Why Do Things Sometimes Get Damaged When They Hit Each Other?

DEVELOPER: OpenSciEd

GRADE: Middle School **| DATE OF REVIEW:** September 2020

Educators Evaluating Quality Instructional Products

NextGen Science WestEd

Why Do Things Sometimes Get Damaged When They Hit Each Other?

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

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EQuIP RUBRIC FOR SCIENCE EVALUATION

Summary Comments

Thank you for your commitment to students and their science education. NextGenScience is glad to partner with you in this continuous improvement process. The unit is strong in several areas, including integrating the three dimensions, using Common Core mathematics and English language arts (ELA) connections, and monitoring three-dimensional student performances. There were thoughtful improvements and changes from the original submission of this unit to the three dimensions, support for expressing student ideas and provision of scoring guidance.

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

- **Scoring Guidance:** This criterion could become an exemplar of three-dimensional scoring guidance for the field if additional support for teachers were added for how to interpret student performance along all three dimensions as well as their integration and use in sense-making or problem solving. Consider including a range of student responses and interpretation guidance with sample student work and scoring guidance tools for teachers with enough information to enable modification of instruction and provision of ongoing targeted feedback to individual students.
- **Student Questions:** This unit often cleverly leverages authentic questions to engage students with a phenomenon. A subtle shift in the ownership of these questions would move this unit closer to exemplary. Teachers are currently supported in the materials to summarize and synthesize learning and next steps for the whole class to navigate between lessons, meaning that the teacher currently has ownership over the navigation between ideas and lessons. Instead, by providing teacher prompts to help students want to answer their own questions, creating a need to know, the materials could shift ownership to the students of this navigation between ideas and lessons.

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 the criterion was not met.

CATEGORY I

NGSS 3D DESIGN

I.A. EXPLAINING PHENOMENA/DESIGNING SOLUTIONS

I.B. THREE DIMENSIONS

I.C. INTEGRATING THE THREE DIMENSIONS

I.D. UNIT COHERENCE

I.E. MULTIPLE SCIENCE DOMAINS

I.F. MATH AND ELA

Why Do Things Sometimes Get Damaged When They Hit Each Other?

EQuIP RUBRIC FOR SCIENCE EVALUATION

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 the materials are organized so students are figuring out a central phenomenon. Throughout the unit, students add layers of understanding directly related to how a cell phone case does or does not protect a cell phone. The unit supports students to understand how the learning they are doing will help them better explain the anchor phenomenon. In Lesson 1, the phenomenon of breaking phones is introduced and students brainstorm related phenomena, leading to the unit driving question "Why do things sometimes get damaged when they hit each other?" This question, as well as the phone phenomenon and the phenomena brainstormed by students drive student learning in Lessons 1–11. However, although students are able to apply the DCIs learned to the engineering task, as it is currently constructed, the task in and of itself doesn't motivate additional sense-making of the DCIs.

Student focus on making sense of phenomena in the unit. For example:

- The anchoring phenomenon, introduced in Lesson 1, is data about cell phone damage. Students are asked to listen to a set of statistics and are asked "Have any of you ever experienced cell phone damage before?" (Teacher Edition, page 31). The phenomenon is introduced to students by providing them with information about cell phone damage. "Introduce cell phone damage information. Display slide A. Say, I came across some interesting data about cell phone damages. Listen to the things I learned! Read each statistic aloud" (Teachers Edition, page 31).
- Lesson 2: Students watch videos of several collisions. These videos motivate student learning over the next several lessons.
- Lesson 3: Students are reminded how current the discussion connects to the original phenomenon: "Say, we need to resolve this question about whether all objects bend or not in a

collision so that we know how this idea applies to the sort of materials like those in a collision between a glass phone screen and a concrete floor" (Teacher Edition, page 80).

- Lesson 4: Students look back at the activities done in this and previous lessons to develop a list of key ideas that have been figured out. The following teacher guidance is provided: "Shift to co-developing a list of key ideas that we figured out from our work with these sources of data. Have students look back at what they wrote in their individual Progress Trackers for ideas. Use prompts similar to these, inviting students to contribute ideas and to work with the ideas that others contribute."
- Lesson 5: Students begin the lesson by rediscussing the collisions they watched in earlier lessons in light of what they have learned up to this point. The following teacher prompts are provided which bring the discussion back to the phone phenomenon introduced in Lesson 1: "So what happens when something like a phone falls and hits the ground and breaks? The two objects are the phone and the ground—what's pushing on what?" "We figured out that for an object to break, it needs a force applied to it that deforms it beyond its elastic limit. So, if you drop a phone and it breaks when it hits the floor, what could be pushing on the phone?" (Teacher Edition, page 111).
- Lesson 5: "Before we do that more-formal assessment, let's complete a short exit ticket to check in on how you are thinking these ideas we developed would apply to something from our anchoring phenomenon" (Teacher Edition, page 126).
- Lesson 7: Students complete a handout that contains the following question: "How do the mathematical relationships you figured out about the effects of mass and speed of an object on its kinetic energy help you make more-accurate predictions for whether a collision would produce damage in some cases and not others?" (Looking Back: Explaining and predicting kinetic energy changes in the system handout,
- page 2).
- Lesson 10: "Say, now that we have this great list of the big ideas we've discovered so far, let's see if we can apply these to explain collisions from Lesson 1. Let's look back at our Different Collisions poster" (Teacher Edition, page 198).
- Lesson 11: The original anchoring phenomenon is revisited. The following teacher prompt is provided: "Say, when we started this unit, we looked at some interesting data. I was looking at it again and one piece of data stuck out. We've learned about and explained how different objects can get damaged in a collision, but even when some objects are protected sometimes they still get damaged. Look at this data from our original phenomena" (Teacher Edition, page 213).
- Assessments are used as opportunities to apply new learning to different phenomena. For example, in Lesson 6, students are asked to explain how "the amount of force on the head compare to the amount of force on the object it collides with in each system A, B, and C" (Lesson 6 Soccer Assessment). In Lesson 10, students apply learning to baseball "graph. In each free body diagram, show all the contact forces on the ball after the ball has left the pitchers' hand. Draw arrows to show the relative strength of forces on the ball. Make sure to include the relative strength and direction of the forces on the ball due to its interaction with the air"

(Lesson 10 Baseball Assessment). In Lesson 15, students draw free body diagrams to show contact between a person's head and headgear: "Draw three free body diagrams, one for each object in your system above. In each diagram: show the strength of the forces applied to each object in the system above – Label what is applying this force to that object – Show the direction of these forces – Label the surface they are applied to" (Lesson 15 Assessment Part 1 Cheerleading).

Student questions and prior experiences motivate sense-making. For example:

- Lesson 1: Students brainstorm related phenomena. "Motivate related phenomena. Say, these categories of collisions could be useful for thinking about other related phenomena where something other than a phone was involved in a collision. But not all collisions result in damage. Think of examples where something other than a phone was damaged in the collision. I also want you to think of examples where you were surprised that something other than a phone was not damaged in a collision" (Teacher Edition, page 35). Students then go through a process of brainstorming related phenomena.
- Lesson 1: Students generate questions for a Driving Question Board (DQB). The DQB is revisited throughout the unit specifically in Lessons 6, 12, and 15.
- Lesson 1: The teacher models three different types of collisions: "As each student shares their experience, create a diagram on a blank piece of paper using squares to represent the two objects that collided. After creating each diagram, attach it on the Different Collisions poster. Draw large enough for students to see. The diagrams will become part of an anchor chart for students to refer to later" (Teacher Edition, page 32).
- Lesson 1: "Forecast that we will investigate our questions. Display slide T. Say, Wow. We have accomplished so much. We now have a broad mission to accomplish as a class. That is thanks to all the questions you shared and how you connected them together. These questions really represent what it is we hope to be able to figure out. And we have a lot of ideas for investigations we could do to try to figure this all out. I am very excited for us to be able to get started on investigating all of this. Let's plan to start exploring some of those questions and ideas in our next lesson" (Teacher Edition, page 50).
- Lesson 6: "This lesson provides an opportunity for students to revisit key ideas by taking stock of ideas learned in Lessons 1–5. We revisit the DQB and utilize the ideas to answer select questions from the beginning of the unit. Students do this before applying those ideas to a real-world soccer scenario in Soccer Assessment" (Teacher Edition, page 132).
- Lesson 7: "Save the last minute to have students make note of what new questions they have. If time permits you could have them write these new questions on sticky notes and add them to their science notebooks to share next time. Either way, suggest to the class that we will pick up our next lesson with this line of thinking by having students share some of the new questions that they are now considering about the entire system we used in the first two investigations in this lesson" (Teacher Edition, page 161).

Students apply the DCIs learned to the engineering task, but as it is currently constructed, the task in and of itself doesn't motivate additional sense-making of the DCIs. For example:

- Lesson 10: "Say, Now that we have this great list of the big ideas we've discovered so far, let's see if we can apply these to explain collisions from Lesson 1. Let's look back at our Different Collisions poster" (Teacher Edition, page 198).
- Lesson 11: The original anchoring phenomenon is revisited. The following teacher prompt is provided: "Say, When we started this unit, we looked at some interesting data. I was looking at it again and one piece of data stuck out. We've learned about and explained how different objects can get damaged in a collision, but even when some objects are protected sometimes they still get damaged. Look at this data from our original phenomena" (Teacher Edition, page 213).
- Lesson 11: After brainstorming some ideas about protecting cell phones, students decide on another object that would need to be protected. Developing a case to protect this device becomes the motivating problem that drives the remaining lessons of the unit. Although students engage in learning related to structure and function relationships in regard to types of materials that reduce peak force on an object and apply some ideas from Disciplinary Core Ideas (DCIs) related to early lessons, there is no direct learning of grade level DCIs that are required to solve this problem. Students could develop a solution to the problem with use of the Physical Science DCIs generated in Lessons 1 through 10 and it wouldn't require development of new ideas.

Suggestions for Improvement

- Consider moving the introduction of the design challenge to an earlier lesson. Introducing or previewing the task in an earlier lesson would provide students with increased opportunities to tie the learning of the core Physical Science DCIs to their design when they revisit the original anchoring phenomenon again.
- Ideally, student questions or prior experiences related to the phenomena would create a student's need to engage in the material. Materials could provide opportunities for students to feel as though they are driving the learning sequence. This could be done with an explicit mapping of student questions and discussions (e.g., individual reflection, small group discussions, and large group consensus) on the next investigation that "needs to be done" in order to better understand the anchor phenomenon or answer questions that the students have about the anchor phenomenon.
- Consider additional opportunities to shift language from teacher-directed instruction to reinforce the students' "need to know" about the phenomena that drive the learning. For example, rather than "You are going to use this handout to develop a model to show what interactions are happening..." (Teacher Edition, page 39) it could say something like "You have been asking a lot of great questions about collision types. How might we represent different types of collisions..." Similarly, the script "This seems like a lot of cell phone damage happening in our world. That got me wondering how common this sort of phenomenon is in our classroom

community" (Teacher Edition, page 31) could be shifted to something like "What do you wonder about the data? Is this data meaningful to our classroom community? In what way?"

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 engage in elements of all three dimensions in order to make sense of the anchoring or lesson-level phenomena.

The unit centers on students consistently engaging in all three dimensions as they work towards an explanation about contact forces. The targeted elements of all three dimensions are identified and addressed throughout the unit.

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

The reviewers found extensive evidence that students have the opportunity to use and develop the SEPs of Planning and Carrying Out Investigations in this unit because there are sufficient SEP elements developed and used at the proper grade level in service of students making sense of phenomena and developing a solution to a problem. Each lesson has at least one SEP identified in the lesson-level performance expectation. These SEPs are identified in the supporting documents, including the Rationale for the Elements of the SEPs and CCCs.

Planning and Carrying Out Investigations:

- *Collect data to produce data to serve as the basis for evidence to answer scientific question or test design.*
  - Lesson 2: Students discuss the things they want to observe more closely in a collision that may or may not result in damage. The following guidance is provided: "Discuss

initial ideas. Project slide A. Give students a couple of minutes to talk with a partner" (Teacher Edition, page 59).

- Lesson 3: "We have two competing claims in our classroom. Some of us think that all solid objects bend or change shape in a collision, while others of us think that not all solid objects bend or change shape in a collision. In a moment we'll start collecting data to serve as evidence to support or refute these two different claims. Our first source of evidence will be from three slow-motion videos of different objects colliding" (Teacher Edition, page 78). Later in Lesson 3, students observe motion of solid objects using a laser-mirror setup: "Direct students to write 'sponge and laser' as a new data source on their handouts" (Teacher Edition, page 82). "Videos from engineers testing how a concrete joint responds to different amounts of contact force" are used as a third source of data. The teacher is instructed to say: "Go back now and evaluate all the data we've collected on the handout to determine if any of it supports or refutes your initial claim" (Teacher Edition, page 84).
- Lesson 7: Students carry out investigations to answer the question "How much does doubling the speed or doubling the mass affect the kinetic energy of an object and the resulting damage that it can do in a collision?" (Teacher Edition, page 147). Students graph kinetic energy relationships using data collected from a computational simulation. "We were debating the effects of tripling the mass or speed of a moving object on its kinetic energy. How would this simulation allow us to answer this question?" "What is the relationship between how far the box moves and the kinetic energy of the virtual cart?" (Teacher Edition, page 155).
- Lesson 9: Students rotate through four stations and "investigate other instances of objects slowing down or producing another interesting outcome related to one of the two additional types of contact forces we have discussed are missing from our system model - friction and air resistance." As students are conducting station activities, their focus should be on gathering evidence to explain additional effects from friction and air resistance that cause changes in motion and KE of subsystems within the collision system" (Teacher Edition, page 185).
- Lesson 12: Students carry out an investigation to collect data about cushioning material and potential protective material. "During this investigation students work in small groups to record multiple trials and calculate averages in the data for a control condition and one cushioner on Cushioning Materials Testing Procedures. Students use this data to determine the average amount of force reduction in their cushioner" (Teacher Edition, page 236).

- *Plan an investigation individually and collaboratively, and in the design identify independent and dependent variables and controls, what tools are needed to do the gathering, how measurements will be recorded, and how many data are needed to support a claim.*
  - Lesson 4: "Ask students what the independent and dependent variables are for this investigation. Students should say that the independent variable is how much we push on an object or the amount of force applied and that the dependent variable is how

much it deform." "Remind students that we have a way to measure the amount of push by reading the amount of newtons on the push-pull spring scale. Ask for ideas about how to measure how much the object bends or deforms. Help students narrow in on the idea of recording the height of the beam before and after they push on it." "Discuss some things that would be important to keep constant in the investigation and add them to the experimental setup diagram. If students don't suggest the placement of the object and the scale as things to keep constant, ask if the location of the spring scale on the material would affect the results and if the distance between the bricks and the amount of overlap of the material on the bricks would affect the results. Suggest that all groups test their objects in the center of the beam and make sure that their beams overlap the bricks by the same amount." "Tell students to use the procedure described on the Investigation Procedures handout to record the data from their investigation on the Deformation Results handout. Give students a couple of minutes to look through the procedure and then ask if there are any questions" (Teacher Edition, pages 94–95).

  - Lesson 4: Students plan investigations and have a discussion to identify what the independent and dependent variables would be for this experiment. An anchor chart is created and the terms are added to their word wall (Teacher Edition, page 93).
  - Lesson 12: Students receive Cushioning Materials Testing Procedures. "While students check their data after their trial set for variances, they may find that there are variances larger than the allowable amount and do not meet the goals of the investigation. From this point, students will have to assess what potential revisions were imparted on the experimental design for the variance in data, and then revise their data collection method to better align with the class data collection protocol for this lab" (Teacher Edition, page 234).

- *Conduct an investigation and/or revise the experimental design to produce data to serve as the basis for evidence that meet the goals of the investigation.*
  - Lesson 2: Students complete the "Exploring Horizontal Collisions" activity and collect data to help answer the investigative question "What happens to the motion and shape of the objects (and the subsystems they are part of) when they collide?" The students work in groups and rotate between stations collecting data used to identify patterns related to changes in motion and shape (Teacher Edition, page 63).
  - Lesson 2: There is an opportunity for students to engage in the practice of planning and carrying out investigations. The call out box "SUPPORTING STUDENTS IN ENGAGING IN PLANNING AND CARRYING OUT INVESTIGATION" says, "As students work, ask, what kind of data is your group collecting and what question do you think it will help answer? Additionally, ask them to tell you why it might be important to collect data from different collision scenarios. Students should recognize that collisions in the real world happen in many different ways, and to make sense of what happens during collisions will require a variety of lines of evidence from varied scenarios. Both of these will help prepare them for a second, more focused and controlled investigation in the later part of the lesson" (Teacher Edition, page 60).

- Lesson 5: The materials claim that "students carry out investigations to produce data to answer the question: 'How does changing the mass or speed of a moving object before it collides with another object affect the forces on those objects during collision?" (CF.L5 Slide J). However, students were told to carry out the investigations and there is no evidence that they are doing so because they want to answer the question.
- Lesson 7: The class collaboratively designs an investigation to answer the question "How much does doubling the speed or doubling the mass affect the kinetic energy of an object and the resulting damage that it can do in a collision?" Through the discussion (for which teacher prompts are provided) students collaboratively identify variables and tools that will be used. (Note: Students are eventually provided with a handout for the Procedure for Investigation) (Teachers Edition, pages 147–153).
- Lesson 12: "In the next step, students will receive Cushioning Materials Testing Procedures. While students are checking their data after their trial set for variances, they may find that there are variances larger than the allowable amount and do not meet the goals of the investigation. From this point, students will have to assess what potential revisions were imparted on the experimental design for the variance in data, and then revise their data collection method to better align with the class data collection protocol for this lab." (Teacher Edition, page 234).

Constructing Explanations & Designing Solutions

- *Optimize performance of a design by prioritizing criteria, making tradeoffs, testing, revising, and retesting*.
  - Lesson 14: "Students prioritize stakeholder considerations and assign numerical rates to the different consideration priority levels in an effort to quantify the data. Multiplication is used to weight higher ranking considerations against other lower ranking considerations. By comparing the total scores for each material, students are able to get a picture of which material best meets the needs of the design" (Teacher Edition, page 285).
  - Lesson 14: "Let's think about some of these trade-offs we are now considering with the use of certain materials. It is clear from our different ratings that certain changes and decisions have unintended consequences. By elevating certain criteria, we may be discounting something else important to the stakeholder, or by only looking at the total scores we may miss something else that is more important to the overall rankings. Let's spend some time reflecting on these choices that we would like to make to optimize our designs" (Teacher Edition, page 287).
  - Lesson 15 (optional lesson): Students create an "optimal headgear design for a cheerleader to wear in a competition" and prepare a design pitch that includes "the purpose of your design (what it will protect), the materials it will be made of and why, the tradeoffs you made and why" (CF.L15 slides 2–4).
  - Lesson 15 Final Design Proposal Handout (page 3): "Investors will want to know that you have made good decisions in your design. Explain what you ranked as your primary vs.

secondary vs. tertiary considerations and why. Explain how this decision has helped to optimize your design."

Engage in Argument from Evidence

- *Construct, use, and/or present an oral and written argument supported by empirical evidence and scientific reasoning to support or refute an explanation or a model for a phenomenon or a solution to a problem.*
  - Lesson 2: Students use the evidence gathered in the investigations from the unit to answer the question "What causes the changes in motion and changes in shape of colliding objects?"
  - Lesson 3: "Introduce the organizer and make a claim. Project slide B. Distribute Claim and Observations Organizer to students and have them add it to their notebooks. Explain that students will use Claim and Observations Organizer to record their claim as well as the data they collect from a variety of sources to help them keep track of whether their claim is supported or refuted by the evidence" (Teacher Edition, page 78).
  - Lesson 3: After watching several videos, observing the experiment done with the laser, and watching a video of a concrete joint, the following teacher guidance is provided: "Say, OK, we've seen the results from applying more and more contact force to a concrete joint. Go back now and evaluate all the data we've collected on the handout to determine if any of it supports or refutes your initial claim. Even if we were in disagreement at the start of the period, all the different data we analyzed should provide us adequate evidence to evaluate those initial claims and, if needed, revise them so we are all in consensus on what common claim we can now all make about our original question" (Teacher Edition, page 84).
  - Lesson 9: "Discuss norms for giving and receiving feedback. Display slide F. Ask students to revisit the classroom norms and to share ideas for which norms are especially important when giving and receiving feedback. Allow a few students to quickly share their thinking with the class and listen for ideas such as the following: We critique ideas, not people. We encourage other voices that haven't been heard yet. We listen carefully and ask questions to help us understand. Say, these are all important to help us learn from each other as we share our designs with other teams" (Teacher Edition, page 188). Students use "Jigsaw Feedback Discussion" handout to push each other's thinking.

Developing and Using Models

- *Develop or modify a model-based on evidence to match what happens if a variable or component of a system is changed.*
  - Lesson 5: The teacher directs students exactly what to draw in their models. "Let's try to represent the relationship between these force pairs in a collision by showing what we know about the state of the system before the collision and during the collision when both objects in it experience peak forces." The teacher draws "a T-chart on two

pieces of chart paper for representing the two subsystems in the system (the two carts with spring scales on them) as shown to the right. Color subsystem A blue and subsystem B red. Show the springs compressed during the collision and uncompressed before it. Add motion lines behind subsystem A before the collision to represent that it is moving and use longer motion lines to represent when it has more speed. This is the convention you established in Lesson 1. Show both carts with their springs compressed during the collision. Label the second system "Greater deformation in both objects that make contact than in the system above." Students are asked questions about the model, for example:

- "Ask students what is pushing on subsystem A during the collision."
- "Ask students to point in the direction that shows which way the force is pushing on subsystem A."
- "Ask students how we can represent what we know happens to the peak forces on these two subsystems when we have more mass or more speed" (Teacher Edition, page 125).

- Lesson 8: "Let's not forget that free body diagrams are a helpful tool for visualizing the forces acting on objects in the system. Let's get ready to develop and revise some free body diagrams for both the box and the cart at time 4." On the "Modeling other force interactions in the launcher, cart, box, and track system" handout, students draw and label two free body diagrams and are asked to "Redraw your free body diagram for the box to the right. Show all of these additional forces on it as well as the contact force from the cart at time 4" (Lesson 8 Handout Modeling other force).
- Lesson 10: Students complete a baseball assessment and use data to model how a ball "can be affected by factors like the wind, which can impact the overall game" (Lesson 10 Baseball Assessment).
- Lesson 12: The following direction is given to the teacher "In Lesson 11, students drafted ideas on how a material might reduce the peak force on the object it was protecting. Since then students have conducted an investigation to determine which readily-available materials reduce peak force more than others, and have observed the structures at a microscopic scale, looking for patterns in those structures that might contribute to a reduction in peak force. As students model the materials in the handout, the structures should become more detailed, and they should start to make connections about the ability of some materials to deform more easily than other due changes occurring in their structure at a microscopic scale when forces are applied to them. Giving students the experience to incrementally revise this model, such as this opportunity here, will aid in their conceptual development of the target science ideas" (Teacher Edition, page 242).
- Lesson 13: Students use free-body diagrams for representing force applied to sub-systems. "These representations include showing external forces on each subsystem that includes the following: The direction of the force arrow indicates the direction of the force applied on the object. Differences in length of an arrow represent differences

in the relative magnitude of a force. The tip of the arrow indicates the surface on which the contact force pushes” (Teacher Edition, page 260).

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

The reviewers found extensive evidence that students have the opportunity to use or develop the DCIs in this unit because there are sufficient DCI elements developed and used at the targeted grade level in service of students making sense of phenomena and developing a solution to a problem. Lessons have a “Where we are Going” and “Where we are NOT Going” section to help educators stay within the bounds of the DCI at this grade band and within the learning goals. However, although portions of an element of LS1.D are developed in the unit, they are not developed or used in service of students making sense of the anchor phenomenon. Additionally, the following element of PS2.A is claimed but not fully developed in unit materials. “*All positions of objects and the directions of forces and motions must be described in an arbitrarily chosen reference frame and arbitrarily chosen units of size. In order to share information with other people, these choices must also be shared.”*

PS2.A: Forces and Motion

- *For any pair of interacting objects, the force exerted by the first object on the second object is equal in strength to the force that the second object exerts on the first, but in the opposite direction (Newton’s third law).*
    - Lesson 4: At the beginning of the lesson the teacher passes around a spring scale to students and explains how the tool is used. “Say, we have a tool we can use to apply a certain amount of force to an object and measure how much force we are applying” (Teacher Edition, page 92). Sample teacher prompts and student responses are provided to facilitate understanding of the tool and how it measures the forces exerted by the first object on the second object(Teacher Edition, page 93).
    - Lesson 5: Students carry out investigations to “come up with another generalization that adds to the rule that the contact forces will be the same on each object in a collision regardless of changes in speed or mass. Connect the results of the investigation to changes in the kinetic energy of the objects and changes in the peak forces in the collision” (Teacher Edition, page 122).
    - Lesson 6: The assessment targets PS2.A. For example, in question 2a “How would the amount of force on the head compare to the amount of force on the object it collides with in each system A, B, and C?” (Lesson 6 Assessment, page 2).
- *The motion of an object is determined by the sum of the forces acting on it; if the total force on the object is not zero, its motion will change. The greater the mass of the object, the greater the force needed to achieve the same change in motion. For any given object, a larger force causes a larger change in motion.*
    - Lesson 4: Students discuss the main ideas they have learned and what they have added to their progress trackers. The following teacher guidance is provided: “Listen for student responses related to the amount of force applied, the amount of deformation

that it causes in the material, and whether the force exceeds the elastic limit of the object and/or its breaking point" (Teacher Edition, page 100).

- Lesson 9: "The current collision system model is only partially complete in terms of energy transfers. As students are conducting station activities, their focus should be on gathering evidence to explain additional effects from friction and air resistance that cause changes in motion and KE of subsystems within the collision system. An important goal of the observations and data collected under different conditions at stations is to push students to think about evidence of changes in motion and KE in terms of particle motion" (Teacher Edition, page 185).
- Lesson 9: "Ask, does anyone have an idea to share about what might be affecting the motion and KE of the cart before the collision, which in turn would affect the damage that would result in a collision? Listen for these ideas: The cart is colliding with air particles and this causes the cart to slow down and lose KE. The cart is slowing down and losing KE because of friction between the cart/wheels and the track" (Teacher Edition, page 189).

- *All positions of objects and the directions of forces and motions must be described in an arbitrarily chosen reference frame and arbitrarily chosen units of size. In order to share information with other people, these choices must also be shared.* This element is not fully developed. The portion in purple is not explicitly found in lesson materials.
    - Lesson 1: Students discuss the types of collisions and describe the motion of objects involved in the collisions. "The purpose of this discussion is for students to determine that there are 3 main types of collisions, and those types may or may not result in damage. As students share their experiences with phones, listen for these three types of collisions to emerge: A. A fragile object moved toward and hit another object that was motionless. B. A fragile object was motionless and was hit by another object that was moving. C. A fragile object was moving and was hit by another object that was moving. The prompts and example responses below are meant to elicit the three different types of collisions" (Teacher Edition, page 32).
    - Lesson 1: "Discuss and alter frames of reference. Revisit the drawings and place the Different Collisions poster in a spot that is easily viewable for students, if not already in a prominent spot in the classroom. First, remove the piece of paper with collision type A that shows the diagram that has a moving, fragile object colliding with a motionless object (collisions type A). Use the prompts below to help students consider changes to the frame of reference" (Teacher Edition, page 34).
    - Lesson 4: Students are introduced to spring scales. "We have a tool we can use to apply a certain amount of force to an object and measure how much force we are applying. This tool is called a push-pull spring scale." "Say, in science, when we use numbers to measure something, we like to include the units that we are measuring in, like meters, feet, seconds, and hours. Sometimes engineers measure the amount of force in pounds, and sometimes they use newtons. We will use newtons. Your push-pull spring scales have markings on them that range from zero to 10 newtons, or capital N. Let's see how

many pounds of force correspond to 5 newtons versus 10 newtons on the scale" (Teacher Edition, pages 92–93).
    - Lesson 5: Students use twist tie collars wrapped on the plunger of spring scales to measure the maximum amount of force applied during a collision. "This position of the twist tie collar can provide you a record of the maximum force or the peak force applied to the spring scale during a collision since each of the marks on the plunger beam corresponds to two of the marks on the newton side of the scale for the amount of force" (Teacher Edition, page 119).

PS3.A: Definitions of Energy

- *Motion energy is properly called kinetic energy; it is proportional to the mass of the moving object and grows with the square of its speed.*
    - Lesson 2: "Connect to previous work with kinetic energy in other units. If students start using the term kinetic energy, push them to explain their definition and to justify why they feel like this would be appropriate terminology to use here. If students don't start using the term kinetic energy, push them to think about energy transfers from previous units. After we have done some work showing how our current discussion of energy fits in with and builds on previous conversations of energy we have had in middle school, argue that the term kinetic energy may be useful for us in this context and that referring to the kinetic energy of moving parts of the system (objects or subsystems) can be a useful way to compare one system to another" (Teacher Edition, page 68).
    - Lesson 5: Students carry out collision investigations and answer the following questions: "Which object(s) had kinetic energy before the collision? How did the strength of the peak forces on each of these two objects compare during the collision? Were they equal in strength or unequal in strength? If one of your moving objects was moving slower before the collision, how would that have affected its kinetic energy?" (CF.L5 Slide 14).
    - Lesson 6: Students are given a Soccer Assessment and discuss "How would damage be related to peak forces and the amount of kinetic energy in the system before the collision?" (Teacher Edition, page 137).
    - Lesson 7: "Briefly discuss what the data tell us. Students will argue that doubling the speed of a moving object has a bigger effect on its kinetic energy, which causes it to have a greater amount of damage. Ask multiple students to weigh in on how the evidence supports this conclusion. Students should say that objects from condition C (doubling the speed) show more damage (more pieces and/or more cracks) in them than the same objects from condition B (doubling the mass)" (Teacher Edition, page 151).
    - Lesson 7: During "Changes in Kinetic Energy Investigations 1 and 2" students collect and analyze data to "develop a mathematical model for quantifying the amount of kinetic energy an object has in order to be able to more accurately predict and explain what causes damage in some collisions and not others" (Teacher Edition, page 153).

- Lesson 7: With a partner, students discuss the following: "In math we sometimes try to represent patterns between two variables using symbolic expressions. How might we do that for the following relationships?
  - mass and kinetic energy
  - speed and kinetic energy" (CF.L7 Slides).
- Lesson 7: Students engage in a class discussion to summarize the relationship between mass and kinetic energy. Teacher prompts include:
  - "If we think back to Lesson 2 and work you have done in math class, how could we describe this relationship between mass and kinetic energy?
  - Let's see what this means: How much would the kinetic energy of a moving object increase if it had three times as much mass but the same speed?
  - Wait, are you saying that however many times more the mass is, that tells you how many more times kinetic energy the object has?"
- Lesson 7: Students engage in a class discussion to summarize the relationship between speed and kinetic energy. Teacher prompts include:
  - "What about patterns about speed? What patterns do you notice in your graphs and tables?
  - How much would the kinetic energy of a moving object increase if it had five times as much speed but the same mass?
  - Wait, are you saying that however many times more the speed is, you can just take that number and square it and it tells you how many more times kinetic energy the object has?"

PS3.B: Conservation of Energy and Energy Transfer

- *When the motion energy of an object changes, there is inevitably some other change in energy at the same time*.
  - Lesson 9: Students rotate through four stations and "investigate other instances of objects slowing down or producing another interesting outcome related to one of the two additional types of contact forces we have discussed are missing from our system model - friction and air resistance." "An important goal of the observations and data collected under different conditions at stations is to push students to think about evidence of changes in motion and KE in terms of particle motion." Students apply what they learn to answer the question "How do other contact forces, like friction or air resistance, cause energy to be transferred from a moving object to other parts of a system?" (Teacher Edition, pages 185–186).

ETS1.B: Developing Possible Solutions

- *There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem.*

- Lesson 11: Students begin building towards this middle school element while using the Grade 3–5 element when students consider criteria and constraints for designing a phone case. “We have some ideas about what a phone case would need to better protect our phones. Let’s try to create a list of the criteria and constraints a phone case designer would need to consider in making a better phone case” (Teacher Edition, page 214). In Lesson 11, students develop a list of criteria and constraints a phone case designer would need to consider. Students are reminded of what criteria and constraints are by referencing a previous unit.
- Lesson 12: “Testing specific materials leads to an understanding of which type of materials help to reduce peak forces in a collision. The testing of materials provides evidence that will serve to better refine design solutions. By understanding which materials work better to reduce peak forces, students can make an informed decision to modify devices to better meet their criteria and constraints, which will be built upon in lesson 12” (Teacher Edition, page 237).
- Lesson 14: Students observe a kneepad design and answer the questions “What are some constraints that would apply to this protective device? Are there any constraints that the design would have to think of as more important than others?” They collect feedback from stakeholders: “To make sure we don’t limit our feedback; we will first need to get ideas from different stakeholders about potential designs without the stakeholders being influenced by our designs.” Students then use a decision matrix to evaluate choices in designs (Teacher Edition, pages 279–283).
- Lesson 14: Students are prompted to use “trade-off thinking to analyze designs” with the Additional Material Considerations Matrix and a Decision Matrix to systematically evaluate their solutions against the criteria and constraints of the phone case problem (Teacher Edition, page 285).

ETS1.C Optimizing the Design Solution

- *Although one design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the redesign process—that is, some of those characteristics may be incorporated into the new design.*
    - Lesson 14: Students revise designs “using our protective material science ideas.” They redraft their designs and identify “the scientific reasoning behind the change(s)” and “effects of that change on the performance of structure of the device (positives or negatives)” (CF.L14 Slides C and D).

LS1.D Information Processing

- *Each sense receptor responds to different inputs (~~electromagnetic~~, mechanical, ~~chemical~~), transmitting them as signals that travel along nerve cells to the brain. The signals are then processed in the brain, resulting in immediate behaviors or memories.*
    - Lesson 5: Students engage in a reading titled “How does touch work?” The reading discusses the sensors present on the skin which respond to different sensations and

how these signals send information to the brain. However, this learning is not in direct service of making sense of the phenomenon.

- "When these sensors are deformed they send a chemical signal to nerve cells that they are connected under your skin. These nerve cells are called neurons. An image of the structures that make up a neuron is shown below…" (Handout 8.1, page 3).
- "When an immediate response isn't needed, a signal travels from sensory receptors in your skin to your brain. Then your brain interprets the signal, and you decide how you want your body to respond. Imagine you wake from sleep feeling uncomfortable pressure on your shoulder from being in the same position for too long. You decide to roll over to get more comfortable. To do this you will need to send a signal to those muscles in your body to move yourself around" (Handout 8.1, page 4).
- "So, remember, when you feel forces on your skin they are really deforming specialized structures (pressures sensors) under the skin, and these structures in turn relay signals through a connected series of nerve cells to your brain" (Handout 8.1, page 5).

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 there are sufficient CCC elements developed and used at the proper grade level in service of students making sense of phenomena and developing a solution to a problem. Students are provided opportunities to use the CCCs to make sense of the anchor phenomenon and to develop a solution to a problem and are also provided with opportunities to strengthen their thinking using the CCCs.

Systems and System Models:

- *Models can be used to represent systems and their interactions such as inputs, processes and outputs – energy, matter, ~~and information flows~~ within systems.*
  - Lesson 1: Students "develop a model to show what interactions are happening between the objects during a collision" (Teacher Edition, page 39).
  - Lesson 2: Students investigate a collision between a cart with a CD case attached and a cart with a golf ball attached. Students engage in the following consensus conversation: "Let's see if we can come to consensus about how to represent these ideas. Let's use what we already know about energy and forces to show what we think is happening in collisions" and create a diagram of "interactions in the system" from an energy perspective and a force perspective (Teacher Edition, page 69).
  - Lesson 2: Supporting Students in Developing and Using Systems and System Models Section states: "Referring to the objects in this collision as being part of subsystems primes students for developing models for free-body force diagrams (subsystems) in

Lesson 5. Students also have prior experience describing energy transfers between systems in OpenSciEd Unit 6.2: How can containers keep stuff from warming up or cooling down? (Cup Design Unit) and OpenSciEd Unit 7.2: How can we help people design a flameless heater? (Homemade Heater Unit) when they describe and model energy transfers in the form of heat and particle motion once they recognized that those systems are made of many different, individual parts interacting together (e.g., molecules colliding, atoms in reactant molecules rearranging). They will leverage this thinking in Lesson 8. This system framing in this lesson primes students for making particle-level connections later in Lesson 8 to account for energy transfer to the surroundings via friction and air resistance" (Teacher Edition, pages 61–62).

- Lesson 8: "Say, in order to think about the energy transfer into and through the entire launcher system, scientists and engineers often break bigger systems into sub-systems to try to figure out what is going on. You've done this in many of the previous units in earlier grades. Let's recall a few of those examples, to think about how powerful this type of system thinking has been for us in the past. Ask students for examples from these, based on the prior OpenSciEd unit experiences. Suggested prompts are included below…" (Teacher Edition, page 167). Teacher prompts are provided to facilitate student thinking related to subsystems and their interactions. "Say, these are great examples of where breaking the bigger systems into sub-systems helped us figure out what was going on. Such system thinking is a powerful cross-cutting concept that scientists and engineers do to try to make sense of a more complex system. Sometimes they try to break up the system into smaller objects or smaller sub-systems. And sometimes they try to break up periods of time that something is happening in the larger system into smaller chunks to try to better understand what is happening in a smaller window or scale of time within a longer phenomenon. In our launcher system, there was a lot happening between getting ready to launch the cart and seeing what the results were. So, it may be useful to think about specific moments in time, before, during, and after the cart is launched, as well as before, during, and after the box is pushed. Throughout each period of time it may also be useful to think about the interactions occurring between different sub-systems and objects within the larger system" (Teacher Edition, page 168).
- Lesson 13: Students create free-body diagrams of the systems they have tested and label the individual components of the system they model.
- Lesson 13: "Introduce two different ways to model the two-ring condition. Say, For the two-ring condition, you could choose to represent the two rings as a single sub-system OR you could represent them as separate subsystems. In the first case you would need to show three free-body diagrams, while in the later you would need to show four. You and your partner should decide how you want to model that system, but remember to look back at our results from the video so that your model accurately represents the relative strength of all the peak contact forces from the interactions between each subsystem in your model" (Teacher Edition, page 263).

Scale, Proportion, and Quantity

- *Scientific relationships can be represented through the use of algebraic expressions and equations.*
    - Lesson 7: "To support using the crosscutting concept of scale, proportion, and quantity in this lesson you will help students calculate and use a type of ratio called a scale factor" (Teacher Edition, page 145).
    - Lesson 7: "To support using the crosscutting concept of scale, proportion, and quantity in this lesson you will refer to an idea from mathematics called a scale factor. Students will have encountered this concept when engaging in work around two related learning goals from the CCS for mathematics in 7th grade. In this lesson, scale factors are used to describe the ratio of two different masses or two different speeds or two different amounts of kinetic energy. So, for example, doubling any amount of mass would mean the ratio of the new mass to the old mass is 2, which is the scale factor. Halving the speed would mean the ratio of the new speed to the old speed is 0.5, which is the scale factor. Predicting and ultimately discovering how such changes affect the corresponding scale factor for kinetic energy (the ratio of the new kinetic energy to old kinetic energy) is the key discovery students will be making in the next investigation" (Teacher Edition, page 154).
    - Lesson 13: "We've made an argument here that this larger scale structure represents something important we are seeing in many microscopic structures of all of these top force reduction materials. They all have a large amount of air or space gaps in between the solid matter, just like this structure does. Now that we have analyzed a large-scale physical model that represents this important aspect of the structure of peak force reducers, we could use it to understand what might be happening at a much smaller scale within the microscopic structures of our top force reducing materials" (Teacher Edition, page 255).

Energy and Matter

- *Within a natural or designed system, the transfer of energy drives the motion and/or cycling of matter.*
    - Lesson 2: Supporting Students in Developing and Using Energy and Matter section states: "Students should recall from their work with marbles in the OpenSciEd Unit 6.2: How can containers keep stuff from warming up or cooling down? (Cup Design Unit) that moving objects and particles have kinetic energy and that collisions transfer energy. So though energy transfer in a system is not a focal crosscutting concept in this lesson, students should be able to describe the energy transfer between two objects in a collision" (Teacher Edition, page 66).
    - Lesson 9: Supporting Students In Developing and Using Energy and Matter section states: "This modeling activity is helping deepen the understanding that energy is not created or destroyed when you start tracking into, through, and across (sub)systems. In

their descriptions of energy transfer in the class collisions system model they should be able to describe qualitative gains and losses of energy between the subsystems within the cart launcher system model" (Teacher Edition, page 189).

- *The transfer of energy can be tracked as energy flows through a designed or natural system.*
    - Lesson 7: Students are told that thinking "about where the energy is coming from and where it is going in a collision could help us understand and explain even more about collision-related phenomena." They are asked to "consider an energy perspective for the entire system we used in this lesson with the cart, spring scale launcher, track, cracker, and box" (Teacher Edition, page 160).
    - Lesson 8: Students use "Tracking energy transfers in our launcher system" handout to track where energy transfers occurred in the launcher system.

Structure and Function

- *Complex and microscopic structures and systems can be visualized, modeled, and used to describe how their function depends on the shapes, composition, and relationships among its parts; therefore, complex natural and designed structures/systems can be analyzed to determine how they function.*
    - Lesson 12: "Some students may want to look at them more up-close. Explain to students that we can get a better idea of what might be happening by looking at the material properties closer. Tell students that we do have some microscopic images that might help us explain how the properties of the protective materials differ from the properties of materials that did not reduce peak force as well" (Teacher Edition, page 241).
    - Lesson 13: Students use observations and microscopic models to "describe what the structure of each of the top 4 force reducing materials looked like when we examine a cross-section of each material." They watch slow motion videos and are asked to "to summarize the relationship they discovered between the number of structures that have space in them to deform, the length of time the deformation is occurring over, and the peak forces produced in the collision" (Teacher Edition, pages 253–257).
    - Lesson 14: Students revisit their testing results using a prompt from a slide. "Think back to the last class. What did we learn about the role of shape, thickness, or properties of protective materials that we should be using in our designs?" Additional guidance about what should come from that conversation is provided for the teacher. "The ideas about the properties of a material that provides more protection and how these properties contribute to a reduction in peak force on an object will be utilized as students revise their designs. If some students need a more concrete version of this list, consider writing these ideas down on a piece of chart paper or whiteboard in the front of the room to serve as an idea list for the redesign and potential new selection of materials for their protective devices."
    - Lesson 14: "In previous lessons, students have worked to uncover the properties of the microscopic structures of protective materials that aid in the reduction of peak forces on objects. In this lesson, students shift from thinking about the structure and function of

the individual parts of the material to how well the material structure fits the design considerations based upon those properties for the use of the material within the overall system of our protective device design" (Teacher Edition, page 283).

- *Structures can be designed to serve particular functions by taking into account properties of different materials, and how materials can be shaped and used.*
    - Lesson 11: Supporting Students in Developing and Using Structure and Function section states, "Drafting Our Protection Device Design provides an opportunity to engage in both main elements of structure and function. Column 1 reflects student understanding of how particular structures can be utilized to serve certain purposes/functions based upon the science ideas learned thus far in the unit. Column 2 allows students to start thinking about how the structures (shape, material, and properties of these materials for the designed device) are affected and change over time as well as at a microscopic level during the collision. Students are likely to show the protection device deforming, based on the previous work in the unit, but may be less likely to show it transferring force to the object it is in contact with" (Teacher Edition, page 218).
    - Lesson 12: Students answer the following questions (which are on slide J): "How do you think the structures of the materials behave in a collision that would reduce the peak forces on the objects? Was the peak force reduced on both objects, or just the one object with the protective material?"
    - Lesson 13: Students discuss the following questions as a class: "What structures did the materials seem to have in common that were good at reducing peak forces? How would this type of structure help reduce peak forces in a collision?" (Teacher Edition, page 252)
    - The following suggested teacher prompts are provided after students view videos of the large-scale model and analyze the data collected (Teacher Edition, page 258): "What can we conclude will happen to the peak force in a collision then when we add more structures that have gaps, space, or air pockets in them in between the two colliding objects? What can we conclude will happen to the amount of time the collision takes when we add more structures that have gaps, space, or air pockets in them in between two colliding objects? In every case the motion of the cart changed in the collision. It went from moving in one direction to moving in the reverse direction. Let's try to summarize what this tells us about the relationship between the time it takes to change the motion of an object and the strength of forces used to do it. So, when weaker forces are applied to an object to change its motion, what will happen to the amount of time it will take to do that? When stronger forces are applied to an object to change its motion, what will happen to the amount of time it will take to do that?"
    - Lesson 14: Supporting Students in Developing and Using Structure and Function section states: "In previous lessons, students have worked to uncover the properties of the microscopic structures of protective materials that aid in the reduction of peak forces on objects. In this lesson, students shift from thinking about the structure and function of the individual parts of the material to how well the material structure fits the design

considerations based upon those properties for the use of the material within the overall system of our protective device design" (Teacher Edition, pages 283–284).

Suggestions for Improvement

Science and Engineering Practices

Though **Developing and Using Models** is not one of the identified SEPs being developed in this unit, to strengthen this SEP, consider ways to have the students use what they already know about **Developing and Using Models** and provide additional opportunities for students to directly engage in the practice. For example, in Lesson 5, the students could draw and revise the initial individual models, small group models, and consensus models based on peer and teacher feedback and apply those models again in Lesson 6.

Disciplinary Core Ideas

- Consider adjusting the timing of the reading about LS1.D so that students use the DCI to make sense of the phenomenon, rather than learning about the DCI in the article before engaging in the activity.
- The claimed element of ETS1.C Optimizing the Design Solution could be strengthened. Although students perform tests of types of materials throughout Lesson 14, students' final designs are not currently tested or optimized throughout the process unless students engage in the optional final activity. To ensure that all students engage in the claimed element of ETS1.C, the final lesson could be listed as non-optional.
- Consider fully developing the element of PS2.A by including opportunities for students to discuss the arbitrary nature of units of measurement.

Crosscutting Concepts

- The inclusion of the Rationale for the Elements of the SEPs and CCCs document is helpful for teachers to see the CCCs in each lesson. Consider being more explicit in how students should engage fully in all the CCC elements. For example, in Lesson 2, prior to engaging students in a consensus discussion and having the teacher capture the class's thinking on chart paper, students could be asked to first model their own thinking, then share in a small group, revise, and then come to a consensus. This would provide students with time to process and make sense of the interactions in the system prior to the consensus conversation and provide an additional opportunity to apply background information shared in the Where Are We Going Section — "Students should also leverage prior knowledge that collisions transfer energy as evidenced by changes in the speed of the objects in the system before vs. after the collision" (Teacher Edition, page 58).
- Consider providing support for teachers to help students think explicitly about the CCC elements and how they are helpful in figuring out the phenomena. For example, in Lesson 2 rather than starting with the prompt "Tell me about the patterns you noticed," teachers could begin with something like "What could patterns tell us about..."

Why Do Things Sometimes Get Damaged When They Hit Each Other?

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 events that require students to use each of the three dimensions for the purpose of figuring something out. Each lesson provides a three-dimensional lesson-level performance expectation that describes the major three-dimensional learning that should occur in the lesson.

Related evidence includes:

- Lesson 3: Students "Construct and revise a written argument (SEP) using evidence from various sources of data (slow-motion videos, photos, and firsthand investigations) to support or refute the claim that all objects do bend or change (CCC) shape when pushed in a collision (DCI)." The written arguments require use of the CCC idea that *small changes in one part of a system might cause large changes in another part*" (Teacher Edition, page 312).
- Lesson 4: All students are engaged in three-dimensional learning when they **plan an investigation** (SEP) identifying controls to keep constant, and carry out the investigation to produce data to serve as the basis for evidence to develop a mathematical model for the relationship (**Patterns** CCC) between the amount of force applied to an object and the amount it deforms (**PS2A** DCI). Using the data that students choose to gather and analyze they can make sense of the relationship between force applied and the amount it deforms (Teacher Edition, page 96).
- Lesson 5: Students "Plan and carry out an investigation and identify patterns in the data collected from the investigation to provide evidence that when peak contact forces on each object during the collision are equal in strength, the strength of those forces increases when the mass or the speed of the object that was moving before the collision increases" (SEP: **Analyzing and Interpreting Data**, DCI: **PS3.A.** Definitions of Energy, CCC: **Patterns**) (Teacher Edition, page 313).
- Lesson 8: Students develop and use a model to identify other parts of the system the cart and box are making contact with or colliding into that could be producing contact forces on these subsystems, causing energy to be transferred to or from them as a box and cart travel down

the track" (SEP: **Developing and Using Models**, DCI: **PS2A**: Forces and Motion, CCC: **Systems and System Models**).

- Lesson 12: Students analyze data to determine which materials reduce peak force in a collision and analyze the similarities (visual patterns across materials) in the properties of those materials (macroscopic deformability) (Teacher Edition, page 239).

Suggestions for Improvement

N/A

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 because the lessons work together to provide opportunities to build proficiency towards targeted performance expectations MS-PS2-1, MS-PS2-2, and MS-PS3-1. Each lesson builds directly on prior lessons in a way that is explicit to students. However, this coherence is predominantly based on teacher statements throughout the unit rather than student-generated questions.

Throughout the unit, there are many clear examples of how lessons are connected in a way that allows what students figured out to lead to the next lesson. The Teacher Background section outlines where the unit falls within the scope and sequence: "This unit directly builds off the Disciplinary Core Ideas (DCIs), Crosscutting Concepts (CCCs), and Science and Engineering Practices (SEPs) developed in the 6th grade unit that preceded this one." It provides an overview of how the unit is broken down. "This unit is broken into three lesson sets, focusing force interactions between colliding objects, energy transfer in collisions, and how the structure of materials can mitigate the damage that the collision can cause" (Teacher Edition, page 16). For example:

- Lessons begin with an outline of “Previous Lesson,” “This Lesson,” and “Next Lesson” Summaries. For example, Lesson 7 states, “Previous Lesson: We looked back at questions from our Driving Question Board and answered questions we had made progress on during Lesson Set 1. We took an assessment to apply our science ideas to a new context and determined that we needed to figure out what causes more damage and energy transfer in a collision—increases in mass or increases in speed.” “This Lesson: We carry out an investigation to determine how doubling the speed of an object vs. doubling its mass affects the amount of damage it does in a collision. We analyze data to determine how to quantify the relative change in the kinetic energy of an object. We use a computer simulation to collect additional data on changes in the mass and speed of a moving object and the amount of kinetic energy. We develop mathematical models of these relationships and use them to predict and explain how this could affect the amount of damage in a collision.” “Next Lesson: We will develop a model to show where energy is transferred between the spring, cart, box and how contact forces cause this energy transfer. We will use this to start brainstorming other places where contact forces may be causing energy transfer in the system” (Teacher Edition, page 139).
- Lesson 1: “Forecast that we will investigate our questions. Display slide T. Say, Wow. We have accomplished so much. We now have a broad mission to accomplish as a class. That is thanks to all the questions you shared and how you connected them together. These questions really represent what it is we hope to be able to figure out. And we have a lot of ideas for investigations we could do to try to figure this all out. I am very excited for us to be able to get started on investigating all of this. Let’s plan to start exploring some of those questions and ideas in our next lesson“ (Teacher Edition, page 50).
- Lesson 3: “Recall the question we decided we needed to investigate last time. Say, Last time, we were looking at slow-motion video and noticed some surprising shape changes happening in some objects during a collision. That led us to realize we had a new question to investigate further which we took a poll on and brainstormed some ways to investigate it” (Teacher Edition, page 78)
- Lesson 12: “Recall criteria for our device protection from the previous lesson. Project slide A. Say, Let’s look back at our criteria list from yesterday. We know that in order to have an effective protection device design we need to meet our criteria. One criterion we identified was using materials that will protect our device. What does that mean?” (Teacher Edition, page 232). Teacher prompts are then provided to guide students to share their ideas.
- Lesson 13: Teachers prompt students to update individual progress trackers: “Say, these ideas are all based on observing these large-scale structures. But let’s remind ourselves that these weren’t the specific structures we were interested in explaining at the start of our lesson. We were initially interested in explaining how and why the microscopic structure of an effective cushioning material decreases the peak forces in a collision, Let’s take a moment to think about how we apply what we figured out to those materials” (Teacher Edition, page 259).

Although the navigation section at the beginning and end of each lesson provides a strong connection between lessons, it is typically in the form of the teacher presenting the next question or activity to students. For example:

- Lesson 2: At the end of the unit students take a quick poll regarding the question "Do you think the force from a collision always causes shape changes in the objects that collide, but sometimes we just can't see or detect it?" The lesson ends with the following: "Say, Let's plan to investigate this question further next time to see if we can collect evidence to support one of these claims and refute the other one" (Teacher Edition, page 71).
- Lesson 3: "Motivate the next lesson. Say, we've been thinking about how forces cause the shape of any object to change. And in an earlier lesson we argued that there are forces involved in a collision. Let's consider forces in collisions again. Think back to the slow-motion videos we analyzed. All of those situations we looked at involved one moving object and one motionless object before the collision. What about situations where both colliding objects are moving, like when a baseball bat and ball collide in a game of baseball? Does the bat hit the ball or does the ball hit the bat? What would be pushing on what? How about in the case of the golf club and golf ball?...Give students time to discuss the questions on the slide with a partner and tell them we will explore this further in our next lesson. Remember to collect Results from other materials tests" (Teacher Edition, page 102).
- Lesson 10: "Say, we have learned a lot about collisions, but we still seem to have questions about the materials in a collision. I was looking back at our phone case problem and found some interesting data from our first lesson about phones that were protected and still broke! We will revisit that data next class" (Teacher Edition, page 206).
- Students have a chance to generate questions in lesson one to create a DQB. The DQB is revisited in later lessons, however, the purpose of revisiting the DQB is not to motivate future lessons, but rather to check if learning done up that point has addressed the questions.

The lessons in the unit are designed to build toward the following Performance Expectations:

- MS-PS2-1. Apply Newton's Third Law to design a solution to a problem involving the motion of two colliding objects.
    - Lessons 2–10: Students investigate colliding objects through a variety of investigations to answer the question, "Why do things sometimes get damaged when they hit each other?"
    - Lessons 11–15: Students investigate the structure and function relationship of various materials in relation to how they are able to reduce peak force with the purpose of designing a protective case for an object of their choosing.
- MS-PS2-2. Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.
    - Lesson 2: Students investigate colliding objects to note changes in their motion and shape.

  - Lesson 4: Students investigate how the amount of force applied to an object affects the amount of deformation that occurs for different materials.
  - Lesson 5: Students plan and carry out an investigation to determine how the mass and speed of an object affect the forces applied in a collision.
- MS-PS3-1. Construct and interpret graphical displays of data to describe the relationships of kinetic energy to the mass of an object and to the speed of an object.
  - Lesson 5: Students plan and carry out an investigation to determine how the mass and speed of an object affect the forces applied in a collision.
  - Lesson 7: Students generate data through an investigation to determine the effect of changes in mass and speed on a moving object.
- MS-ETS1-2. Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.
  - Lesson 14: Students are prompted to use "trade-off thinking to analyze designs" with the Additional Material Considerations Matrix and a Decision Matrix to systematically evaluate their solutions against the criteria and constraints of the phone case problem (Teacher Edition, page 285).
- MS-ETS1-3. Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.
  - The following evidence relates to both MS-ETS1-2 and MS-ETS1-3:
    - Lesson 11: Students identify a problem to be solved (a case made to prevent a device from being damaged) and determine criteria and constraints.
    - Lessons 12—13: Students investigate which materials have the greatest impact on reducing peak force and how the structure of those materials contribute to that function.
    - Lesson 15: Students look at several different designs of head protection from cheerleaders to determine which one best meets criteria and constraints.

Suggestions for Improvement

- This criterion could be moved to extensive by providing increased opportunities for *students* to generate questions at the end of lessons, thereby creating the "need to know" for the subsequent lessons and learning from the students' perspective. For example:
  - Lesson 1: After students observe the anchoring phenomenon and students generate questions about collisions, the teacher could listen for and make sure a question about related phenomena is added to the DQB. This question could then be posed as "we have questions about related phenomena" followed by the "Brainstorming Related Phenomena" activity on page 36 of the Teacher's Edition.
  - Lesson 5: After the students revisit the questions they were considering in Lesson 4, consider explicitly connecting the new learning to student questions. For example, rather than saying "it seems like figuring out what is pushing on what is something we need to resolve in order to explain why some things break and others don't in a

collision," the teacher could respond by having a scientist circle around the DQB where students identify the questions they still have/need to answer. When the students identify the need to know what is pushing on what, this could be highlighted and used to drive the new learning.
    - Later in Lesson 5, rather than suggesting that the teacher motivate an investigation about whether generalizations hold true with collisions, the teacher could suggest that they revisit the DQB and student questions about collisions, using student questions and need to know as the motivation for new learning.
    - Lesson 7: Consider providing an opportunity for students to uncover the need to quantify kinetic energy. This need could be uncovered by providing them with time to reflect, share with a partner, or discuss results from the Changes in Kinetic Energy Investigation 1.
- Consider revisiting the DQB more often with the purpose of determining which questions should be addressed in future lessons.

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. The phenomena and problem presented are able to be completely addressed through use of the claimed physical science disciplinary core ideas. Although a life science disciplinary core idea (LS1.D) is introduced, it is not clear how it is used to explain the phenomenon or design the solution. Also, there is an opportunity to strengthen the instances when students use the crosscutting concepts to make sense of the phenomenon or design solutions to the problems across the physical and life science domains.

Related evidence includes:

- The Life Science Disciplinary Core Idea LS1.D is introduced in Lesson 5 when students engage in a reading titled "How Does Touch Work?" The reading is connected to the broader unit in the following ways:
  - Lesson 5: "Revisit using fingers as force detectors in prior investigation. Say, you have used your fingers as force detectors today. Other places on us can detect contact forces against the skin too. Take a moment to touch the tip of your finger to the following: your forehead, your cheek, and your elbow. Pay attention to which of these seems most sensitive to being able to detect something touching it. Give students a moment to do this as you distribute Reading: How does touch work? to each student" (Teacher Edition, page 117).
  - After the reading, students are asked to represent the phenomenon of moving your arm when becoming uncomfortable which demonstrate the cause and effects relationships in the system. This model and the use of the cause and effect relationship in the model is related to the free body diagrams students have constructed to model collisions in the lesson.
  - Lesson 6: The assessment provided in the lesson deals with concussions and relates the ideas of axons and neurons to forces and kinetic energy. However, while the DCI is used in this assessment, the DCI is taught through a reading as homework rather than students being given the reading when they realize they will need the information in it to make sense of the phenomenon presented at the beginning of the unit.
  - Lesson 13 continues the connections to LS1-8. "Critically read a scientific text adapted for classroom use to determine how concussions can result in breaks in the axons of neurons (structure) and why this can lead to memory loss (function), how a snug fit (structure) for a helmet would affect its performance (function), and how other changes in the structure of cushioning material (in a helmet) would affect its performance (function)."
- The anchoring phenomenon of cell phone breakage data can be fully explained using Physical Science Disciplinary Core Ideas PS2.A Forces and Motion, PS3.A Definitions of Energy, and PS3.B Conservation of Energy and Energy Transfer. The phenomena and problem presented are able to be completely addressed through use of the claimed physical science disciplinary core ideas. However, the CCCs are not currently used explicitly across science domains. For example:
  - "The unit is broken into three lesson sets, focusing force interactions between colliding objects, energy transfer in collisions, and how the structure of material can mitigate the damage that a collision can cause" (Teacher Edition, page 15).
  - "In the first set of the unit students make general observations about what happens to objects during collisions, and quickly move to analyzing data that shows that objects deform when forces are applied. This leads them to plan and carry out investigations and analyze and interpret data to figure out that all solid objects behave elastically up to a point and that the forces between objects in a collision are always equal in size, and opposite in direction. The results of these investigations allow them to Develop

and use free-body diagram models to represent the changes in the relative strength of forces on different objects in a collision" (Teacher Edition, page 16).

- "In the second lesson set of the unit students create and use mathematical models to determine how changes in the mass and speed of an object affects the amount of kinetic energy that object has. They unite two different perspectives (energy and forces) to develop and use system models to support explanations for how contact forces, including friction and air resistance, cause energy to be transferred from one part of the system to another before, during, and after a collision" (Teacher Edition, page 16).
- “In the third part of the unit students design solutions to protect an object of their choice in a collision. They gather design input from stakeholders to refine the criteria and constraints for their design solution, and the class works together to carry out a series of investigations to answer the questions they have about optimizing their design solutions. This leads them to plan and carry out investigations to determine which cushioning materials reduce peak forces the most in a collision, and to develop macroscopic models of microscopic structure of these materials. They use these models to generate data about how space to deform, contact time in a collision, and peak forces in a collision are related. And they carry out additional investigations and analyze data about how the shape and size of cushioning materials affects force distribution in a cushioning structure. They use what they figure out from these investigations: Identify trade offs, analyze and critique design solutions, and optimize a design solutions to solve different design problems for different stakeholders and different contexts" (Teacher Edition, page 16).

Suggestions for Improvement

- Consider introducing the concussion phenomenon prior to the “How Does Touch Work?” reading so that it motivates student learning of LS1.D and the connection to a phenomenon is clearer to students.
- Consider making students aware of the explicit references to the crosscutting concepts used to make sense of the phenomena and to connect the Life Science and Physical Science domains. For example, consider making the references to **Structure and Function** in Lesson 13 more explicit across science domains to students.

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.

Why Do Things Sometimes Get Damaged When They Hit Each Other?

EQuIP RUBRIC FOR SCIENCE EVALUATION

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

The reviewers found extensive evidence that the materials provide grade-appropriate connections to the Common Core State Standards (CCSS) in mathematics, English language arts (ELA), history, social studies, or technical standards because mathematics and ELA CCSS are clearly identified and used throughout the unit. Students are provided with a wide variety of opportunities to engage in reading and writing tasks along with a wide variety of opportunities to engage in discussions with peers.

Throughout the unit, a variety of specific opportunities for students to engage in CCSS are explicitly called out. Some examples are below:

- “Supporting Students in Making Connections in ELA” sections are included in Lessons 1, 2, 4, 10, and 12.
- Lesson 1: The standard “CCSS.ELA-LITERACY.SL.8.1.C. Pose questions that connect the ideas of several speakers and respond to others' questions and comments with relevant evidence, observations, and ideas” is used: “When the class is building the Driving Question Board (DQB), if a student forgets to explain why or how their question is linked to someone else’s question, press that student to try to talk through their own thinking. This is a key way to emphasize the importance of listening to and building off of each other’s ideas and to help scaffold student thinking” (Teacher Edition, page 51).
- Lesson 4: The standards “CCSS.ELA-LITERACY.SL.8.1.C. Pose questions that connect the ideas of several speakers and respond to others' questions and comments with relevant evidence, observations, and ideas” and “CCSS.ELA-LITERACY.SL.8.1.D Acknowledge new information expressed by others, and, when warranted, qualify or justify their own views in light of the evidence presented” are used. “Both of these ELA goals are the focus of the discussion in the Scientists Circle at the end of day 2 of this lesson when the class works together to decide how to update their Progress Tracker. The focus on connecting questions, sources of evidence, what was observed, and key science ideas from other students in order to create an agreed-upon set of consensus ideas to add to the Progress Tracker relies on the first ELA goal above” (Teacher Edition, page 102).
- The Teacher Background Knowledge section includes guidance for developing a word wall. “The Word Wall becomes an ongoing collection of words we will continue to use, including all the words we learn in the unit and possibly a few key words we encounter” (Teacher Edition, page 23).
- Suggestions to promote vocabulary acquisition are made throughout the unit. For example, in Lesson 2 the teacher is guided to say, “As groups were working, I noticed a lot of us are using different words to describe permanent shape changes to the fragile things in our investigations. Let’s add the word ‘damage’ to our Word Wall. It might also be helpful for us to show the different kinds of damage we are seeing. Using students’ own words to describe damage (e.g., nicked, bent, cracked, broken into pieces) and input from students, draw diagrams on the Word

Wall to show different degrees of damage. Emphasize that all of these involved shape change" (Teacher Edition, page 60). In Lesson 2: "If students start using the term kinetic energy, push them to explain their definition and to justify why they feel like this would be appropriate terminology to use here" (Teacher Edition, page 69).

- "CCSS.ELA-LITERACY.SL.8.1.C. Pose questions that connect the ideas of several speakers and respond to others' questions and comments with relevant evidence, observations, and ideas." "When the class builds the Driving Question Board (DQB), if a student forgets to explain why or how their question is linked to someone else's question, press that student to try to talk through their own thinking. This is a key way to emphasize the importance of listening to and building off of each other's ideas and to help scaffold student thinking. Don't worry if some questions are raised that are not part of topics in this unit. Over time, students will get better and better at forming testable questions within the scope of the driving question. This type of activity gives them practice at doing that. If students can't figure out which question to connect theirs to, encourage them to ask the class for help. After an idea is shared, ask the original presenter if there is agreement and why, and then post the question" (Teacher Edition, page 51).
- In Lesson 10, the "Supporting Students in Making Connections in ELA" section supports the following three CCSS:
    - **CCSS.ELA-LITERACY.W.8.1.** Write arguments to support claims with clear reasons and relevant evidence
    - **CCSS.ELA-LITERACY.W.8.1.B.** Support claim(s) with logical reasoning and relevant evidence, using accurate, credible sources and demonstrating an understanding of the topic or text.
    - **CCSS.ELA-LITERACY.SL.8.1.C.** Pose questions that connect the ideas of several speakers and respond to others' questions and comments with relevant evidence, observations, and ideas.
        - Students write an explanation to support claims around mass and speed and how this affects kinetic energy of a moving object. In addition, students revisit the Driving Question Board to identify what questions they can answer and which questions they still need to investigate" (Teacher Edition, page 207).

Students are provided with opportunities to use grade appropriate mathematics concepts throughout the unit when appropriate. Some examples follow:

- Lesson 4: "Since this may be the first time students have drawn a trend line in 8th grade, talk with your math teachers in 8th grade to determine when students will be encountering this idea in their math class. It is a CCMS target learning goal for 8th grade. If students struggle with these graphing skills, coordinate with the grade-level math teacher to ask about additional contexts that students may be familiar with from math class that they can practice applying these skills to. These examples can be a useful reference for students. You may want to post these as anchor charts in your class to help students see how to transfer to their science class the ideas and skills they are developing in math" (Teacher Edition, page 97).

- Lesson 7: The teacher is provided with an opportunity to connect student learning to math class: "Connect to the idea of scale factors from math class. Say, when you are saying you predict the new value compared to the old value will be 3 times more or 6 times more, you are describing the ratio of the new value to the old value as a scale factor." (Teacher Edition, page 154).
- Lesson 7: When students describe and compare the qualitative relationships between the mass of a moving object and its kinetic energy and the speed of a moving object and its kinetic energy they develop and use ideas related to this current-grade math standard: **8.F.B.5** Describe qualitatively the functional relationship between two quantities by analyzing a graph (e.g., where the function is increasing or decreasing, linear or nonlinear). When students describe and compare the quantitative relationships between speed of a moving object and its kinetic energy they develop and use ideas related to this current-grade math standard: **8.EE.A.1** Know and apply the properties of integer exponents to generate equivalent numerical expressions.

Discussion with peers is a major component of the unit with students having multiple opportunities to engage in discussion with peers. For example:

- Lesson 9: Students pair up with someone who did the opposite at home investigation to explain their findings. "Connect to previous explanations for investigation stations. Display slide E. Say, today we are going to work in jigsaw feedback groups to share our claims. Each group will consist of fellow students who wrote claims about different stations. There will be at least one person in each group who wrote claims about each station. Before we begin, take some time to think about how you will share your claim and highlight or underline the important ideas you want to emphasize with your classmates" (Teacher Edition, page 187).
- Lesson 12: "Share ideas with a partner. Project slide D. Once students have had a chance to make predictions about materials, have students turn and talk to a partner about their predictions. Have students use the following questions to guide their partner discussion: What material do you think will reduce peak force the most? Why? What material(s) do you think will perform the worst? Why?" (Teacher Edition, page 233).

Students also have an opportunity to engage in a variety of formats for the purpose of learning new material. However, some of the additional formats are optional, rather than used for all students.

- Lesson 4: Students read "Results from Other Materials Tests," which contains text, diagrams, and graphs. Students use the information to update their Progress Trackers.
- Lesson 5: Students engage in a reading titled "How Does Touch Work?" The reading discusses the sensors present on the skin which respond to different sensations and how these signals send information to the brain. Students use information from the reading to develop a model and discuss what they learned with a partner the next day.
- Lesson 13: The alternate (optional) extension activity links to resources from the Centers for Disease Control and Prevention about head injuries. The linked website includes formats such as fact sheets and infographics (Teacher Edition, page 272).

Suggestions for Improvement

- Consider adding additional rich text options to further strengthen the ELA supports with reading materials in additional formats, the content of which relate to the instructional materials: fictional or narrative stories; news articles; journal articles; infographics; and websites of scientific entities that are included with the lesson, and not an optional alternate activity or extension.

- Consider identifying what CCSS ELA standard the data set in Lesson 14 and optional infographics in Lesson 13 align to and how students use them to see the connections between content areas.

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

The reviewers found adequate evidence that the materials engage students in authentic and meaningful scenarios that reflect the real world because students have multiple opportunities to connect to the phenomena and apply to real-world scenarios. However, the opportunities for students to connect their explanations of a phenomenon or their design solution to a problem arises from teacher direction, rather than student experiences and questions.

Students are provided with the opportunity to experience the anchor phenomenon and supporting sports phenomenon:

- Lesson 1: Students are shown data about cell phone damage and discuss their own prior experiences with cell phone damage. They then use CD cases as substitutes for phones to demonstrate what happened to the phone when it got damaged.
- Lesson 1: “Introduce a CD case to represent a phone in collisions. Display slide C. Say, I would love to hear about your experiences with phones breaking, but sometimes it's easier for us to understand a situation where something occurred when we can see a representation of how it happened rather than just hearing about it. Phones are expensive, so I have a CD case here that we are going to use as a substitute for a phone. I thought we could use this as a manipulative to represent what happened to the phone when it got damaged.” “Demonstrate phone breaking experiences. Select one volunteer at a time to come up in front of the class and demonstrate what happened with the cell phone when it broke. Let students know it's OK if what they show us ends up causing the CD case to break too, as we want to try to understand the interactions that happened and the results as accurately as possible. Remind them to be responsible and avoid moving the CD case or any other object in a direction that might remotely come in contact with another living thing or fragile object” (Teacher Edition, page 31).

- Lesson 6: The Soccer Assessment asks students to apply what they have learned about collisions to a new situation — soccer. For example, "How would the forces from a header with such a light soccer ball cause a concussion? Draw two free body diagrams showing how the amount of peak force on the head would compare to the amount of peak force on a soccer ball in a header that causes a collision" (8.1 Lesson 6 Soccer Assessment).
- Lesson 7: Students double the speed and then double the mass of a moving object to determine which results in greater damage during a collision. They directly observe the damage done to a saltine cracker attached to a file card. "Gather students around the pooled class results (crackers on paper) or give them a couple minutes to do a gallery walk past all the collected results. Ask students to study the results and be prepared to make an argument for the answer to this original question based on our results: How much does doubling the speed or doubling the mass affect the kinetic energy of an object and the resulting damage that it can do in a collision?" (Teacher Edition, page 151).

Students are provided an opportunity to connect the anchoring phenomenon of the cell phone breaking with events in their own lives. For example:

- Lesson 1: Students brainstorm related phenomena. "Motivate related phenomena.
  Say, these categories of collisions could be useful for thinking about other related phenomena where something other than a phone was involved in a collision. But not all collisions result in damage. Think of examples where something other than a phone was damaged in the collision. I also want you to think of examples where you were surprised that something other than a phone was not damaged in a collision" (Teacher Edition, page 35). Students then go through a process of brainstorming related phenomena.
- Lesson 10: "Say, we will have a chance to revisit each collision type in small groups. Remember we brainstormed related phenomena that went with each collision type in Lesson 1. We should go back and try to explain our real-world scenarios! (Teacher Edition, page 198).
- Lesson 11: Students select an object that needs better protection "If you had to pick only one object that you interact with a lot that you would want to protect from damage, what would you pick and why? If we were to make a protection device for this object, what damage-reducing solutions could you come up with?" Students then complete the "Drafting Our Protection Device Design" activity (Teacher Edition, pages 216–218).

When developing their design for a case, students have an opportunity to choose something that is relevant to them. Their design is also connected to their lives and community through seeking of stakeholder feedback. For example:

- Lesson 11: Students identify some other objects which would need to be protected.
  "Say, it seems like we have identified some of the criteria and constraints the designer of a phone case should consider. But we all know phones aren't the only objects that people might want to protect from damage. Let's brainstorm some other possibilities. Is there anything other than a phone that you would like to (better) protect?" (Teacher Edition, page 215).

- Lesson 11: Design tasks are established with the purpose of meeting the goals of the design. The overall design of how the device meets those goals is directly impacted by the needs and considerations of the community (stakeholders). Taking home the student-created designs for additional feedback allows students to get more relevant stakeholder input and engage with others in their community to understand how designs affect and are shaped by people involved. Additional stakeholder feedback will also contribute to the relevance and authenticity of the task to design a protective device for the object of the student's choice (Teacher Edition, 219).
- Lesson 14: Students gather and use stakeholder feedback for their designs. "Universal Design for Learning: Engineers routinely engage stakeholders in the feedback process. As students work as engineers they will engage in these same processes to refine their designs. When students utilize the stakeholders in their communities to refine a design of their choosing, authentic engagement in the task increases as students see themselves, their decisions, and the effects that they can have on their communities. This will help students express solutions that are more relevant for their personal stakeholders, and therefore ultimately more optimized for the problem they are trying to solve" (Teacher Edition, page 282).

Unit materials provide suggestions on how to respond if students make connections to previous units. For example:

- Lesson 3: The Supporting Students sidebar shares that in a previous unit students "determine that large sections of rock (in plates) can bend when large forces are applied to them. If students raise this idea, emphasize this connection to the entire class" (Teacher Edition, page 84).
- Lesson 4: In the Supporting Students sidebar, "If students are struggling with the ideas of variables, you may need to review some examples from previous investigations they have done in prior years. OpenSciEd units will have multiple examples to draw from in the following units: OpenSciEd Unit 6.2: How can containers keep stuff from warming up or cooling down? (Cup Design Unit) OpenSciEd Unit 6.3: Why does a lot of hail, rain, or snow fall at some times and not others? (Storms Unit) OpenSciEd Unit 7.1: How can we make something new that was not there before? (Bath Bombs Unit) OpenSciEd Unit 7.3: How do things inside our bodies work together to make us feel the way we do? (Inside Our Bodies Unit) OpenSciEd Unit 7.4: Where does food come from, and where does it go next? (Maple Syrup Unit)" (Teacher Edition, page 94).

The opportunities for students to connect their explanations of a phenomenon and their design solution to a problem arise from teacher direction, rather than student experiences and questions. For example:

- Lesson 5: Students revisit the questions they were considering in Lesson 4. The teacher is then instructed to say, "We've been using forces to explain deformation of objects in a collision or any time they make contact." Then "It seems like figuring out what is pushing on what is something we need to resolve in order to explain why some things break and others don't in a collision. Let's look more closely at the interactions between two objects to see if we can figure out what is getting pushed in a collision" (Teacher Edition, page 111).

- Lesson 7: "Finding a way to quantify how much kinetic energy an object has when we change its mass or its speed could provide us another tool for explaining why some things get damaged in a collision and others don't. It could also help us more precisely predict the amount of damage a moving object could do and maybe even give us ideas about ways to design solutions to prevent such damage from happening" (Teacher Edition, page 152).

Suggestions for Improvement

- Consider providing additional prompts for drawing out student questions related to their learning and prior experiences. This could happen in the navigation sections or during scientist circles when students engage in making sense of what they have learned or developing models.
- It is important that all students be supported when working with meaningful and engaging phenomena. Students who do not own a cell phone or have not experienced a cell phone dropping might not find the cell phone breaking data personally relevant. Consider engaging all students in the phenomenon by also showing a video of a falling cell phone or using a real, broken phone as a demonstration. Student questions about frequency of falls would create a *need to know* and need to analyze statistical data.
- Lesson 1: Rather than having the teacher model the collision, consider ways that students could be involved in creating models.

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 the teacher has support to act as an expert facilitator and students have opportunities to reflect and respond to teacher and peer feedback.

The unit provides opportunities for students to receive and respond to peer feedback. For example:

- Lesson 1: "Have students ask an elbow partner to quickly check their collision types." "Find someone and share your collision. As you share, be thinking about what is similar and different between the two collisions" (Teacher Edition, pages 36–37). "Tell students that as their classmates share their models, they should place a small check mark (✓) near what is similar and a question mark (?) near what is different on their own model. Ask students to explain what they think is happening that we can and cannot see between the two objects" (Teacher Edition, page 42).

- Lesson 1 slides and Teacher Edition documents prompt students to engage with the ideas and models of others. The Teacher Edition provides support in the "Attending to Equity" section so that emergent multilingual students are successful with this task: "For this reason, partner talk or small-group talk should precede whole-group sharing to give students an opportunity to share their ideas with one or two peers before going public with the whole class" (Teacher Edition, page 36).
- Lesson 5: "Reintroduce the questions students were considering at the end of the last lesson. Say, we've been using forces to explain deformation of objects in a collision or any time they make contact. So, let's consider some of the cases we've looked at before using this force perspective. Show slide A. Give students a moment to reread the text on the slide. Then say, what did you and your partner predict about these two different cases? Were you in agreement or did you have different ideas? Share ideas about forces between objects in a collision. Anticipate some disagreement in students' responses. Encourage students to weigh in on the ideas that are shared so you can help students recognize that we are either not in agreement or we are uncertain about some of our predictions and need additional evidence to support alternate ideas" (Teacher Edition, page 111).
- Lesson 9: Student jigsaw feedback groups work through four different claims to discuss in alignment with each of the four stations investigated in the previous class meeting. Students are asked to discuss all questions on Jigsaw feedback discussion (Teacher Edition, page 197).
- Lesson 10: "After students have completed a first pass at Explaining A Collision, tell students that they will get a chance to give and receive feedback on their ideas. Explain to students that they will find a person from another group with the same collision type. They will then share their specific phenomenon and show how they represented their ideas for question 3. After that, they can discuss similarities and differences in their representations and overall ideas using the guiding questions on slide D" (Teacher Edition, page 201).
- Lesson 10: After completing the "Explaining a Collison" handout students have an opportunity to receive feedback from peers and the teacher. However, it is unclear what feedback the teacher will provide for the student explanations. For example:
    - Students have the opportunity to respond to teacher feedback when they are working on "Explaining a Collision." "As students are working, circulate from group to group. Use this time to provide individual feedback in the form of questioning to guide students to the big ideas and representations needed in each box." Teachers are provided with a list of questions to ask students. "The following questions can be used to help students as they are working on different boxes." For example: "Look back at box 1. If something were different in box 1, would it affect the collision? If so, document that in box 3" and "Look back at box 2. If you were to alter something in box 2, would it affect the outcome of the collision? If so, add it to box 3" (Teacher Edition, page 200).

- Students have the opportunity to respond to peer feedback: "Say, after you have had a chance to share with your partner, you will get a chance to revise your ideas and make a stronger explanation based upon what you may have seen in your partner's model or the feedback that your partner has given you. After we have completed our revision cycles, you will be turning this in." "As students are giving feedback, circulate and remind students to use the guiding questions on the slide to help give feedback" (Teacher Edition, page 201).

- Lesson 11: Suggested prompts for feedback are provided. "Tell students to use these questions to answer as they give feedback to their partners. What do you like about the design? What changes would make it 'better' at protecting the object? What other changes would you make to make the device more appealing to stakeholders?" (Teacher Edition, page 219).
- Lesson 14: Students use feedback from stakeholders to revise their designs. Students rate their design, then "have a partner look at your ratings and see if they agree with your ratings. If they agree, keep the rating the same. If they do not agree, discuss why each of you would give a different rating. If needed, ask a third person to weigh in. Try to come to a consensus" (CF.L14 Slide T).
- Lesson 15: In previous lessons, it was suggested to teachers to allow students who needed additional time to build understanding to revise their previous assessments. The following guidance is provided in Lesson 15: "If students had previously needed additional learning experiences to show conceptual understanding on the Lesson 6 or Lesson 10 assessment and have been revising their questions as the unit has progressed, instruct students to get back out their prior assessment they have been updating during Lessons 11–14. Tell students to use their updated answers to aid them in developing their responses on both Parts 1 and 2 of the current assessment" (Teacher Edition, page 294).

Students are provided with opportunities to clarify, justify, interpret, and represent their ideas. For example:

- Lesson 1: Students set up and organize their science notebooks. "Keeping a science notebook allows students a space in which to reflect and communicate their developing understandings about science ideas and to track changes in their understandings. Students should be encouraged to record their ideas using linguistic (e.g., written words) and nonlinguistic (e.g., taping in photographs, creating drawings, tables, graphs, mathematical equations, and measurements) modes" (Teacher Edition, page 37).
- Scientist Circles are used throughout the unit. For example:
  - Lesson 1: "Setting up the norms and logistics for forming, equitably participating in, and breaking down that space is important to do if this is your first time forming such a space. Having students sit in a circle so they can see and face one another can help build a sense of shared mission and community of learners working together" (Teacher Edition, page 41).

  - "One way to ensure that all student ideas are shared and get up on the board or poster is to pass a marker to the first person nearest you in the circle. The student with the marker should share one idea. Write it on the board or poster. Once that student sees that you have almost finished writing it, that student should pass the marker to the next student" (Teacher Edition, page 50).
  - Lesson 8: "Convene students in a Scientist Circle to discuss some of their ideas" (Teacher Edition, page 169).
  - Lesson 11: "Arrange students in a Scientist Circle around a piece of chart paper. Pass out sticky notes to students. Ask students to look back at the class-created charts, their handouts, other's designs, and the feedback they received from others. Have students consider what questions they now have about the materials, design, structure, and function of the protection devices" (Teacher Edition, page 222).
- A DQB is used to record student questions about "Why do things sometimes get damaged when they hit each other?"
  - Lesson 1: Every student adds at least one question to the DQB. "The first student reads a question aloud to the class, then posts it on the DQB. Students who are listening should raise their hands if they have a question that relates to the question that was just read aloud. The first student selects the next student whose hand is raised. The second student reads a question, says why or how it relates, and posts it near the question it most relates to on the DQB. That student selects the next student. If another student has shared the same question that you have, try to share a different question that has not been shared. We will continue until everyone has at least one question on the DQB" (Teacher Edition, page 48).
  - Lesson 6: Students revisit the DQB questions and "spend some time working with a partner on identifying at least [sic] questions they feel the class has made progress on and one question they feel they can answer from our Driving Question Board" (Teacher Edition, page 134).
- Turn and Talk opportunities are provided in many lessons, including lessons 2, 4, 5, 7, 10–14, and 16. For example:
  - Lesson 2: "Give students two minutes to share their ideas with a partner, and then hear ideas from 2–3 groups. These are sample student responses: When objects collide, energy is transferred from one object to another, and we observe changes in their motion. When objects collide, one or more forces push on one or more objects, and we observe changes in shape" (Teacher Edition, page 66).
  - Lesson 12: "Once students have had a chance to make predictions about materials, have students turn and talk to a partner about their predictions. Have students use the following questions to guide their partner discussion: What material do you think will reduce peak force the most? Why? What material(s) do you think will perform the worst? Why?" (Teacher Edition, page 223).

    - Lesson 16: "Have students turn and talk about the following question: If you were an investor, what would be the most important thing you would want to know about someone's proposed design solution?" (Teacher Edition, page 303).
- Teacher prompts are provided to elicit student ideas and reasoning but the modality and specifics for teacher feedback are not as explicit as they could be.
    - Lesson 3: Students are asked "Do really solid objects bend or change shape when pushed during a collision?" The teacher is then directed to "Ask students to give a thumbs up for yes or a thumbs down for no. Ask a few students to explain their reasoning, both from students who voted yes and from students who voted no" (Teacher Edition, page 79).
    - Lesson 4: "Use prompts similar to these, inviting students to contribute ideas and to work with the ideas that others contribute: Who can suggest one idea we should add to our Progress Tracker about how materials respond when a force is applied to them? Is this true for all solids? How do we know? Can someone summarize an important idea about what it means when we say solids are elastic up to a point? If all materials are elastic up to a point, what is the difference between a rigid material like steel or glass and something that is more flexible? Does someone have an important idea about elastic limits or breaking points related to forces that we haven't included yet in our class Progress Tracker?" (Teacher Edition, page 100).
    - Lesson 9: "When you develop your explanation, you will focus on the evidence collected and the observations and insights you recorded from only one station. Your explanation should help answer the question: How do other contact forces, like friction or air resistance, cause energy to be transferred from a moving object to other parts of a system? Be sure to describe what causes these forces, how these forces transfer energy in the system, and the evidence from your assigned station investigation supports your explanation. I will collect your explanations so I can get a sense of what you are thinking and then return them to you tomorrow. Give students time to write and collect claims at the end of class. Students can write claims in their notebooks or on blank paper for ease of collection" (Teacher Edition, page 187). It seems that teachers might give feedback to students at this point but guidance for this process is not included in the materials.
    - Lesson 11: "As students are drafting ideas, circulate and ask students the following questions to clarify their thinking and refine their decisions. What shape are you using for your structure? What is special about that shape compared to other shapes? Would another shape work better or worse to help protect your device from damage? Why or why not?" (Teacher Edition, page 218).

Suggestions for Improvement

Consider specifically noting where clear teacher feedback to all students is necessary to ensure that all students have a fair opportunity to learn and confirm their ideas. Consider indicating in what modality teachers will respond to students and when students will respond or incorporate feedback.

II.C. BUILDING PROGRESSIONS

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

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

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

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

The reviewers found adequate evidence that the materials identify and build on students' prior learning in all three dimensions because the material explicitly states expected levels of proficiency prior to the unit and teachers are provided with support to clarify student misconceptions. Targeted elements of all three dimensions are included but CCC and SEP element learning progressions are not explicitly stated.

General support is provided for building progressions. For example:

- Supporting Student sidebars provide guidance for building progressions. In Lesson 2: "Supporting Students in Developing and Using System and System Models-Referring to the objects in this collision as being part of subsystems primes students for developing models for free-body force diagrams (subsystems) in Lesson 5." "They will leverage this thinking in Lesson 8. This system framing in this lesson primes students for making particle-level connections later in Lesson 8 to account for energy transfer to the surroundings via friction and air resistance" (Teacher Edition, pages 61–62).
- Lesson 2: Teacher materials suggest "If students are struggling to get started, model completing a cause-effect statement using an example that leverages prior knowledge. For example, say, In the weather and climate unit you learned about what happens when two different air masses interact. Let's write a cause-effect statement describing what you figured out about interactions between warm and cold air masses" (Teacher Edition, page 65).
- Lesson 5: "The students' prior experiences with planning an investigation are elicited from a previous lesson. In that lesson, as in this one, they identify an independent and a dependent variable and variables to keep constant. The structure of that handout is the same as the one they are using in this lesson: Comparing Forces on Two Push-Pull Spring Scales. That should help make the investigation planning in this lesson a familiar process. As Lesson 5 continues, students determine the independent and dependent variables they change and keep constant and record them on the Lesson 5 sheet: "Independent, Dependent, and Controlled Variables."

This is similar in structure to what they did in the previous lesson, but with less guidance. Students also plan their own data table. And they are asked to make note of any challenges or any sources of error they encounter in the investigation. This helps motivate the later need for calibrating the system being used to collect data in the investigation they carry out in Lesson 7" (Teacher Edition, page 110).

- Lesson 7: "The lesson, as written, plans for students to start thinking about the qualitative relationship between changes in the maximum force from the launcher on the cart and the amount of energy transferred to the cart subsystem at the end of the lesson, rather than now. But if students spontaneously raise these noticings now during the investigation, follow up with additional questions in the moment to encourage additional reasoning about what they notice" (Teacher Edition, page 151).

Unit materials identify expected prior learning for all three dimensions. For example:

- "This is the first unit in the 8th grade scope and sequence for OpenSciEd. There are six total units designed for 8th grade. This unit directly builds off the Disciplinary Core Ideas (DCIs), Crosscutting Concepts (CCCs), and Science and Engineering Practices (SEPs) developed in one the 6th grade units that preceded this one" (Teacher Edition, page 16). However, a progression of specific elements of prior expected learning in the SEPs is not provided.
- The section "What DCIs should my students know from earlier OpenSciEd units?" outlines what DCIs from previous units should be understood by students. The section "What should my students know from earlier grades?" outlines performance expectations from previous grade levels that students should have previously worked towards (Teacher Edition, page 18).
- The "Where We are Going" section also provides teacher support for linking related DCIs from prior grades as well as related elements of the CCC which will provide an opportunity to bring related DCIs from prior grades: grade 4 (energy transfer in collisions), grade 2 (objects pull or push each other when they collide), and the middle school grade band explanation (such as equal force pairs between the two objects in contact). There are phrases in the prompts that ask students to consider related elements of CCCs as well, particularly elements related to **Cause and Effect**, **Systems and System Models**, and **Stability and Change** (Teacher Edition, page 30).
- The "What are the Focal Science and Engineering Practices (SEPs) for this unit?" section outlines which SEPs students will already have developed fluency in during previous grades. However, specific elements are not provided (Teacher Edition, pages 18–19).

The learning progresses logically for Disciplinary Core Ideas throughout the unit as lessons build on each other to develop the conceptual understandings. For example:

- Lesson 2: Students learn that collisions can cause objects to change shape and that energy transfers during a collision.
- Lesson 3: Students learn that all solid objects bend or change shape when forces are applied.
- Lesson 5: Students learn that when objects collide they apply equal forces on each other.

- Lesson 6: Students learn that the more kinetic energy an object has the more damage is caused in a collision.

A progression for CCCs is briefly outlined in the "What are the Focal Crosscutting Concepts (CCCs) for this unit?" section on pages 19–20. This section provides information on CCC elements that have been previously developed (Teacher Edition, page 19–20). Although this guidance outlines where these ideas are used or leveraged, there is not specific guidance as to how individual elements are developed. For example:

- **Structure and Function** element: *Complex natural and designed structures and systems can be analyzed to determine how they function.*
  - "This idea is leveraged in Lesson Set 3 (Lessons 11–15). Students will have encountered this idea in their work in a prior unit of instruction: OpenSciEd Unit 6.2: How can containers keep stuff from warming up or cooling down? (Cup Design Unit)."
- **Structure and Function** element: *Structures can be designed to serve particular functions by taking into account properties of different materials, and how materials can be shaped and used.*
  - "This idea is leveraged in Lesson Set 3 (Lessons 11–15). Students will have encountered this idea in their work in a prior unit of instruction: OpenSciEd Unit 6.2: How can containers keep stuff from warming up or cooling down? (Cup Design Unit)."
- **Structure and Function** element: *Microscopic structures and systems can be visualized, modeled, and used to describe how their function depends on the shapes, composition, and relationships among its parts.*
  - "Students will be doing new work related to this idea."
  - "To support the use of this idea in Lessons 11–15, students prior work related to patterns will be helpful."
- **Patterns** element: *Macroscopic patterns are related to the nature of microscopic and atomic-level structure of the matter.*
  - "Though this is not a focal CCC in the unit, be prepared to provide students greater support in this CCC, which students will have already developed substantial fluency with related to this idea, in prior units of instruction."
  - "Students will do a large amount of structure and function thinking at the microscopic level to account for macroscopic properties of cushioning materials in Lessons 12 through 15. This structure and function thinking leverages students prior work with patterns related to the idea listed above. Students will have modeled zoom in bubbles to show what is happening to the particles of the matter in units and they will develop and use cellular and tissue level structures (microscopic) to explain life science related phenomena. The scale of the structures they are modeling in this unit are larger than particles or cells, but still at the microscopic scale" (Teacher Edition, page 20).

Support for understanding possible student misconceptions about forces is provided:

- In the Teacher Edition, a page with "What are some common ideas that students might have" addresses what students may think about forces including:
    - "Students may think that: a force is a property of a single object, rather than the result of two interacting objects" (Teacher Edition, page 22).
    - Links to other prior conceptions documented by the American Association for the Advancement of Science, Project 2061 are included for related ideas about Force and Motion as well as Energy: Forms, Transformation, Transfer, and Conservation (Teacher Edition, page 22).

Suggestions for Improvement

- Consider providing a specific progression of learning for SEP elements and CCC elements in the Teacher Background Knowledge section of the Teacher Edition, along with the "And what prior learning related to the SEPs/CCCs does this unit build on" sections. A small addition of wording related to the element-level descriptions of student progressions could move this rating to Extensive. For example, the materials could say "Students should already be familiar with the general ideas of cause and effect relationships but are not yet expected to understand that causes generate observable patterns." NGSS Appendices E, F, and G are resources that could be used when identifying what learning students are expected to come in with for all three dimensions from previous grade bands, and details of student proficiency in individual elements from previous years could be described based on student expectations in prior middle school units.
- Though reviewers note that PS1.A: Structure and Properties of Matter is not identified as a target DCI in this unit, the language in the CCC **Structure and Function** is used in Lessons 11–16 and connects to PS1.A in younger grades. Listing the Performance Expectations in 2nd and 5th grade that address PS1.A (and has very similar CCC language for **Structure and Function**) may help teachers see the arc of learning between the DCI and CCC: 2-PS1-1 and 5-PS1-3.

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 ideas and representations are accurate and the materials allow for and address student expression of scientifically inaccurate information.

Related evidence includes:

- A "What are some common ideas that students might have?" section is included in the Teacher Background Knowledge: "Some students may have heard that for any action there is an equal and opposite reaction, but may not see that this describes what is happening at any point of contact and in any collision between two objects. They may confuse this idea with situations where the net force on an object is zero, and the motion of the object isn't changing. This is an instance of Newton's first law, whereas the former is Newton's third law" (Teacher Edition, page 21).
- Links to the American Association for the Advancement of Science, Project 2061 bring the teacher to specific misconception data on Force and Motion and Energy: Forms, Transformation, Transfer, and Conservation topics for grades 6–8 and 9–12 (Teacher Edition, page 22).
- Lesson 2: "Motion changes outside in systems where the motion isn't bounded in one dimension are outside the boundary of the target performance expectations for the middle school grade band" (Teacher Edition, page 58).
- Lesson 5: "Students will not be using free body diagrams to represent coordinate systems since the grade-band focus of forces should be limited to the study of forces in one dimension" (Teacher Edition, page 110).
- Lesson 7: "When students compare the relative amount of kinetic energy an object has by determining how far a cart can push a box it collides with and maintains contact with across a surface, they are using relationships that are part of the work-energy theorem. This theorem describes the quantitative relationship between the change in kinetic energy of an object and the force applied over a distance on that object. That quantitative relationship is not a focus of the unit and is beyond the grade-band learning targets. But, establishing a qualitative relationship between the net force applied to an object and how much this changes an object's motion (and the kinetic energy it has) is a focus of the unit" (Teacher Edition, page 144).
- Lesson 8: The additional guidance section provides information about scientific accuracy: "Referring to this energy stored in the configuration of the parts of a system as potential energy has some tradeoffs in terms of simplicity of understanding versus accuracy of representation." Teachers are told "So more exactly, it's not the spring that is storing the potential energy, it is the spring system. In that system it ultimately is the electric field between the atoms that make up the spring launcher and the matter that it is in contact with that holds the spring in a compressed form. In that form, the position and orientation of the atoms that make up the matter shift and the field between them stores the energy in the system. This is beyond grade level understanding and would not be beneficial to introduce here" (Teacher Edition, page 171).

Suggestions for Improvement

N/A

II.E. DIFFERENTIATED INSTRUCTION

Provides guidance for teachers to support differentiated instruction by including:

i. Appropriate reading, writing, listening, and/or speaking alternatives (e.g., translations, picture support, graphic organizers, etc.) for students who are English language learners, have special needs, or read well below the grade level.

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 the unit provides multiple differentiation activities and methods that support struggling students and include reading, writing, and speaking supports for accessibility for all students including English language learners. Extension activities are also provided for students who have high interest in the subject matter, however, they do not support building a deeper understanding in all three dimensions, only the DCIs.

Some examples of general supports are below:

- Attending to Equity section in margin: “Emergent Multilingual Learners: For students who are learning English or who need support following a whole-group discussion, it can be helpful to use gestures in addition to talking. For example, as you describe a phone hitting a wall, demonstrate the collision by holding a phone (or another object to represent a phone) in your hand and moving it slowly toward the wall” (Teacher Edition, page 31).
- Lesson 1: Attending to Equity section in margins: “Supporting Emergent Multilinguals: Before students engage in whole-class discussions, it can be helpful to first provide them with the opportunity to work with others—either in pairs, triads, or small groups—on ideas related to their reasoning. These smaller group structures can be especially helpful for emerging multilingual students because they offer students a chance to engage in sense-making with

their peers and also the space to use their linguistic and nonlinguistic resources to express their ideas (and learn from other students' uses of these resources too)" (Teacher Edition, page 40).

- Lesson 3: "A Word Wall will become a useful space for recording a shared meaning of new words as students develop a deeper meaning for them. When developing new vocabulary, some strategies that may benefit emergent language learners are to use student-friendly definitions, make connections to cognate words when possible, and include a visual representation of the word. Students may find it helpful to have you add additional images of objects deforming, both permanently and temporarily, next to the word deform on the Word Wall in the next lesson as well" (Teacher Edition, page 85).
- Lesson 5: "The ideas presented in this reading can be conceptually challenging for some students, so having different modes for interacting with the reading will provide different ways to access the reading. Some students may benefit from having this reading available as an audio reading so they can listen as they read along on the handout. Other students may benefit from doing a partner reading. Some students may benefit from expressing their understanding by annotating and adding to the existing diagrams in the reading rather than drawing a new body system diagram from scratch as is prompted at the end of the reading" (Teacher Edition, page 117).
- Lesson 6: "For question 5 of the assessment, students are asked to write an explanation supporting which type of head collision would potentially do more damage to the brain. Because students are synthesizing what they have figured out about collisions with new information they are reading during the assessment about the brain, offering students a choice in modality to demonstrate this synthesis provides equal access for all students. Some students may benefit from drawing a representation of the one collision they feel will do the most damage and labeling it to support why they chose the one they chose. As another alternative, some students may find more success explaining this orally through recording themselves and then turning in the recording, or presenting to the class, or presenting to you during an appropriate time in the classroom."
- Lesson 10" There are two versions of the assessment to support differentiation with the amounts of scaffolding students receive embedded in the assessment itself.
- Lesson 12: "Universal Design for Learning: Taking a poll allows for students to engage in presenting their ideas in a low-risk manner. Students can share their ideas without being pressed for going public individually and/or having to explain their predictions without specific evidence to cite. By asking the entire group about the identification of certain materials falling into the categories of being best and worst performers, not just the students who have their hands raised, students feel less pressured to make a prediction about a material as their classmates can chime in and give their perspective on the polling choice" (Teacher Edition, page 233).

Some supports are provided for students struggling with the mathematics in the unit, but the suggested supports might not work in all classrooms. Additionally, suggestions for adaptations if students begin the lesson with higher or lower levels of prior proficiency than expected for the grade level are not provided. For example:

- Lesson 4: Students are asked to engage with their data by drawing graphs and drawing trend lines. "If students struggle with these graphing skills, coordinate with the grade-level math teacher to ask about additional contexts that students may be familiar with from math class that they can practice applying these skills to. These examples can be a useful reference for students. You may want to post these as anchor charts in your class to help students see how to transfer to their science class the ideas and skills they are developing in math." In this case, if teachers are not able to coordinate with a math teacher, students may not be supported.
- Lesson 4: In the Supporting Students sidebar "If students are struggling with the ideas of variables, you may need to review some examples from previous investigations they have done in prior years. OpenSciEd units will have multiple examples to draw from in the following units: OpenSciEd Unit 6.2: How can containers keep stuff from warming up or cooling down? (Cup Design Unit) OpenSciEd Unit 6.3: Why does a lot of hail, rain, or snow fall at some times and not others? (Storms Unit) OpenSciEd Unit 7.1: How can we make something new that was not there before? (Bath Bombs Unit) OpenSciEd Unit 7.3: How do things inside our bodies work together to make us feel the way we do? (Inside Our Bodies Unit) OpenSciEd Unit 7.4: Where does food come from, and where does it go next? (Maple Syrup Unit)" (Teacher Edition, page 94). In this case, if students had not previously used OpenSciEd units, they may not be as supported by these directions.
- Lesson 7: "If you anticipate that some students may struggle with setting up the axes and intervals for their graphs in investigation 3 using the blank graph on two copies of Graphing Kinetic Energy Relationships, make a copy of alternate handouts Alternate: Graphing Mass vs. Kinetic Energy and Alternate: Graphing Speed vs. Kinetic Energy for each of those students. In addition, you may wish to have extra copies of Graphing Kinetic Energy Relationships if students need to remake a graph or re-label axes" (Teacher Edition, page 142). Note that three videos are mentioned in the Teacher Edition, but listed as TBD. "Orient students to an example of such a measurement by showing this video clip: TBD" (Teacher Edition, page 152).
- "Some students may need assistance with the multiplication of a long set of numbers. Offer these students the use of a graphing calculator that displays the multi-step equation as it is added to the calculator. Remind these students to use parenthesis where appropriate. Some students may benefit from the use of a ruler to keep track of numbers on a line, or two rulers to block out unneeded data for the row and "chunk" only the needed information together for each material" (Teacher Edition, page 286).

Examples of provided extension activities are included for students who have already met the performance expectations, but they do not support building a deeper understanding in all three dimensions—only the DCIs. For example:

- Lesson 4: Extension activities are suggested in the "Universal Design for Learning" section: "Students with high interest in materials science or engineering may be curious to learn more about how other materials deform in response to contact forces. For those students, you can encourage them to test other materials or objects at home and bring in a graph to share with the class what they found. Other materials that are easy to collect data from include strips of cardboard and plastic rulers" (Teacher Edition, page 98). "Students with high interest in materials science or engineering may be curious to learn more about how other materials deform in response to contact forces. For those students, you could provide an opportunity to research how the modulus of elasticity, yield strength, and ultimate tensile strength are related to things like the linear region of the force vs. deformation graphs, the elastic limit, and the breaking point on the graphs" (Teacher Edition, page 99).

- Lesson 7: "For students who find more-complex computational thinking highly engaging, you could give them an optional set of questions to consider to express their understanding of how combined effects of changing both the mass and the speed of an object would affect its kinetic energy." The optional questions include: "How would the kinetic energy of an object change if it had three times as much mass and double the speed." "How would the kinetic energy of an object change if it had half as much mass and half as much speed?" "How would the kinetic energy of an object change if it had ten times as much mass but moved 1/10th as fast?" "How would the kinetic energy of an object change if it had sixteen times as much mass but 1/4th the speed?" (Teacher Edition, page 159).
- Lesson 12: "If students are interested in learning more about how contact forces applied to the skin lead to these different sensations, they can read How do we sense different textures? This reading is optional, and will not affect the overall conceptual understanding of why some materials work better than other materials at reducing peak forces in a collision, but may help answer some student questions on the Driving Question Board" (Teacher Edition, page 242).
- Lesson 16: It is an optional extension for use after this end of the unit, for classrooms that have a strong interest in building and producing and testing physical prototypes for design solutions students have been refining on paper in the previous lessons.

Examples of physical accommodations provided include:

- Lesson 5: Students are asked to use "built-in force sensors: our fingers." The Attending to Equity call out box states "If you have a student with a physical disability who can't use fingers for this activity, revise the instructions to include the option to use other parts of their body, such as their knees or elbows, to feel forces. Or if they are not able to do any of these, they could do the activity with a partner at any place on their body that is appropriate for them to interact with and report that they can detect feeling (e.g., on their chin or forehead)" (Teacher Edition, page 112).
- Lesson 10: "Universal Design for Learning: Some students may not be able to see the smaller questions on the driving question board, or visually track from one question to another in a group of questions due to their perception. If students are having trouble seeing or would be better able to complete the task with a list of questions in front of them, give students a copy of the typed questions from Lesson 6. Students may have added questions to this list in the interim, but the list will provide a great starting point for the DQB discussion. The list can also be modified and re-printed if desired" (Teacher Edition, page 203).

- Lesson 12: “Some students may be able to physically manipulate materials better than others due to motor skill differences. When assigning materials, it may be helpful to keep in mind the effort it takes to attach the materials to the carts. It also might be helpful to have ready-made tape loops for students to use. If something other than tape is used, make sure that it is very lightweight so that the mass is not affected from cart to cart” (Teacher Edition, page 234).

Suggestions for Improvement

- The rating for this criterion could be easily moved to extensive with the addition of a few more extensions for students who have already met the performance expectation(s) or who have high interest in the subject matter and are ready to develop deeper understanding in any of the three dimensions, not just the DCIs. Supports for these students could include applying learning in new contexts (e.g., transfer phenomena) or through the lenses of different CCC elements or could include extending to learning from the next grade level.
- Consider providing additional resources to support the development of mathematical concepts in the unit for a teacher without a math colleague with whom they can collaborate.
- When providing connections that teachers can use when they help struggling students, consider including examples that are not solely from OpenSciEd Units. Some students might be new to the curriculum and therefore would not benefit from referencing unfamiliar units.
- Consider providing additional alternative texts and videos that could allow on-ramps and differentiation for those unable to access the text itself through the suggested differentiation strategies.

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

The reviewers found adequate evidence that the materials support teachers in facilitating coherent student learning experiences over time because strong teacher support and strategies are provided for linking learning across lessons. However, students are not supported to use the lens of a CCC as a central part of their sense-making throughout the unit.

Teacher guidance is provided to support the teacher in linking lessons. For example:

- The Unit Storyline document provides a “Navigation to Next Lesson” statement at the end of each lesson.
- Navigation sections at the beginning and end of each lesson provide teacher guidance for connecting lessons.
- Progress Trackers are used throughout the unit. “This is the place where students will individually reflect on their progress and also add key consensus modeling work completed by the class” (Teacher Edition, page 37).
    - Lesson 2: “Tell students to add the lesson question to their Progress Trackers: What causes the changes in motion and changes in shape of colliding objects?” (Teacher Edition, page 70).
    - Lesson 4: “Have students look back at what they wrote in their individual Progress Trackers for ideas” (Teacher Edition, page 100).
    - Lesson 13: “The individual progress tracker is designed to be a space for students to make sense of what they have figured out and therefore these individual entries may or may not be shared and reviewed by the teacher at different points in the unit” (Teacher Edition, page 259).
- “Where We Are Going“ sections include information about prior learning students might bring to the lesson. For example:
    - Lesson 1: “You may also see some students developing particle-level representations for changes happening to the matter in the system in their initial models, based on their extensive work in developing such models in prior OpenSciEd units” (Teacher Edition, page 30).
    - Lesson 3: “The idea that all objects are elastic (or springy) up to a point (the elastic limit) and return to their original shape when the forces are removed is one that students will start to develop across this lesson and the next. This idea will help provide students a mechanism to explain why inanimate objects push back (or pull back) on anything that pushes on them (or pulls on them) within a certain range of forces. This will be used to help students explain what causes Newton’s third law between two objects in contact with each other. This connection is something they will uncover in Lesson 5” (Teacher Edition, page 77).
- “Where We Are NOT Going” sections provide lesson boundaries. For example:
    - Lesson 1: “If students do not talk about physics concepts like force, energy, or motion in this first lesson, do not introduce them yet. These words will be explicitly introduced in the next lesson” (Teacher Edition, page 30).
    - Lesson 2 “Don’t raise the ideas of force pairs existing between objects when they collide. This is an idea they will develop fully in Lesson 5” (Teacher Edition, page 58).

- Lesson 10: "Lessons 7–9 build upon learning from Lessons 2–6. Some classes may mention ideas from Lessons 2–6 as they are referencing ideas developed in Lessons 7–9. These classes or students may not need to go back as far as Lesson 2 to encapsulate the big ideas in their big idea list. This is fine as long as these ideas from Lessons 2–6 are also present in the final Big Ideas poster" (Teacher Edition, page 198).
- Suggested prompts to aid unit coherence are embedded throughout the unit. For example:
  - Lesson 3: "We need to resolve this question about whether all objects bend or not in a collision so that we know how this idea applies to the sort of materials like those in a collision between a glass phone screen and a concrete floor. Let's collect some additional observations to see if we can get evidence for whether those objects bend when they get pushed on too" (Teacher Edition, page 80).
  - Lesson 3: "Let's consider how all objects respond to any amount of forces applied to them, since ultimately we want to explain what happens in all collisions that causes objects to get damaged in some cases but not others" (Teacher Edition, page 86).
- Lesson 7: "This is the first time you will have raised the suggestion of designing solutions to prevent damages in a collision. This is designed to start foreshadowing the direction of Lesson 9 and beyond in the unit" (Teacher Edition, page 152).
- Lesson 10: Teachers are provided with an example list of Big Ideas to guide them as they work with students to develop a class list. "This activity of co-constructing a list of the Big Ideas, or takeaways students will have figured out up until this point in the unit, is in service of recalling past concepts, so that students can readily applying these ideas to developing their own models that connect the ideas together to explain their own phenomena from lesson 1" (Teacher Edition, page 197).
- While strong unit coherence is provided around building understanding around DCIs, the same guidance or strategies are not provided for linking progress made towards developing SEPs or thinking around CCCs.

Throughout the unit, guidance is provided that allows students to recognize what they have figured out and what still needs to be figured out. However, this guidance is often in the form of a teacher statement outlining this for students rather than prompts for drawing this information from students. For example:

- Science Notebooks are maintained by students to support coherence. "This periodic time for organization helps students look back on the trajectory of their learning journey. For many students, this is a helpful way to support coherence" (Teacher Edition, page 51).
- Lesson 2: The teacher is guided to "Ask students to consider what additional sources of evidence could help us see if shape changes in the objects that are colliding are occurring during that brief moment of contact. Listen for students to suggest that we would need video of the collision from a slow-motion or highspeed camera." This is followed with the direction "Say, I've pooled together slow-motion videos of collisions for us to analyze in order to investigate this question

further. Let's get ready to collect some observations from these data sources" (Teacher Edition, page 65).

- Lesson 4: "Recall what we figured out. Say, In our last lesson, we looked at slow-motion videos of really rigid objects, used a glass and laser setup, and looked at images of engineers testing a concrete beam. We figured out that even really rigid things can bend or change shape in collisions. We had some questions at the end of Lesson 3 about how any amount of force would affect solid objects. Discuss ideas with a partner. Present slide A. Say, What were some of your ideas for how we could figure out if any amount of force would cause any solid object to start bending or to change shape? Turn and talk with a partner about the questions on the slide" (Teacher Edition, page 92).
- Lesson 7: "Summarize what we figured out so far. Say, Let's remind ourselves what we figured out so far and where we think we need to head next. Show slide A. Discuss the questions on the slide as a whole class. This can be a quick check-in on the set of ideas the class should already be in consensus about" (Teacher Edition, page 146). Students discuss questions related to their learning up to this point. Students then connect what they know to the final question on their assessment and determine they were not in agreement as to whether mass or speed had the biggest impact. "Say, so if we weren't in agreement on our predictions related to this question, we will need some data in order to resolve this question about whether changes in mass or changes in speed have a bigger effect on the kinetic energy of a moving object and the damage it can do in a collision. Let's think through what we will need to do to collect that kind of data from an investigation using our cart system in order to try to answer this question" (Teacher Edition, page 147).
- Lesson 10: "Say, Wow, we have really figured out a lot about collisions and damage! Tomorrow let's see if we can answer any more questions from our DQB and then apply what we have figured out to a new scenario- baseball! Say, it seems that we still have a section left over materials and protecting objects. We will definitely have to revisit that and figure out how some materials work and seem to protect devices better than others. Figuring that out seems to lend itself to an engineering approach to developing solutions too that can help protect objects from getting damaged in a collision. But before we start down that path of questions and ways to investigate them, let's make sure we can apply our current understandings to another set of collision related phenomena. Let's prepare to do that in the context of another sport - this time related to baseball. I found some interesting claims, data, and questions related to baseball game play that involve collisions. I'd love to share them with you and see if you can use what we figured out to explain these as well" (Teacher Edition, pages 202–203).

Teacher support is provided to give the teacher strategies to connect lessons to student questions and ideas. For example:

- Lesson 1: "Forecast that we will investigate our questions. Display slide T. Say, Wow. We have accomplished so much. We now have a broad mission to accomplish as a class. That is thanks to all the questions you shared and how you connected them together. These questions really represent what it is we hope to be able to figure out. And we have a lot of ideas for investigations we could do to try to figure this all out. I am very excited for us to be able to get started on investigating all of this. Let's plan to start exploring some of those questions and ideas in our next lesson" (Teacher Edition, page 50).

- Lesson 2: "Brainstorm what sorts of things we'd want to look for in a collision. Refer to the Different Collisions poster from Lesson 1 as you say, Last time, we came up with lots of examples of two objects hitting each other. Here is our poster of these. We decided to refer to all these examples as collisions, which is the word scientists use to describe these types of interactions. Since most of our ideas for investigations were to explore some collisions ourselves, let's get ready to start doing that today" (Teacher Edition, page 59).
- Lesson 2: At the end of the unit students take a quick poll regarding the question "Do you think the force from a collision always causes shape changes in the objects that collide, but sometimes we just can't see or detect it?" The lesson ends with, "Say, Let's plan to investigate this question further next time to see if we can collect evidence to support one of these claims and refute the other one" (Teacher Edition, page 71).

Suggestions for Improvement

- Consider providing teacher prompts that reflect on progress made in developing SEPs and CCCs in the Navigation sections found at the beginning and end of lessons. This criterion could easily move to an Extensive rating with evidence that the students are supported to use the lens of a CCC as a central part of their sense-making throughout the unit.
- Lesson 2: After students share that there is a need to see a slow-motion video, consider not immediately having the teacher tell students "I've pooled together slow-motion videos of collisions for us to analyze in order to investigate this question further." If this were removed, students could feel that their questions created the need to know and were driving the learning versus the teacher already knowing the questions and answers. By waiting a day following the student questions, the teacher could introduce the videos by sharing that *because* the students shared the need for slow-motion videos, the videos were gathered and brought to help with the sense-making process. To help maintain the timing of the lessons, day one of Lesson 2 could provide the opportunity for students to express the need to know.

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 students are increasingly responsible for making sense of the cell phone phenomenon while **Planning and Carrying Out Investigations** throughout the course of the unit. However, the teacher guidance for this differentiation throughout the unit is specific to Planning and Carrying Out Investigations and not as robust for other SEPs in the unit.

The unit primarily develops the SEP of **Planning and Carrying Out Investigations**. Throughout the unit, scaffolding for this practice is slowly decreased. For example:

- Lesson 4: Students use the handout "Independent, Dependent, and Controlled Variables" to assist with designing the investigation. Students identify the variables as a class through a discussion and identify the terms to add to the word wall. The following teacher guidance is provided in the Supporting Student In Planning and Carrying Out Investigations section in the margins: "Students will be planning other investigations by identifying these variables in future lessons in this unit and in other units in this grade. Having an anchor chart and their copy of Independent, Dependent, and Controlled Variables will be a helpful reference to serve as an example to work from as needed, for the remainder of their investigation plans at the start of the year" (Teacher Edition, page 93).
- Lesson 5: Students plan an investigation. While there is teacher instruction to provide the "Independent, Dependent, and Controlled Variables" handout to students, the handout is filled out independently by students and there is no discussion of the variables as a class. Instead of the discussion focusing on the types of variables, the discussion focuses on the challenges of data collection and how they may need to be addressed. The following teacher guidance is provided: "In this investigation, students are now determining the independent and dependent variables they will be changing and keeping constant and recording them on Lesson 5: Independent, Dependent, and Controlled Variables. This is similar in structure to what they did in the previous lesson, but with less guidance. Students also plan their own data table. And they are asked to make note of any challenges or any sources of error they encounter in the investigation. This help motivates the later need for calibrating the system being used to collect data in the investigation they carry out in Lesson 7" (Teacher Edition, page 119).
- Lesson 7: Students consider an investigation with multiple variables. Students identify the variables in the experimental design. Students are provided with a way to calibrate the system to reduce sources of error.
- Lesson 12: Students are responsible for revising the experimental design on their own in order to ensure accuracy of data for their purpose.

In Lesson 2, there is some teacher guidance provided for how teachers could support students who are struggling with the SEP. However, this guidance is reliant upon the student having familiarity with previous unit, and such guidance is not provided for other elements of the SEP. For example:

- Lesson 2: "If students are struggling with the ideas of variables, you may need to review some examples from previous investigations they have done in prior years. OpenSciEd units will have multiple examples to draw from in the following units:
    - OpenSciEd Unit 6.2: How can containers keep stuff from warming up or cooling down? (Cup Design Unit)
    - OpenSciEd Unit 6.3: Why does a lot of hail, rain, or snow fall at some times and not others? (Storms Unit)
    - OpenSciEd Unit 7.1: How can we make something new that was not there before? (Bath Bombs Unit)
    - OpenSciEd Unit 7.3: How do things inside our bodies work together to make us feel the way we do? (Inside Our Bodies Unit)
    - OpenSciEd Unit 7.4: Where does food come from, and where does it go next? (Maple Syrup Unit)" (Teacher Edition, page 93).

There is some guidance for where and when to add and remove supports to move students towards independence with specific elements of the SEPs. The call out boxes embedded in the Teacher Edition provide guidance for how to support students with specific SEPs in the lessons, but do not always provide specific guidance for when to add or remove supports so that students and teachers are aware that the supports are adjusted gradually throughout the unit, so that students are increasingly responsible for making sense of phenomena and/or designing solutions to problems using the SEPs. For example:

- Lesson 2: The "Supporting Students in Engaging in Argument from Evidence" box states, "If students argue that motion changes should also be categorized as an effect for the "Force perspective" row, add that too if everyone is in agreement. If there is some uncertainty about that idea, then still add it and put a question mark after it. The lesson assumes that students will see shape changes as stronger evidence of pushing occurring during collision, rather than motion changes, and that they will be more ready to make that latter connection in later lessons rather than now. The structure of this chart lays the groundwork for making that connection in later lessons" (Teacher Edition, page 66).
- Lesson 3: The "'Supporting Students in Engaging in Argument from Evidence Claim and Observations Organizer' supports students in engaging in argument from evidence by providing a structured way to record evidence from our investigations. Students will use the evidence collected on the handout to support or refute their original claim, All solid objects [do/do not] bend or change shape when pushed in a collision. This process of making a predictive claim and then collecting data to support or refute it was introduced in the second lesson of the first unit in the 7th grade OpenSciEd scope and sequence. The alternate arguments that students had established were around whether the gas produced when a bath bomb was added to water was part of the bath bomb to start with (trapped in it) or made from the matter that was in the bath bomb.
- Lesson 9: The "Supporting Students in Engaging in Argument from Evidence" box instructs teachers to "Emphasize to students that claims should be written so as to answer the lesson

question. Encourage them to think carefully about organizing their evidence and reasoning so that their explanation is persuasive. This is important because in the next class meeting they will shift to sharing this as an argument they make to their peers in mixed groups so that all stations are represented" (Teacher Edition, page 186–187).

Suggestions for Improvement

- Consider providing additional guidance in the "Supporting Students In Planning and Carrying Out Investigations" sections on how to additionally assist students who may be struggling to develop the practice with a focus on helping ensure that students have increasing ownership and proficiency in the practices over time, even if they struggle initially. This might look like differentiation for a practice for the earlier grade band element, but by the end of the unit students are expected to demonstrate the element at a grade appropriate level.
- Providing clear guidance on how scaffolding is adjusted over time would be helpful to the teacher. For example, a progression of how students will become independent with the element of a practice by the end of the unit might start with a statement such as "By the end of this unit, every student should be able to independently ~~and collaboratively~~ plan an investigation, and in the design identify independent and dependent variables and controls, what tools are needed to do the gathering how measurements will be recorded, and how many data are needed to support a claim. In Lesson 2 'Exploring Horizontal Collisions' teachers support students in their identification of the independent and dependent variables and controls and provide them with a data table. In Lesson 5, students work with a partner to design an investigation to figure out how the doubling of speed or doubling of mass affect kinetic energy of an object, together they identify the independent and dependent variables and controls and develop the data table they will use to collect data. By Lesson 9..."
- Consider providing guidance for where and when to add and remove supports to move students towards independence with additional specific elements of the SEPs.

Why Do Things Sometimes Get Damaged When They Hit Each Other?

EQuIP RUBRIC FOR SCIENCE EVALUATION

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

Why Do Things Sometimes Get Damaged When They Hit Each Other?

EQuIP RUBRIC FOR SCIENCE EVALUATION

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 core ideas and crosscutting concepts to make sense of phenomena or design solutions because throughout the unit there are several instances where students are asked to provide evidence of three-dimensional learning that requires use of grade-appropriate elements of all three dimensions to make sense of phenomena.

There are multiple documents that provide support for monitoring student performance:

- The Teacher Edition, and the Assessment Overview document include a comprehensive Assessment System Overview, which includes a summary of the overall unit assessment that explains what the assessment is, the type of assessment (formative or summative), and what to look for.
- The Assessment System Overview also includes a section called Lesson-by-Lesson Assessment Opportunities, which lists the three-dimensional lesson-level performance expectations, the targeted SEP(s) and CCC(s), and the DCI understandings students should be able to demonstrate.
- The Lesson-by-Lesson Assessment Opportunities document provides a “What to do” section if students are struggling to meet the expectations. For example, in Lesson 2 “Building towards 2.B.2: Construct an argument supported by empirical evidence and scientific reasoning to support a model showing that changes in motion of colliding objects (connected to subsystems) result from energy transfer between them (cause) and changes in the shape of those objects result from force(s) between them (cause). What to look/listen for: Students making arguments that leverage prior knowledge about changes in kinetic energy, energy transfer, and/or forces in the initial cause-and-effect statements they make. It’s OK if students reference only one of these rather than all of them. What to do: If students struggle with identifying any causes, model the completion of a cause-and-effect statement using understanding from a previous unit. An example from the OpenSciEd Unit 6.3 Why does a lot of hail, rain, or snow fall at some times and not others? (Storms Unit) is provided in the Learning Plan. Collect and review students’ Progress Trackers at the end of day 2 to see if students are referencing ideas related to kinetic energy, energy transfer, or forces that they may not have mentioned here” (Teacher Edition, page 66).

Assessment opportunities are provided for each of the three-dimensional learning outcomes presented in the unit. Several examples are listed below:

- Lesson 3: Students construct a written argument using the information from the data they have collected to support or refute the idea that all objects bend or change shape in a collision.
- Lesson 5: Students complete the "Soccer Assessment," during which students investigate the phenomena of concussions being caused by headers in soccer. In the assessment, students construct free body diagrams to explain how a soccer ball hitting the head could be the cause of a concussion. Students are asked to consider the types of collisions that occur in soccer as systems in order to construct an argument as to which type of collision would have the lowest peak force.
- Lesson 10: Baseball Assessment:
  - "Question 1: Draw three different free body diagrams (a, b, and c), one for each point you marked on the graph. In each free body diagram, show all the contact forces on the ball after the ball has left the pitchers' hand. Draw arrows to show the relative strength of forces on the ball. Make sure to include the relative strength and direction of the forces on the ball due to its interaction with the air." (**Developing and Using Models**, **PS2.A** Forces and Motion, CCC: **Cause and Effect** element #2) (Lesson 10 Assessment, Question 1 and Assessment System Overview, page 9).
  - "Question 2: Use your free body diagrams above to help answer this question: If all three pitches (a, b, and c) had equal amounts of KE when they left the pitcher's arm, would they all have the same amount of KE when they reach home plate? Why?" (SEP: **Constructing Explanations**, CCC: **Cause and Effect** element #2: DCI: **PS3.C** Relationship Between Energy and Forces)
- Lesson 15: Students evaluate three different designs for head protection for cheerleaders to determine which would be most effective. Students are asked to design a model using structure and function to describe the design features of the most effective head gear.

Suggestions for Improvement

- Consider providing increased opportunities for students to independently use SEPs in service of sense-making. For example, rather than developing free body diagrams representing collisions as a class, provide increased opportunities for the students to independently develop the models with the purpose of exploring what is occurring in the collision.
- Consider including additional artifacts that provide direct, observable evidence of students using specific elements of the crosscutting concepts to make sense of phenomena. Although there is opportunity for using CCCs, many tasks could currently be completed by the students without knowingly leveraging the CCCs.

III.B. FORMATIVE	
Embeds formative assessment processes throughout that evaluate student learning to inform instruction.	
Rating for Criterion III.B. Formative	Adequate *(None, Inadequate, Adequate, Extensive)*

The reviewers found adequate evidence that the materials embed formative assessment processes throughout that evaluate student learning and inform instruction because formative assessments are varied and are accompanied by clear guidance for the teacher for modifying instruction based on student responses, especially for the DCIs. However, formative assessments do not provide support for student thinking across all three dimensions at a middle school level.

Progress Trackers are used to formatively assess students, with a focus on their progress toward the DCIs. For example:

- Lesson 4: "Listen for and have students make note of these ideas on their Progress Tracker: From previous lesson: All solid objects bend or change shape in a collision and when other contact forces are applied to them. All solid objects deform elastically when smaller amounts of force are applied to them; they will spring back to their original shape when this force is removed. How much a solid object deforms for a given amount of force applied to it is dependent on the type of material it is made of, its shape, and its thickness. Different objects have a different elastic limit = the maximum amount of force or deformation they can withstand, beyond which they will deform permanently. breaking point = the maximum amount of force or deformation they can withstand, beyond which they will crack or split apart" (Teacher Edition, page 100).
- Later in Lesson 4: "Go around and look at what students are writing in their Progress Trackers so you can determine if there are any lingering areas of disagreement or controversy about whether the forces are equal in every case tested. If so, you could use this video as an additional source of evidence to resolve any remaining uncertainty" (Teacher Edition, page 121).

Entrance and exit tickets are identified as a method for formatively assessing student learning. For example:

- "For practice (e.g., exit or entrance ticket) the following two questions can be answered at the end or start of any future lessons: -What questions were raised for us (now or from the end of the last class)? How might we investigate one or more of those questions using equipment in our classroom to collect our own data or using data that other people have collected in other places?" (Teacher Edition, page 48).

- Lesson 2: “If students still don’t have a lot of ideas, add an optional exit ticket at the end of day 1 that asks students to reflect on what about the new setup in the Exploring Horizontal Collisions Lab helped address some of the challenges they raised at the end of the Dropping and Breaking Lab and/or what about the new setup allowed them to make the kinds of observations they were not able to make as easily before” (Teacher Edition, page 61).
- Lesson 5: “Let’s complete a short exit ticket to check in on how you are thinking these ideas we developed would apply to something from our anchoring phenomenon” (Teacher Edition, page 126).
- Lesson 5: “What to look/listen for: Transferring the representations of the ideas developed in the class consensus model to a new context to explain a different phenomenon. The following ideas should be show up in students’ responses: A) Students identify one or both objects. B) The forces would be equal in strength. C) The kinetic energy would be less. D) The forces would be weaker but still equal in strength. **What to do:** Review student exit tickets before Lesson 6. These can serve as a useful benchmark for whether students are ready for more formal and extended assessment in that lesson. If students struggle with the ideas on this exit ticket, revisit the consensus model at the start of next class and ask those students to co-articulate what the representations in it show and how these could be used to explain what is happening in another collision scenario (e.g., the ball and the bat or the golf club and the golf ball).”
- “When evaluating student ideas on this assessment, it may appear that some students may need to receive additional support in understanding the science ideas. As interventions are being conducted that are listed in the “what to do” area of the assessment guidance and students’ progress through Lessons 7–9, students may find value in the revision of their ideas. As the unit progresses, ask students to go back to [missing reference] and revise their answers. Students can then use this document of evolving understanding to aid in their responses on the Lesson 10 assessment” (Teacher Edition, page 136).

Assessment Opportunity sections are embedded throughout the unit. For example:

- Lesson 10: Teachers are told to use the Explaining a Collision handout “to gauge student understanding of variances that can occur to impact damage in a collision.” “As students hand in Explaining a Collision check the handout for the ideas above. If an idea is missing or misrepresented, revisit the Big Ideas poster with the student(s) before the assessment on day 2. Use the big ideas poster for a checklist and make sure student(s) sees that a concept is missing, or that a concept may be misrepresented” (Teacher Edition, page 202).

Assessment Opportunity Boxes are found throughout the materials. Each of these boxes provides information on the assessment including what students should look for and what to do with the response. Some examples are found below:

- Lesson 1: **The “What to look for/listen for” includes:**
  - “Unobservable mechanisms: Prompts in this task ask students to engage in two elements of the modeling practice related to representing descriptive aspects of the phenomena as well as unobservable mechanisms (energy transfer in collisions and

objects pushing on each other when they collide). You may also see some students using particle-level representations to help explain changes occurring in the objects in the collision, based on their extensive work in developing such models in prior OpenSciEd units:"

- Factors or variables that cause the materials to break or not break in a collision, such as mass, speed, area of contact, material type and thickness, any other structural differences students wish to identify.
- Other connections to CCCs: There are phrases in the prompts that ask students to consider connections to related elements of CCCs, particularly cause and effect, systems and system models, and stability and change. These may lead students to develop and use ideas that help them connect ideas about forces, energy, and changes occurring in the object. These ideas will be developed later in this unit. Here is a good opportunity to see if students are already making some of these connections.
  - In a collision objects exert forces on each other; those forces cause energy to be transferred (effect) to or from the objects. Each object in the collision (subsystem) exerts a force on the other object in the collision; these forces are equal in strength and opposite in direction.
  - These forces (cause) also result in some deformation (change or effect) of each object" (Teacher Guide, page 39).

- Lesson 8: Assessment Opportunity section states: "**Building towards:** 8.A Develop and use a model to identify other parts of the system the cart and box are making contact with or colliding into that could be producing contact forces on these subsystems, causing energy to be transferred to or from them as the box and cart travel down the track. **What to look for**: See Key for Modeling force interactions in the launcher, cart, box, and track system for guidance on what to look for. **What to do:** Treat this as an informal assessment of prior knowledge related to how forces from friction and air resistance act on moving objects. Do not correct preconceptions at this point. Make a copy of student responses on Modeling other force interactions in the launcher, cart, box, and track system so you can return the original to students to revise at the end of the end of the next lesson (Lesson 9) as a home-learning assignment. This will provide you a reference to compare student thinking before lesson 9 to what they are thinking by the end of Lesson 9" (Teacher Edition, page 175).
- Lesson 11: Assessment Opportunity section states: "**Building towards:** 11.A Define a problem that can be solved with the development of a protective device to reduce damage (peak force) during a collision by identifying and considering multiple criteria and constraints along with specific materials, shapes, and designs of devices that reflect our science ideas of how certain material properties function in a collision. **What to look for/listen for:** On Protection Device Design Thinking students define the problem at the top of the page. Look for students to identify that the purpose of the device is for protecting it from damage in a collision. Look for relevant criteria and constraints as students engage in the handout, and for justification of the type of material and the shape of the materials they propose to use in their designs**. What to**

do: If students are struggling with identifying the purpose of the device, refer them back to the Building A Better Phone Case chart. Ask students why they place a case on their phones, and what that case is meant to do. While identifying criteria and constraints, have students think about the common example of the phone case once again. Criteria are directly related to the purpose. Ask students questions like…"(Teacher Edition, page 217).

Suggestions for Improvement

- During classroom discussions, consider embedding additional opportunities to engage students on a more individualized level. For example, in Lesson 8 the teacher is directed to "Direct students' attention to time 2 and time 0. Ask students which objects/subsystems have kinetic energy and which do not at time 0 and time 2. Students should say only the cart in time 2 has kinetic energy and nothing else does. Add a sticky note label to the cart at time 2 'has KE'. Label the cart at time 2 and the box at time 0 and time 2 as 'no KE' These are shown in blue to the right" (Teacher Edition, page 170). This could be changed to providing every student with a set of sticky dots and ask them to add their individual dots to locations where there is KE. This would provide an opportunity to formatively assess individual thinking and an opportunity to engage students in sense-making discussions.
- For exit tickets used as formative assessment, consider providing even more specific guidance for individual follow-up instruction for each incorrect option students select. For instance, in Lesson 5, if students select incorrect answer X, consider asking these sample questions to clarify their thinking. These questions could take the form of "Questions to Use" (Lesson 10, Teacher Edition, page 200). This type of chart could be modified to support teacher formative assessment responses based on student responses.
- Formative assessment processes would ideally provide routine varied support for student thinking across all three dimensions. For example, the example above from page 39 identifies student engagement with an CCC element as part of an instructional task. This could be called out and supported with additional formative assessment opportunities. This could also be supported by sample student responses that show levels of student use of each dimension.
- Consider adding individualized progress monitoring and response strategies that provide support for attending to the levels and needs of every student.

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.

Why Do Things Sometimes Get Damaged When They Hit Each Other?

EQuIP RUBRIC FOR SCIENCE EVALUATION

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

The reviewers found adequate evidence that the unit included aligned rubrics and scoring guidelines that help the teacher interpret student performance for all three dimensions because material includes clear assessment targets and there is guidance for teacher and student interpretation of progress. However, strong guidance for interpreting student performance along the three dimensions to support teachers in planning instruction and providing ongoing feedback to students is not provided.

Assessment targets for all three dimensions are explicitly stated in the Teacher Edition, Lesson-by-Lesson Assessment Opportunities section. For example:

- Lesson 1: The Assessment Opportunity section states:
    - **"Building towards: 1.A** Develop a model to describe interactions between two objects as they collide and show the changes that occur in the structure of both objects when one object is damaged as a result and also when neither object is damaged as a result. **What to do:** If students do not include connections to any of these ideas listed above, that is OK for now. Students will build on and revise their models over the course of the unit. Make a copy of these explanatory models and compare them with what students show in their individual model and explanation at the end of Lesson Set 1 and the end of Lesson Set 2. You may also want to have students analyze their growth by comparing these artifacts related to the elements mentioned above." (Teacher Guide, page 40).
- Lesson 3: The Assessment Opportunity section states:
    - **"Building towards: 3.A** Construct and revise a written argument using evidence from various sources of data (slow-motion videos, photos, and firsthand investigations) to support or refute the claim that all objects do bend or change shape when pushed in a collision. **What to look/listen for:** By this point in the lesson, students should provide evidence and support or refute their original claim to reflect that all objects do bend or change shape when pushed in a collision. **What to do:** If students are not in agreement that all objects bend or change shape in a collision, observe what evidence the students have collected in their organizers to verify that the evidence was recorded correctly. If any evidence was not recorded accurately, have students review that part of the investigations and compare this with their evidence on their handouts. Ask students to refer to the evidence collected from the laser investigations and the concrete joint video to support or refute their original claim. All the observations made by students should provide evidence that the objects are changing shape or bending as a force is applied. The one exception would be the head of the golf club when it strikes the golf ball. But by the end of the lesson, students should be able to argue that it too may actually bend or change shape, but this may be occurring at too small of a scale for us to see in the video. If students are still struggling with this concept, pull up each video again at the start of the next lesson and/or go over the glass demonstration individually with students, making sure that they are

observing that the objects are indeed changing shape when a force is applied. Pointing out the observations and helping students connect the observations to their claim will help students understand the key idea" (Teacher Edition, page 85).

Lesson-level "What to look/listen for" sections in the Teacher Edition, and the Assessment Guidance System provide a general overview of what to expect from students, however, these serve as a summary or ways to respond to the whole class rather than providing specifics about how to provide feedback to individual students. For example:

- Lesson 2: "If students struggle with identifying the role of forces or energy transfer, leave a sticky note in their Progress Tracker with a prompt or question to push them to continue thinking about how forces or energy transfer could help them explain the changes they observed in the objects when they collided. You may encourage them to respond to this at a later point (e.g., the start of the next lesson). A couple of example prompts are below: What else can energy transfer help us explain based on our consensus model from last time? What else can force(s) help us explain based on our consensus model from last time?" (Teacher Edition, page 71). This is a summary of how to respond, rather than specifics about how to provide feedback to individual students
- Lesson 7: "If you see students assigning the mass or the speed to the y-axis rather than the x-axis, encourage them to reference their graph from Lesson 4 to identify which variable was their independent variable and which axis they put it on in that graph. If you see students trying to assign a label to every interval on their axes, suggest they take the approach they see on a metric ruler, where only major intervals are labeled, such as every 10 mm intervals, so that the in-between interval lines are assumed to be 1/10 of the value between each major interval. If you see students alter their y-axes scale to go by nonlinear intervals, point out that it's easier to see linear vs. nonlinear patterns in coordinate graphs if the intervals for each axis are always equal along that axis and give students a new piece of graph paper to reset these up on" (Teacher Edition, page 156).
- Lesson 5: "Review student exit tickets before Lesson 6. These can serve as a useful benchmark for whether students are ready for more formal and extended assessment in that lesson. If students struggle with the ideas on this exit ticket, revisit the consensus model at the start of next class and ask those students to co-articulate what the representations in it show and how these could be used to explain what is happening in another collision scenario. (e.g., the ball and the bat or the golf club and the golf ball)" (Teacher Edition, page 126). Revisiting the consensus model is a general suggestion rather than a specific piece of feedback for individual students.
- Lesson 6: Teachers are provided "What to Look/Listen For" when students are taking the Soccer Assessment. "Peak forces on the head and the ball are shown as the same during a header, both drawn in the diagram in question 1 and the selected answer in question 2a. Contact forces are applied to both objects and are always equal regardless of speed or mass in question 2b. A player hitting a nonmoving object should experience the least amount of peak force in questions 3a and 3b due to the moving player #84 having the same amount of kinetic energy in each

collision. The masses and speeds of the other objects determine their kinetic energy before the collision, and the less total kinetic energy in the collision, the less the peak forces on each object during the collision. Collisions with objects that are moving with a greater mass or speed in comparison with collisions that have lesser mass and speed will experience more peak force, as seen in the two potential answers for question 5" (Teacher Edition, page 136). A Soccer Assessment Key is provided with additional information on what to look for in student responses (Teacher Edition, pages 331–334).

- Lesson 14: A 5-point scale is used. "5 points mean that the design meets the criteria or constraint very well. 1 point means that the material does not meet the criteria or constraint." "Look at your chosen considerations for each material – Spend some time transferring over the consideration ratings from the MSU matrix to your matrix for these materials" (CF.L14 Slides O and P).
- Lesson 6: Helpful teacher guide supports are provided for teachers. "What to do: If after the lesson you find that students are struggling with equal and opposite forces with varying masses and speeds, revisit Lesson 5. First, revisit the handouts and data to make connections to a small ball and larger person from questions 1 and 2 on the assessment. Take time before Lesson 7 to do this. Vary the mass and speed of different carts in collisions to simulate different collisions between the player and other objects in questions 3–4 and have students make note of their force observations as masses and speeds change on the back of the assessment. After reviewing the amount of force produced in each collision from the new demonstration, ask students to keep their observations out as they work through questions 5–6 again. You may also want to create a word bank with the key terms from Lessons 1–5 and refer students to the What We Have Discovered poster to make connections between our science ideas and the assessment questions."
- Lessons 6, 10, and 15 assessment opportunities include teacher answer keys.
- Lesson 10: "Building towards: 10.A Apply scientific ideas to explain why some collision related-phenomena resulted in damage, while others did not, and explain how the contributing factors (energy, matter, peak forces) could change to result in a different collision outcomes." The "What to look/listen for" "What to do": Look for students to use the ideas off of the Big Ideas poster…." are focused on what elements of the DCI are present and developed. The SEP and CCC are not explicitly called out in the assessment for students and could be easily added to the look fors assessment to make this three dimensional.

Suggestions for Improvement

- Consider including the specific rubric criteria for what mastering, developing, and missing could look like for all three dimensions. It would also be helpful to see examples of scored student work to see how various students respond.
- Consider adding explicit "what to look for" sections aligned to elements in each of the three dimensions. Scoring guidance would ideally target all grade-appropriate elements of the dimensions being assessed and provide guidance for how to interpret student performance along all the dimensions as well as their integration and use in sense-making or problem solving.

This kind of guidance supports teachers, students, and possibly parents in monitoring student progress toward their ultimate learning goals.

- Consider this resource: Task Screener, Criterion D.iii for additional support in this area.

III.D. UNBIASED TASK/ITEMS	
Assesses student proficiency using methods, vocabulary, representations, and examples that are accessible and unbiased for all students.	
Rating for Criterion III.D. Unbiased Task/Items	Extensive *(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 multi-modal tasks are included throughout the unit for all students.

Related evidence includes:

- Lesson 1: Students are asked to "turn and talk with a partner about the slide question: "Have you or someone you know ever broken a phone? What caused it to break? Describe your experiences." Teachers are told to "Select one volunteer at a time to come up in front of the class and demonstrate what happened with the cell phone when it broke" (Teacher Edition, page 31). However, some students might not have broken or known anyone who broke a phone.
- Lesson 8: Teachers are provided with the following choice of prompts: "Students may or may not have used the words friction and air resistance at this point in the unit. If students have used the terms, acknowledge the terms here. If they have not, start to link the words with the concepts. Use one of the two prompts below that fit your classroom case best. Option 1: Introduce what these two sources of contact forces are commonly called. Say, the contact forces between a moving object and something it is sliding against are commonly called friction and the contact forces between a moving object and the air particles it collides with is commonly called air resistance Option 2: Acknowledge the use of the words friction and air resistance. Say, I hear you all saying the word friction to describe the forces between an object and something it is sliding against. I also hear you using the word air resistance to describe contact forces between a moving object and the air particles that it collides with. These are interesting words. Let's see if we can really develop our ideas of what these terms mean as we explore these contact forces" (Teacher Edition, page 177).

- Lesson 8: Students are provided with a choice for their home learning Investigating Interactions assignment. “Tonight, you have an option to do one of two investigations. One of these involves folding and dropping index cards to see which shapes you can get to travel more quickly and more slowly through the air. The other involves pulling on a shoe with a rubber band to see how much force it takes to get it to start moving when it is on different surfaces. I will give you some of the supplies for both investigations, which includes 4 index cards and a rubber band. You pick which investigation you want to do. If you do the later investigation you will need a shoe too” (Teacher Edition, page 177).
- Lessons include a section called Attending to Equity that provides ways to make sure the learning appreciates students from various backgrounds and experiences.
- Grade appropriate vocabulary is used throughout the unit, including on the formal assessments provided. The Developing your Word Wall sections support teachers in vocabulary use with students.
- A variety of modalities are utilized throughout the unit when collecting student thinking. For example:
    - Lesson 2: “Universal Design for Learning: Recording observations with words may be challenging for students. Encourage all students to use words and/or drawings when representing and recording their investigation setup and observations. Student drawings of broken things can be elevated as class artifacts that clarify different kinds of damage seen in collisions” (Teacher Edition, pages 59–60).
    - Lesson 6: “Universal Design for Learning: As students read through their questions and think about which one they can answer with evidence; some students may find it easier to draw a representation or model of the answer to the question as they have been doing that in class. Allowing students to represent their answer in this way, for this low-risk assessment, will support multiple access points. If a student chooses to answer the question in this way, allow them to. Then if they answer a second question using the same modality, you could choose to follow up on their second drawing, by asking them to explain in writing what they modeled. In this way, the drawing provides the student something to write about. With practice over time, students will find more success writing arguments with evidence as they find confidence in their writing about models they have constructed using other modalities” (Teacher Edition, page 134).
    - Lesson 6: “For question 5 of the assessment, students are asked to write an explanation supporting which type of head collision would potentially do more damage to the brain. Because students are synthesizing what they have figured out about collisions with new information they are reading during the assessment about the brain, offering students a choice in modality to demonstrate this synthesis provides equal access for all students. Some students may benefit from drawing a representation of the one collision they feel will do the most damage and labeling it to support why they chose the one they chose. As another alternative, some students may find more success explaining this orally through recording themselves and then turning in the recording, or presenting to the

class, or presenting to you during an appropriate time in the classroom" (Teacher Edition, page 135).
  - Lesson 15: "For question 3b of the assessment, students are asked to support or refute their claim by citing evidence from investigations we did and using any related science ideas we developed to defend your argument. Offering students a choice in modality to share their explanation provides equal access for all students. Some students may benefit from drawing a representation of the potential collision results when one cheerleader collides with another and labeling it to support why they think this. As another alternative, some students may find more success explaining this orally through recording themselves and then turning in the recording, or presenting to the class, or presenting to you during an appropriate time in the classroom" (Teacher Edition, pages 294–295).
  - Lesson 15: "For question 5 of this part of the assessment, students are asked to write an argument for why their design solution is optimal and meets the needs of the stakeholder and to discuss what tradeoffs were made and why. As part of this question, students are offered their choice of modality for expressing this explanation. They can either construct a written explanation or present their explanation orally.
    Offering students a choice in modality to share their explanation provides equal access for all students. Some students may benefit from drawing a representation of their design with labeling to point out how, why and where their design solution is optimal. Some students may wish to put together this explanation using technology so they could present it to an audience. While other students may wish to orally present their design" (Teacher Edition, pages 295–296).
- Lesson 10: Two different versions of the baseball assessment exist depending on student skill level in the event that students need a more challenging version of the assessment.
- Lesson 10: The teacher is provided with guidance suggesting they provide students who need additional supports with a Big Idea Table.
- Lesson 15: Prior to giving the assessment, it is suggested to teachers that they show the cheerleading video to the class. "It is advised you should show at least half the video so students can see what this sport looks like, especially in a competition. This will help them think about the idea of adding helmets to the uniform for cheerleading" (Teacher Edition, page 294).

Suggestions for Improvement

- Consider providing supports beyond previous experience with OpenSciEd units for struggling students. For example, a chart could be provided with the key learnings that were referenced as a way to support students and corresponding brief videos or short activities as an alternative method for reinforcement and/or clarification.
- Consider adjusting the unit phenomenon to ensure all students are able to apply their funds of knowledge. For example, while all students might not have experience breaking a cell phone, they all have experience stumbling over an object or tripping on something. This could be leveraged with a video collage of individuals walking and tripping, causing the objects they are

carrying to fall. This would help all students further engage with the cell phone breaking and the corresponding data. Although students have the opportunity to brainstorm related phenomena later in Lesson 1, adjusting the initial phenomenon could lead to a more meaningful brainstorming and increased engagement.

- Consider adding increased background information or video for students who may not be very familiar with the rules of either soccer and/or baseball.

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

The reviewers found adequate evidence that the materials include pre-, formative, summative, and self-assessment measures that assess three-dimensional learning because all tasks are multi-dimensional. There are multiple assessment opportunities and the assessment system includes pre-assessments, formative, summative, and self-assessments. However, support for explicitly measuring and interpreting student progress in the CCC and SEP dimensions indicated in lesson-level learning goals is not included.

The following is a list of evidence related to this criterion:

- The Assessment System Overview provides a chart of when assessments are given, the name of the assessment and scoring guidance and the purpose of the assessment. For example, the overview for Lesson 6 Assessment and Scoring Guidance “Soccer Assessment” “Soccer Assessment Key” Purpose of Assessment: “Formative Lesson 6 provides students the opportunity to apply their understanding of peak forces, damage, and kinetic energy on different parts of a system in a collision. Students also draw a freebody diagram of the parts of a system during a collision. It’s critical that students first understand that the forces during a collision are always equal and opposite and the peak forces experienced by each object are the same before they attempt to make a freebody describing that relationship. However, once students become adept at using the freebody diagram to describe forces and energy transfer as objects interact, they will better be able to use freebody diagrams to predict the changes in motion to objects and changes in kinetic energy in a collision” (Teacher Edition, page 309).

- Lesson 1: Students are asked to “Develop a model to describe interactions between two objects as they collide and show the changes that occur in the structure of both objects when one object is damaged as a result and also when neither object is damaged as a result.” Teachers are told “This is an opportunity to pre-assess students’ engagement in all three dimensions of NGSS to explain a phenomenon.” More specific information is includes: “Students are prompted to explain the mechanisms that caused the observable changes, which will provide an opportunity to bring related DCIs from prior grades: grade 4 (energy transfer in collisions), grade 2 (objects pull or push each other when they collide), and the middle school grade band explanation (such as equal force pairs between the two objects in contact). There are phrases in the prompts that ask students to consider related elements of CCCs as well, particularly cause and effect, systems and system models, and stability and change” (Teacher Edition, page 40).
- The Lesson-by-Lesson Assessment Opportunities Chart includes the Lesson, Lesson-Level three-dimensional Performance Expectation, and Assessment Guidance. For example, Lesson 11 has two Lesson-Level Performance Expectations: "11.A Define a problem that can be solved with the development of a protective device to reduce damage (peak force) during a collision by identifying and considering multiple criteria and constraints along with specific materials, shapes, and designs of devices that reflect our science ideas of how certain material properties function in a collision. 11.B Design a solution to a problem to reduce the damage to an object in a collision (by reducing peak forces by considering the properties of different individual materials and shapes being used to serve particular functions.” Assessment guidance is provided for the SEP and CCC, though not at the element level: “11.A Asking Questions and Defining Problems; Structure and Function When it happens: Students engage in defining a problem that could be solved with the design of a protective device for an object and identifying the overall purpose of a protective device in Protection Device Design Thinking. Students identify criteria and constraints and consider what materials and properties are important to the protective device. What to look for/listen for: On Protection Device Design Thinking students define the problem at the top of the page. Look for students to identify that the purpose of the device is for protection. Look for relevant criteria and constraints as students engage with the handout, and for justification of the type of material and the shape of the materials they propose to use in their designs. 11.B Constructing Explanations and Designing Solutions; Structure and Function When it happens: Students engage in designing a protective device for an object of their choosing when they complete Drafting Our Protection Device Design What to look for/listen for: Treat this as a pre-assessment of students; understanding of new ideas that they will develop in the last lesson set of the unit. The first is related to the microscopic structure of cushioning materials. Many effective cushioning materials provide pockets/gaps of space or air between the materials for the cushioner to ‘give’. Look for this in the second column of the design drawing. The second is related to how cushioners reduce peak forces in a collision. Look for: The amount of peak forces is reduced because the cushioner applies a weaker force over a larger distance in a collision, which has as much effect on reducing the kinetic energy of an object as a stronger force over a shorter

distance. These forces are transferred to both objects that the cushioner is a contact with (including the object it protecting) The shape of a cushioner can be designed to distribute that force over a greater surface area, thereby reducing the amount of peak force occurring at a single location on the object being protected."

- The Lesson 6 Assessment provides an opportunity for both summative and formative assessment. The science ideas built in Lessons 1–5 are applied in questions 1–5. Questions 6–7 are formative and would help gauge student understanding of the relationship between changes in kinetic energy, peak forces, and the mass and speed of a moving object. This assessment, from a student perspective, requires sense-making using the DCI and SEP. The prompts and student responses and sense-making leverage thinking related to CCCs, but it is possible for a student to engage in the assessment without intentionally using a grade-appropriate CCC element.

Suggestions for Improvement

- Consider including additional methods for explicitly measuring and interpreting student progress in the CCC and SEP dimensions indicated in lesson-level learning goals.
- Consider increasing the obvious language for students to use a specified CCC in their sense-making in assessment items.

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 core ideas and crosscutting concepts because there are multiple student performances that provide students with opportunities to demonstrate their growth throughout the unit. Throughout the unit, students have an opportunity to respond to feedback from both the teacher and peers to improve their performance, but do not explicitly use peer and teacher feedback to progress towards the learning goals.

Examples of related evidence include:

- Throughout the unit, students construct free-body diagrams to represent what is occurring in a collision. As students learn more and have an opportunity to receive feedback, students have opportunities to create diagrams that demonstrate their new learning.
- Students have an opportunity to receive and respond to feedback throughout the unit, however most feedback provided in the unit from the teacher is only oral rather than both oral and written. For example:
  - Lesson 6: Students are provided with an opportunity to get feedback on their answers to questions on the DQB. "As students share their answers to questions from the Driving Question Board, it is possible that a student might share an incorrect answer. Do not automatically correct. Instead ask the class after each question if we agree or disagree with the answer. If students disagree with the answer, refer students to the What We Have Discovered poster and ask them to use our science ideas to justify if the answer is correct or incorrect" (Teacher Edition, page 135).
  - Lesson 9: Students have an opportunity to receive feedback on their arguments during jigsaw discussions. Students can use this feedback to improve their argument.
  - Lesson 10: Students are given an opportunity to pair with another student in order to receive feedback on their answer to question 3. Students first pair with somebody who had the same collision type, and then with somebody with a different collision type. Guiding questions are provided to facilitate the feedback process. "Say, after you have had a chance to share with your partner, you will get a chance to revise your ideas and make a stronger explanation based upon what you may have seen in your partner's model or the feedback that your partner has given you. After we have completed our revision cycles, you will be turning this in" (Teacher Edition, page 201).
  - Lesson 11: When developing their own design to protect a devicee, students have a chance to gather feedback from other stakeholders to improve their design. For example, students are given an opportunity to pair with another student in order to receive feedback on their answer to question 3. Students first pair with somebody who had the same collision type, and then with somebody with a different collision type. Guiding questions are provided to facilitate the feedback process: "Say, after you have had a chance to share with your partner, you will get a chance to revise your ideas and make a stronger explanation based upon what you may have seen in your partner's model or the feedback that your partner has given you. After we have completed our revision cycles, you will be turning this in" (Teacher Edition, page 201).
  - Scientists circles, which happen throughout the unit, provide students with opportunities to discuss their thinking as a class. For example, Lesson 4 states, "Shift to co-developing a list of key ideas that we figured out from our work with these sources of data. Have students look back at what they wrote in their individual Progress Trackers for ideas. Use prompts similar to these, inviting students to contribute ideas and to work with the ideas that others contribute: Who can suggest one idea we should add to our Progress Tracker about how materials respond when a force is applied to them? Is this true for all solids? How do we know? Can someone summarize an important idea about

what it means when we say solids are elastic up to a point? If all materials are elastic up to a point, what is the difference between a rigid material like steel or glass and something that is more flexible? Does someone have an important idea about elastic limits or breaking points related to forces that we haven't included yet in our class Progress Tracker? Use follow-up prompts, such as Do you agree? and Did anyone say the same idea in a different way? to encourage students to voice agreement on ideas" (Teacher Edition, page 100). Students are able to use the information/feedback from this discussion when constructing their argument later in the lesson.

Suggestions for Improvement

- Consider making feedback loops between students, peers, and teachers more robust by allowing continuous use of revised models or explanations. Throughout many of the lessons, students are prompted to incorporate peer feedback into their models, but do not necessarily need to use those explanations or models again to demonstrate their learning or sense-making.
- Consider providing increased support for teachers giving written feedback that students can respond to. One opportunity for this could be during the formal assessments in Lessons 6 and 10.
- Consider adding opportunities for students to demonstrate formal evidence of growth in each element of the three dimensions.

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

Why Do Things Sometimes Get Damaged When They Hit Each Other?

EQuIP RUBRIC FOR SCIENCE EVALUATION

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)