in various ways. Some students may benefit from orally responding to the prompts, or by using drawings to make their thinking visible. Online tools such as Flip can assist students in showing and explaining their ideas in more than just writing" (pages 6–7).

Suggestions for Improvement

Consider including more frequent tasks that use multiple modalities to present information to ensure all students understand what is expected. This could include orally presenting directions, using a video introduction, or an image to enhance written directions.

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 examples of pre-, formative, and summative assessments are present in the unit. Descriptions and rationales for all assessments in the unit are found in the Assessment Overview section of the Unit Overview Materials.

Teachers are provided with a purpose and rational for how, when, and why student learning is measured across the materials. Related evidence includes:

- Assessment System Overview: This document describes assessments for every lesson and formative assessments embedded in every lesson.

- Lesson-by-Lesson Assessment Opportunities: This document includes what lesson-level PEs are in each lesson and assessment guidance (Unit Overview Materials, pages 39–50).
- Significant summative assessments provide teachers with a three-dimensional rubric, further broken down into elements, to collect observable evidence of three-dimensional student learning. This rubric is provided for Lesson 2: Electronic Exit Ticket, Lesson 5: Orbital Energy, Lesson 7: Changing Asteroid Orbits, and Lesson 15: Moon Formation.

Examples of each type of assessment are provided below:
Pre-Assessment

- “The student work in Lesson 1 available for assessment should be considered a pre-assessment. It is an opportunity to learn more about the ideas your students bring to this unit. Revealing these ideas early on can help you be more strategic in how to build from and leverage student ideas across the unit” (page 240).
- “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. In Lessons[sic] 9 and Lessons[sic] 15, students will revise the Driving Question Board” (page 240).
- Lesson 9: “Students revisit the Driving Question Board. This is an opportunity for pre-assessment for concepts in Lesson Set two” (page 242).

Formative

- Numerous formative assessments are called out throughout the unit. See criterion III.B.
- Some of the most significant formative assessments include:
  - Lesson 4: The model of the Peekskill meteor and Earth collision.
  - Lesson 6: The models of how a meteor could change paths, and the Extinction Evidence Organizer where students summarized central ideas of articles they read.

Summative

- Lesson 7 Assessment Task: “Question 3: According to this strategy, the gravity tractor can change the motion of an asteroid. As we have seen in this and other units, changes in motion are related with energy transfer in the system. Use the image and words to explain how the energy from the gravity tractor transfers to the asteroid without touching it… Question 5: The spacecraft crashed into Dimorphos at roughly 6,258 m/s. Compared with Dimorphos, which has a mass of about five billion kilograms (5 * 109 kg), the DART spacecraft weighed just 550 kilograms (5.5 * 102 kg) at the time of impact. So how did such a light spacecraft affect the orbit of a relatively massive asteroid? Use an energy transfer perspective and the equation below to support your answer.”
- Lesson 15 Assessment Task: “Question 1. Models of the impact between Theia and Earth result in Theia being destroyed, and the Earth melting into liquid rock. Use M-E-F thinking to explain why the models might produce this result (use a combination of words, drawings, and symbols)… Question 3. Scientists use computer models to make inferences about the formation of the Moon, but we don’t have very much direct evidence of the hypothesized impact with Theia. Use words, drawings, and/or symbols to describe how Earth's processes over time might explain why it is so hard to find evidence of this impact.”

Self-Assessment

- Self-Assessment supports are not present in the unit beyond general advice. "Student self-assessment rubrics for giving and receiving feedback can be used throughout the unit. Opportunities include after a discussion or at the end of a class period. The rubric helps students reflect on their participation in the class that day. Choose to use this at least once a week or once every other week. Initially, you might give students ideas for what they can try to improve for the next time, such as sentence starters for discussions. As they gain practice and proficiency with discussions, ask for their ideas about how the whole-class and small-group discussions can be more productive" (Unit Overview Materials, page 38).

Suggestions for Improvement

Consider providing supports and protocols for students to self-assess their progress on three-dimensional learning goals throughout the unit.

III.F. OPPORTUNITY TO LEARN

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

Rating for Criterion III.F. Opportunity to Learn	Adequate *(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 because students are able to demonstrate performance of targeted elements but rarely have a chance to use feedback in an iterative manner to show growth.

For the SEP **Developing and Using Models**, students are given multiple opportunities to show proficiency and growth in using the SEP along with DCI and CCC elements. In a few instances students are given feedback to use to improve their performance.

- Lesson 1: "Ask students to use these different perspectives to talk with a partner for 3 minutes about places where they picture the matter is changing in some way, energy is being transferred, and forces are acting on objects in the system… Update individual models. Present slide F. Give students 4 minutes to update their model using some of the ideas they discussed with their partner. Encourage students to use arrows, words, and colored pencils to express their thoughts. Encourage them to use their model to identify any questions they have about this phenomenon, and record those questions at the bottom of their models" (page 15).
- Lesson 2: "Collect their work and provide feedback that can help students identify areas of strength and growth on the use of this mathematical model. Consider providing additional copies of the Calculating Gravitational Forces handout to all students to practice using this mathematical model to calculate the force of gravity acting on other space objects. Both

feedback and additional practices will help students prepare for carrying out similar calculations on the mid unit transfer task" (page 33).

- Lesson 14: "Prepare for and carry out a silent gallery walk. Display slide V. Distribute 5 sticky notes to each student as they review the directions on the slide. Have students lay out their models on their desk so others can see them. Have students carry out a silent gallery walk… Review and respond to questions. Display slide W. Give students the remaining time to review the directions on the slide and respond to the questions other students left for them" (page 23).

Other examples of students using SEPs along with DCIs and CCCs and receiving feedback include:

- Lesson 2: Calculating Gravitational Forces "What to look/listen for in the moment: Documentation of all the steps to using the Universal law of gravitation to solve for gravitational force between two objects. (SEP: 5.3; CCC: 3.5; DCI: PS2.B.1, PS2.B.2) This could look like: Writing the universal law of gravitation and the known variables, values, and units for G, m, m, and r. Substituting the known values into the corresponding location/order for the variables in the general equation. Performing the related calculations using order of operations. Reporting a predicted force value (F) in Newtons. See Calculating Gravitational Forces for sample answers. What to do: If the students don't document all the algebraic steps for this assessment opportunity, remind them that you will be looking for documentation of these steps in their two assigned objects for Calculating Gravitational Forces. If you feel students need additional practice, assign them the remaining conditions to solve on Calculating Gravitational Forces. Collect their work and provide feedback that can help students identify areas of strength and growth on the use of this mathematical model. Consider providing additional copies of the Calculating Gravitational Forces handout to all students to practice using this mathematical model to calculate the force of gravity acting on other space objects. Both feedback and additional practices will help students prepare for carrying out similar calculations on the mid unit transfer task" (page 70). Students are provided feedback on their performance but no guidance for students using the feedback is provided.
- Lesson 5: Energy Transfer Investigation "What to look for/listen for in the moment: See EnergyTransfer Investigation KEY for guidance. Students develop a mathematical energy transfer model that shows an equal amount of energy transfer between the field and the object. (SEP: 2.3, DCI: PS3.B.2) Students use their mathematical energy transfer model as evidence to show that the Asteroid-Sun system is closed because there are equal amount of energy transfer between the field and the asteroid. (SEP: 2.3, 5.2, CCC: 5.1, DCI: PS3.B.2, PS3.A.2) Students use their mathematical energy transfer model as evidence to show that Kepler's Law is valid because the object experiences high and low kinetic energy points along its path. (SEP: 2.3, 5.2, DCI: ESS1.B.1, PS3.A.2) Students identify that they can use their mathematical energy transfer models to predict where and how fast orbiting objects will be along its path. (SEP: 2.3, DCI: ESS1.B.1, PS3.B.2) What to do: Use the EnergyTransfer Investigation KEY to assess students. If students are struggling, use the guidance provided in the included rubric. Sometimes, students will incorrectly use the values for each stage for the orbital motion. Encourage students to revisit the data for each stage and verify that they used the correct data for the calculations. Sometimes, students can struggle with calculating the changes in energy between stages. Encourage students to think about how we say changes in energy as an after minus before process. When students are asked to provide evidence that the sun-asteroid system is a closed system, students can potentially struggle with thinking about energy transferring in or out of the sun-asteroid system. Encourage students to think about if there are any other forces, besides our gravitational force between the two objects, interacting

with the system that might be transferring energy in or out of it. During the mid unit transfer task, students will use the Kinetic energy equation to calculate the amount of energy of an object at the moment of collusion[sic] with another object. Consider providing additional practice questions at the end of this lesson where students need to calculate the kinetic energy of orbiting objects with varying velocities and masses. During the mid unit transfer task, students will consider how a gravity tractor can transfer energy to an asteroid to change its orbit. See how students describe energy transfer between the object and the gravitational field. If students only mention the values of kinetic energy and energy stored in fields, provide feedback that prompts them to describe whether and how energy is transferred in the system" (page 121). Students are provided feedback on their performance but no guidance for students using the feedback is provided.

- Lesson 10: Meteor Collision revised explanations "What to look/listen for in the moment: Look for the revised explanation to include the following elements: Differences in the kinetic energy of a small and large meteor due to their mass (SEP: 4.5; CCC: 1.5, 5.2) Changes in the surface due to the kinetic energy of the meteors (SEP: 4.5; CCC: 1.5, 5.2, DCI: PS3.B.4) Some of the energy is transferred to the surroundings as sound and heat. (SEP: 4.5; CCC: 5.2) The initial kinetic energy of the large meteor results in more heat in the system upon surface impact, which vaporizes the meteor, while the kinetic energy of a small meteor does not result in enough heat to vaporize it. (SEP: 4.5; DCI: PS3.B.4; CCC: 5.2) Matter from the meteor vaporizes, so it might disperse throughout the surroundings. Some matter from the surface is ejected out to the surroundings. Some matter on the surface is broken down, and maybe[sic] vaporized as well. (SEP: 4.5; CCC: 5.2) What to do: Ask students to use the Matter and Energy connection on the M-E-F poster: 'Energy transfers and matter changes happen together.' Instruct them to first track the changes in matter and then describe where the energy related to these changes transferred from and to. Project slide R to support students in making connections between the amount of energy transferred by a meteor and the changes in matter observed in the system. Suggest they include this idea in their Progress tracker, as it will support their sense making in Lessons 14 and 15. Energy loss to the surroundings as heat is an idea that students have explored during OpenSciEd Unit P.1: How can we design more reliable systems to meet our communities' energy needs? (Electricity Unit). This is a good opportunity to see if students can apply this idea in a very different context. Students will use these ideas about how the amount of energy in a system can determine the observed changes in matter during the summative end-of-unit transfer task in Lesson 15. Provide prompt feedback on these explanations to give students enough time to identify areas where they may need support before the assessment" (page 172). Students are provided feedback on their performance that could be used to improve their performance on the final assessment.
- Lesson 13: Cratering Activity Patterns explanation "What to look/listen for in the moment: Include information from the readings about how plate tectonics, erosion, weathering, accretion contribute to the change in Earth's[sic] at different scales. (SEP:8.1; DCI: ESS1.C.2; CCC: 3.2, 7.1) Explain why the lack of these mechanisms on the Moon help preserve cratering evidence on its surface. (SEP:6.4; DCI: ESS1.C.2; CCC: 7.1) Explain how different geologic processes on Earth have erased evidence of cratering activity. (SEP:6.4; DCI: ESS1.C.2; CCC: 7.1) What to do: Some students might need to be reminded that most of the geologic processes that we read about don't act on the moon. Explanations require students to include mechanisms to account for some of the patterns they observed in the data. You might want to scaffold this practice by asking students to (1) describe a pattern from terrestrial cratering activity data (e.g., left vs. right panels, as shown in slide E), and (2) then include the geological mechanism(s) that help explain this pattern. During the final summative task in Lesson 15,

students will consider why it is hard to find evidence of a hypothesized collision between Earth and another planet. Provide feedback that have students considering the changes in matter that take place as a result of these processes" (page 213). Students are provided feedback on their performance but no guidance for students using the feedback is provided.

Suggestions for Improvement

- Consider adding more places where students receive teacher and peer feedback on their performance of all targeted elements on the first or second performance of that element, as well as opportunities to apply that feedback in a later performance of the same element in an iterative process.
- Consider including more frequent feedback that focuses on improving student performance for all key claimed learning in each of the three dimensions, not just the DCIs.

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

SCORING GUIDES

SCORING GUIDES FOR EACH CATEGORY

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

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

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

OVERALL SCORING GUIDE

Scoring Guides for Each Category

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

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

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

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