EQuIP RUBRIC FOR SCIENCE EVALUATION

Collisions and Momentum

DEVELOPER: OpenSciEd

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

Educators Evaluating Quality Instructional Products

Collisions and Momentum

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	Error! Reference source not found.**3**

Click here to see the scoring guidelines.

This review was conducted by NextGenScience using the EQuIP Rubric for Science.

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

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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 many areas, particularly in its coherence and focus on real-world problems that are highly relevant to students.

During revisions or use in the classroom, the reviewers recommend paying close attention to the following focus areas in order to strengthen materials:

- **Student-driven learning**: Currently, many activities are driven by the teacher without explicit connections to student ideas or questions.
- **Science learning during engineering design**: Currently, students' work in engineering design is separated from science learning; students are only asked to apply science ideas they have previously learned rather than learning new science ideas through engineering.

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

Evidence from the Teacher Edition is referred to as TE.

CATEGORY I

NGSS 3D DESIGN

I.A. EXPLAINING PHENOMENA/DESIGNING SOLUTIONS

I.B. THREE DIMENSIONS

I.C. INTEGRATING THE THREE DIMENSIONS

I.D. UNIT COHERENCE

I.E. MULTIPLE SCIENCE DOMAINS

I.F. MATH AND ELA

I.A. EXPLAINING PHENOMENA/DESIGNING SOLUTIONS

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

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

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

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

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

The reviewers found adequate evidence that learning is driven by students making sense of phenomena or solving problems. Learning is focused on students figuring out an anchor phenomenon, investigative phenomena, and completing a design challenge related to a problem to solve. Students also have many opportunities to ask questions and some opportunities to drive the learning. However, in many lessons, teachers — and not students — are the primary drivers of instructions. In addition, in one third of the unit, engineering is a learning focus without support for students to develop new science Disciplinary Core Ideas (DCIs).

The unit is largely focused on sense-making of phenomena and problems. Related evidence includes:

- Unit Overview: The teacher is told, "The learning is anchored by a puzzling set of patterns in traffic collision data over time: while overall, vehicle fatalities have been decreasing steadily for decades, the trend appears to have reversed, with both collisions and fatalities increasing. This phenomenon provides the context in which to investigate the physical relationships between mass, velocity, momentum, force, time, and acceleration, basic physical quantities that provide the foundation for the study of mechanics" (TE, page 7).
- In the Unit Storyline, there is a column for "Phenomena or Design Problem" for each lesson. However, not all of these represent true phenomena or problems that can be explained or solved with science (e.g., "There are many tradeoffs when considering the balance among science ideas, societal constraints, and ethical issues of a design solution" (TE, page 9).
- Lesson 1: Students are shown the statistic "Car crashes are a leading cause of death in the United States for people aged 1–54" (Lesson 1, Slide A). Students are then asked questions such as, "What makes driving so high-risk?" (Lesson 1, Slide A) and told to, "turn and talk to a partner about their ideas" (TE, page 35). After students see several graphs of data, the teacher is told to, "Ask students to look back at our Puzzling Patterns poster. Pose the questions on the slide to engage them in navigating into the class period: Which of the patterns that we identified last

time do you think you can explain right now? Which is the most puzzling to you?" (TE, page 39). "It sounds like we already have some ideas about what could be causing some of these trends. We've identified some safety features that we think might be affecting collision outcomes. We've also identified other factors, like drivers on cell phones. Let's keep a public record of our ideas about what could affect collision outcomes so we can investigate some of them further and figure out if they can explain any of our national trends" (TE, page 40).

- Lesson 1: "'Does our consensus model help explain why crashes were decreasing in the 1990s? why crashes have become more common after 2010? why non-occupant fatalities have risen steeply since 2010? why the percent of crashes with fatalities has been dropping since 2010?' Elicit ideas. Listen for students to suggest that our consensus model explains some of the trends on the slide but not all, at least not very well. Point out that we still have a lot of questions about our consensus model" (TE, page 44).
- Lesson 2: Students watch videos of distracted vs. non-distracted drivers trying to stop for an obstacle. The teacher is told to, "Ask students what differences they noticed between the two videos. Accept all ideas, but highlight ideas about reaction time and reaction position" (TE, page 54).
- Lesson 6: Students see data that say that small vehicles are much more likely to involve a fatality than large trucks when they are in a collision with a large truck, despite the data they previously saw showing that forces on the two vehicles are the same (e.g., TE, page 131). The class then collects more data to help understand this apparent discrepancy.
- Lesson 6: A reference is made back to the anchoring problem for the unit. Students are asked, "What is changing in a collision between a large truck versus a small car that could affect passenger safety? What new questions does this raise for us?" (TE, page 146).
- Lesson 8: Students are supported to begin figuring out why seatbelts and airbags keep passengers safer in a vehicle collision.
- Lesson 14: Students focus on identifying new problems that their physics learning can help them solve. They also return to the anchor phenomenon. "Take stock of where we have been by revisiting the graphs from Lesson 1. Present slide H. Take a moment to quickly point out the trends that the class identified. Then give students about two minutes to turn and talk about the prompt on the slide and the accompanying graphs: Can we apply our ideas about safety systems and other factors to explain these data trends?" (TE, page 260).

The unit includes some opportunities to be driven by student ideas and questions, but much of the unit is teacher driven. Related evidence includes:

- Lesson 1: After students make predictions, the teacher is told to ask, "What other data could help us quantify safety to test our predictions?... Ask students to briefly share out. Listen for ideas about counting or quantifying injuries, fatalities, types of vehicles, types of crashes, and so forth. Accept 3-4 ideas very quickly and then use them to motivate looking at more data by saying, It sounds like there are some other data sets we could look at that might also tell us about whether driving has become more or less safe since the 1990s, and for whom" (TE, page 38).

- Lesson 1: "Have students assemble their chairs in a circle. Ask each group to spend no more than 1 minute sharing out the major patterns they noticed in the data. Record ideas on chart paper for a public record of 'Puzzling Patterns' we would like to be able to explain" (TE, page 38).
- Lesson 1: "Transition out of the Scientists Circle into group work, with 2-4 students per group. Present slide N. Distribute the Modeling with Toy Cars handout to guide student work" (TE, page 41). Although this is a short activity, it is presented without facilitating students to want to do it or to see the need for doing it.
- Lesson 1: "'What do we need to know more about in order to determine what kinds of solutions we could advocate for to make our community safer, inside and outside of vehicles?' Accept all ideas and revoice them to encourage students to think about questions that will be productive toward real design solutions. Listen for ideas about data for our community specifically, about protecting local lands and waters, about additional events missing from our timeline, about safety features on cars, and about distracted driving or cell phone use" (TE, page 44). "Ask students to think back on all that we have done and to develop some questions. Instruct them to record one question per 3x3 sticky note, using a thick marker, and put their initials on the back of each sticky in pencil. Give them about 5 minutes to develop questions" (TE, page 45). When creating the Driving Question Board (DQB), the teacher is told, "Explain that students will take the lead on this process. Choose the first volunteer to begin and then have the class follow the process outlined on the slide" (TE, page 45). "You may need to facilitate the discussion to choose a title. Ask, What is the big question we are trying to answer? Listen for ideas about making driving safer, such as, 'How can we make driving safer?' or 'Why is driving so risky, and how can we fix it?' Write the question the class agrees on as the title at the top of the DQB" (TE, page 46).
- Lesson 1: "Ask students to work on their own (or with an elbow partner) to record some ideas for data or investigations we need to help answer our questions and inform possible solutions. Have them record ideas on 3x3 stickies. Be ready to add these to the Ideas for Investigations and Data We Need poster under the cluster title, as shown on slide BB…. Listen for ideas about distracted driving or other driver behavior, and be ready to point to them at the start of the next lesson" (TE, page 46).
- Lesson 2: In the "Where We Are NOT Going" section, the teacher is told, "In this lesson, students 'invent' position versus time graphs to analyze and compare two videos of a car stopping. Avoid presenting position versus time graphs in a decontextualized way or as 'something we use in physics.' Instead, use student questions to motivate comparing the position of the car and the time, so it becomes clear why these representations are useful" (TE, page 52).
- Lesson 2: The lesson begins with the teacher saying, "'We wanted to investigate the impact of distracted driving on a vehicle collision. We had some ideas about how drivers might behave differently when they are focused and undistracted to reduce the chance of getting in a collision in the first place.' Direct students' attention to the class consensus model to remind them of this" (TE, page 53).
- Lesson 2: "Elicit ideas about how to calculate the real-life distances. Present slide D. Have students share their ideas about how we could use scale to determine the distances that the car

actually travels. Listen for ideas about wanting to know the real length of something in the video" (TE, page 56).

- Lesson 2: "Say, 'We have two different ways to look at the events in the video: through time and through position. What could we do to visualize what's happening here in both dimensions, time and position, and look for a relationship between these?' Give students a minute to consider this question with a partner, and then elicit their ideas. If students need more scaffolding here, use the prompts below to help them consider what they have done in the past, and if necessary, guide them to think about graphing specifically."
- Lesson 3: "Ask, What could we do to keep track of how this speed changes over time? Listen for students to suggest a plot. If they do, ask, What could a plot of speed over time tell us about distracted driving? Accept all ideas. If they do not suggest a plot, say, Could we do the same thing we did for position, but with speed? What could that tell us?" (TE, page 73).
- Lesson 3: Students are supported to see how their ideas connect to — but do not drive — instruction. "Say, We had some ideas about how our initial speed, meaning the speed we are going before an obstacle appears, might affect our probability of collision. Let's investigate this further and find out exactly how much of a difference initial speed makes" (TE, page 74).
- Lesson 4: "For the second prompt, listen for suggestions of 'how good the brakes are' and maybe mass. If the discussion does not touch upon 'better brakes' or factors associated with the quality of the brakes or the strength of the braking force, use the following prompts: What about the brakes themselves? Are all brakes the same? Use this discussion to transition to the next slide" (TE, page 87).
- Lesson 4: Students are supported to see how their ideas connect to — but do not drive — instruction. "Say, We think the braking force is important. We also think speed is important, and we wrote about that in our exit tickets. I also heard some ideas about the size of the vehicle maybe being important. Let's investigate these variables and make some predictions about how they might affect the outcome of a collision. In the last lesson, we used speed versus time representations to describe the way a car was moving" (TE, page 88).
- Lesson 4: "Then transition to the next activity by using the slide's last prompt: What data would make you more confident about our answers? Accept all answers. Say, I have a simulation that will help us generate data to test our idea" (TE, page 96).
- Lesson 4: Students are supported to see how their ideas connect to — but do not drive — instruction. "But if this is true, does it hold for values that represent the actual mass and speed of a real vehicle? Accept all answers. Suggest we try using our mathematical model to solve a couple of problems with real numbers" (TE, page 97).
- Lesson 5: Students are supported to see how their ideas connect to — but do not drive — instruction. The teacher is told to, "Say, It sounds like the slope of the speed versus time graph is telling us something important. Let's take a closer look" (TE, page 103).
- Lesson 5: "Ask students to gather around the DQB. Quickly review questions on the DQB, focusing on any clusters related to reaction time, stopping time, or other topics from Lessons 1-4. Ask whether any questions can be answered and move any questions that can now be answered to a separate part of the DQB. Once the DQB has been checked, point out that the lessons thus far have been about avoiding collisions. Ask, Do you have any new questions that

we should add to our DQB about objects that are not able to avoid collisions and are colliding?" (TE, page 111). However, connections are not made between this discussion and the next instructional activity. For example, the next activity is introduced without referencing a specific question or cluster on the DQB. The teacher is just prompted to, "Say, 'Let's see if we can apply the ideas and practices we have developed to explain an aspect of the phenomenon we have taken for granted related to friction'" (TE, page 111).

- Lesson 6: A new activity is initiated by the teacher saying, "'Many of us made some pretty reasonable predictions about velocity changes, using mathematical thinking. This seems like a good opportunity to extend our mathematical thinking back to the motion relationship equations we developed last time, to see whether we can apply the values for changes in velocity to make reasonable force predictions" (TE, page 126). This activity is teacher-driven rather than student-driven.
- Lesson 6: "Follow up by asking for ideas about how we can make mathematical comparisons to predicted values if some values in the data set are below the predicted value and some are above it. Accept all ideas. If one of the ideas is an average (the mean), suggest that we compare it to our predicted value. If no one suggests an average, ask for examples of when calculating an average from a set of values helped us make a relatively accurate prediction about a future or typical value" (TE, page 127).
- Lesson 6: "Give students a moment to consider these, and then poll the class with a show of hands for each choice. Use students' likely differences in predictions to emphasize that our different thinking on this is interesting, and that this seems like an important area to resolve to make progress on our Driving Question Board. Suggest that we need to analyze the data from these three collisions to resolve this" (TE, page 129).
- Lesson 6: Students are asked, "What evidence would we need to support or refute our arguments?" Sample student responses include, "We need vehicle fatality or injury data for collision between different-mass vehicles" (TE, page 131). The teacher is then told to, "Propose that we need to analyze some vehicle fatality data to try to figure this out" (TE, page 131).
- Lesson 6: The teacher is told to, "Say, Whenever we think about a conserved quantity in a physical process, it can be useful to represent that quantity with alternate visualizations beyond just numbers or symbols. Let's try to visualize this conserved quantity in our collisions with a geometric model. A geometric model uses shapes to represent quantities visually. In our case, we need a shape to represent a quantity that is the product of two variables" (TE, page 138). This activity and the next (introduction to the concept of momentum) are heavily teacher-driven and not directly connected (from the students' perspective) to solving a problem, explaining a phenomenon, or answering their own questions.
- Lesson 6: At the end of the lesson, the teacher is told, "If time permits, ctivate[sic] students' curiosity and motivate further investigation by asking something like, Why would differences in the Δv of the vehicle that a passenger is in have an effect on their safety?" (TE, page 147). This question is generated by the teacher rather than the students, and this step is framed as being optional, so it is less likely that all classrooms will use it.
- Lesson 7: At the end of the lesson, students use a simulation. Students are told, "I have a simulation we can play around with to get a sense of what factors we still want to investigate to

find out what could be causing changes in collision outcomes over time" (TE, page 156). The teacher is told, "the main goal is to foster questions" and to, "Ask students to post their new questions to the DQB quietly as they leave. Look for most of these to be about safety features such as crumple zones, seat belts, collision avoidance, or airbags" (TE, page 157). However, in the beginning of Lesson 8, student questions are not connected to the activity. "Say, Last class we added questions to our DQB. A lot of our new questions are about safety features that we noticed in the simulation. Then Say, The simulation is a really useful tool. But before we use it again, let's actually look at a collision to try and determine what the safety features might be doing and when they might be acting to keep people safer" (TE, page 163).

- Lesson 8: Students explore why people wearing seatbelts are safer in a collision than people without seatbelts. However, the beginning of this activity is not driven by student questions or their desire to solve the problem of fatalities; instead, it is teacher driven. In the beginning of the lesson there is a reference to the questions students added to the DQB in Lesson 7: "Last class we added questions to our DQB. A lot of our new questions are about safety features that we noticed in the simulation. Then Say, The simulation is a really useful tool. But before we use it again, let's actually look at a collision to try and determine what the safety features might be doing and when they might be acting to keep people safer…. Explain that after we watch the video we will try to create a rough timeline of these events together, similar to what we had done in Lessons 2–3, but without the ticker at the bottom of the screen" (TE, page 163). Students are not supported to come up with any ideas about what to do next, and they might wonder why they are creating a timeline. The teacher is then told to "stir up controversy" about the timeline to help motivate students to learn. Later in the lesson, students are supported to help come up with the next instructional step. "If we simulated these collisions using the Vehicle Collision Simulation, what data might help us make sense of the motion of the vehicle and the crash test dummy? Give students a minute or so to discuss and then have a few pairs share their ideas. Look for students to suggest motion variables they have previously examined in the unit such as position and velocity" (TE, page 169).
- Lesson 10: The lesson begins by eliciting student ideas in response to the question, "What are some ways in which the body of the vehicle could be redesigned to make a collision safer?" Then the teacher is told to say, "It sounds like we're unsure whether we want to use softer or more rigid materials. Explain that engineers have also grappled with this idea, and that older cars have very different bodies than newer ones" (TE, page 195).
- Lesson 10: Student ideas are used to determine parameters of a simulation. "Based on how students responded, test a few of their combinations with the simulation as a class (http://collision-sim.inquirium.org/crumple-zones.html). Use the settings described below to create the different combinations" (TE, page 205).
- Lesson 11: At the beginning of a new activity, the teacher is told to say, "I heard some of you saying that the crumple zone is going to get squished during a collision. In addition to the data on likelihood of survival, we also have information about how much the crumple zone deformed versus the crumple zone length. Let's see what we can figure out from this new data" (TE, page 217). However, at the beginning of the next activity, student ideas are not used to motivate the instruction, and students are unlikely to feel as if they are driving instruction. "Say, 'We analyzed

how the design of crumple zones can affect safety from a force perspective. Let's use some other perspectives from the M-E-F to explain why these design characteristics affect forces'" (TE, page 218).

- Lesson 12: At the end of Day 1, the teacher is told to, "Discuss the prompts as a class. Highlight any student ideas about the evaluations being incomplete with just the science ideas, as these will help on day 3 to motivate revisiting the arguments from a societal perspective" (TE, page 231).
- Lesson 12: "So, it seems that our science ideas from across the unit are helpful in considering decisions related to vehicle safety. Let's revisit our DQB and look for questions we can now answer. Give students some time to individually review the DQB and identify questions they can now answer. Then take a few minutes to have them share as a class" (TE, page 231).
- Lesson 12: "Pause and allow students to add to the DQB any new questions they have. Ask them to quickly share their questions out loud as they post them and to add them to the relevant question clusters. Point out that we have a lot of questions about implementation of design and policy for vehicle safety" (TE, page 237).
- Lesson 15: At the end of the unit, the teacher is told to, "Gather students around the Driving Question Board and point out the unanswered questions. Have a conversation with students about which of those we can now answer. As students pick specific questions, ask them what the answer is to the question. Ask a student volunteer to record the answer. They can do this in pencil on the question they have chosen, by taping the sticky to a separate piece of copy paper, or on a class document in a virtual space. Continue this process until all the answerable questions have been addressed" (TE, page 276).

The materials connect to students' prior learning and experiences to aid with sense-making. Related evidence includes:

- Lesson 1: Students are prompted, "Thinking back to what we figured out about breaking and deformation in the Afar unit, what representations or ideas related to energy, forces, or matter do you see represented in multiple models?" (TE, page 42). "Say, The M-E-F triangle has been powerful for helping us make sense of the motion of plates and resulting changes to Earth's crust. Maybe it can also help us organize our ideas about vehicle collisions" (TE, page 43).
- Lesson 4: "You may want to remind the class that if the ground is exerting a force on the car, the car must also be exerting a force on the ground" (TE, page 87).
- Lesson 6: "Use the second question [Does what we figured out mean that different-mass vehicles should be equally safe if they collide with each other?] to elicit controversy, uncertainty, or examples from students' own experiences that suggest safety outcomes would not be equal. Students may even cite the equation they have been developing as something that predicts different outcomes (for change in velocity) for the same force and time but different masses" (TE, page 130).
- Lesson 13: "Ask students, 'What other should-we questions can you think of in our community that could affect traffic safety?'" (TE, page 248).

Engineering is a focus in Lessons 10–14 in the unit. Although students apply, practice, and deepen their understanding of what they learned in prior lessons, the engineering is not integrated with new science learning in these lessons. For example, in Lesson 10 in the Design Crumple Zones activity, students apply their learning about science to do an engineering activity, but no new science seems to be learned (TE, pages 198–199).

Suggestions for Improvement

- Consider providing support to connect students' ideas and questions to the next instructional step more often such that students would feel as if they were driving the learning.
- Consider providing more connections in Lesson 6 between solving the problem of collisions and the lesson activities.
- Consider adjusting Lesson 10–14 such that more of the unit focuses on new learning of science ideas.

I.B. THREE DIMENSIONS

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

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

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

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

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

The reviewers found adequate evidence that the materials give students opportunities to build understanding of grade-appropriate elements of the three dimensions. Students have many opportunities to use elements of the three dimensions throughout the unit. However, there are several mismatches between claims and evidence of student use of the elements, particularly for DCIs and Crosscutting Concepts (CCCs).

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

The reviewers found extensive evidence that students have the opportunity to use the SEPs in this unit. Students are also supported to develop their proficiency in some of the targeted SEP elements. However, there are a few mismatches between claims and evidence of student use of the SEP elements.

Asking Questions and Defining Problems

- *Ask questions that arise from careful observation of phenomena, or unexpected results, to clarify and/or seek additional information.*
    - Lesson 1: This element is claimed as being used. After students examine graphs of data, they are asked, "What new wonderings related to vehicle safety do these data bring up for you?" (TE, page 38). Later, during the creation of the DQB, students are told to, "think back on all that we have done and to develop some questions" (TE, page 45) in response to the slide prompt, "Thinking back to what we have been doing over the past few days, what questions do you have righ[sic] now?" (Lesson 1, Slide X).
- *Define a design problem that involves the development of a process or system with interacting components and criteria and constraints that may include social, technical, and/or environmental considerations.*
    - Lesson 14: This element is claimed as being used. Students are prompted to, "Decide on a single problem that matters to your team and your community and that seems possible to solve with ideas related to our physics models. Then below, describe or draw the problem you decided on with your team. The questions in a and b may help you prioritize - discuss these questions as a group before or after you choose one problem. How widespread is the problem? How often does it occur? In what kinds of places? Identify details to help your team narrow to a specific location, policy, or safety system. Where and when in our community does this problem occur? Who does it affect, and how?" (Design Challenge Organizer, page 2). Students are also asked, "What might be causing this problem? What are the effects of the problem that might impact safety? Use evidence from experiments or readings to help you identify cause-effect relationships in the system where your problem exists" (Design Challenge Organizer, page 3).

Developing and Using Models

- *Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system.*
    - Lesson 8: This element is claimed as being used. The class develops timeline models and students are asked, "What evidence have our timelines provided us that help us explain what safety features do to keep people safe? After 1 minute of partner talk, allow students to share out their ideas. Look for students to highlight that the safety features didn't change the change in velocity of the crash test dummy, but they did significantly increase the amount of time the change took place over" (TE, page 172). Students are therefore using the timeline models to predict the relationship between safety features (e.g., seatbelts) and safety or time, although neither safety nor time is likely to be considered to be a component of the system.
- *Develop and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems.*
    - Lesson 1: This element is claimed as being fully used in the NGSS elements document but only built toward in the lesson assessment guidance. Students develop a model, but do not develop a model that would generate data.

- Lesson 5: This element is claimed as being used. Students use graphs (mathematical models) to discuss solutions to the problem of slow braking time in the rain. “So, it sounds like a problem has been identified, and we know what we can’t change. But, if we look at our equation and this slope, what can we change with the car system to get drivers in wet and rainy conditions to stop in time?” (TE, page 109). However, they do not use these models to generate data.
- Lesson 14: This element is claimed as being used. The teacher is told to, “point to the posters showing physics models developed throughout the unit and say, We’ve developed quite a strong understanding of these various modeling tools in these posters. Now it’s time to put those models to work and think through how physics can save lives!” (TE, page 268). Students are then told to, “use mathematical models that we have developed in our unit to explain what makes the problem dangerous or how your solution would help make people safer” (Design Challenge Organizer Handout, page 5). Students input approximate numbers in order to obtain reasonable values to test their solutions. An example given is, “Speed humps reduce speeds by 10 mph. If we can reduce vehicle speed on Park Ave. from 30 mph to 20 mph, we can cut the braking distance of cars in half from about 64 ft to 34 ft” (Physics Models Used Handout, page 1).

Planning and Carrying Out Investigations

- *Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly.*
  - Lesson 4: This element is not claimed but is built toward in the lesson. For example, the teacher is told, “The goal of the first round of data collection is to discuss issues of error. During this discussion, push students to consider the accuracy of data, the number of trials needed to produce reliable measurements, and limitations on the data’s precision due to the experimental setup. Encourage them to refine their data collection accordingly” (TE, page 90).

Analyzing and Interpreting Data

- *Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution.*
  - Lesson 2: This element is claimed as being used. Students create a graph of data first together as a class, and then in pairs. “Have students work with a partner to go through the same steps as previously, but for the distracted driver. They can plot the points using the same axes as for the undistracted driver on their Position versus Time graphs, as long as they use a different color” (TE, page 66).
- *Evaluate the impact of new data on a working explanation and/or model of a proposed process or system.*

- Lesson 7: This element is claimed as being used. Students look at new data and are told to, "describe whether their data correlate to any of the trends" the class identified in Lesson 1 (TE, page 155). They are then asked, "Can we say anything about which factor is causing these trends?" (Slide G).

- *Analyze data to identify design features or characteristics of the components of a proposed process or system to optimize it relative to criteria for success.*
  - Lesson 9: This element is claimed as being used. Students compare four simulation set ups with graphs and are asked, "What patterns do you see in these four attempts to optimize the safety features?" (TE, page 185).
  - Lesson 10: This element is claimed as being used. Students compare data from various tests of design solutions. Students are asked, "What do the safest designs have in common in terms of what they were made of or how they were designed?" (TE, page 200).
  - Lesson 11: This element is claimed as being used. Students are prompted to, "Analyze and annotate the following graphs to explain how the design of the crumple zone length affects safety of the crash test dummy" (Survivability vs. Length, page 3).

Using Mathematics and Computational Thinking

- *Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations.*
  - Lesson 3: This element is claimed as being used. Students create and use graphs of phenomena to support claims about breaking distance and reaction time.
  - Lesson 4: This element is claimed as being used. Students graph data from investigations and are asked, "'What relationship have you discovered between mass, speed, and braking force that predicts the stopping time of a vehicle?' Invite volunteers to share. Listen for mentions of how the variables relate mathematically. Use the results in the table to test the proposed relationship. Ask whether other groups found the same or a different relationship…. 'How can we represent the relationship we have identified as an equation?' Guide the class through writing out the equation in words first. For example: Stopping time = mass * initial speed / braking force. Say, 'Equations are often made smaller by using variable symbols instead of words. Which words can we replace with symbols in our equation?'" (TE, page 96).
  - Lesson 5: This element is claimed as being used. Students derive Newton's 2^{nd} law (F=m/a) and use it to analyze real world situations.
  - Lesson 6: This element is claimed as being used. Students are asked, "What does our mathematical model predict the final velocity of cart D would be? Show how you solved for this unknown using one of our momentum equations. Why does your use of this equation provide a reasonable approximation of the outcomes for the system you defined?" (Different Momentum Cases Handout, page 5).
  - Lesson 10: This element is claimed as being used. "Rewrite the last equation on the board: $F\Delta t = m\Delta v$." The left side of the equation is labeled as, "The two variables that are changing." The right side of the equation is labeled as, "The change in momentum of

the vehicle was constant in every case where we brought its velocity to 0." Students are asked, "What does this tell us about how the average net force on an object and the time that force is applied are related to the change in momentum?" (TE, page 202).

- Lesson 11: This element is claimed as being used. Students are prompted, "Choose any of the mathematical models present in the Force and Motion Relationships poster to describe one of the patterns that you identified in question a of Part 2" (TE, page 215). The suggested student response is "FΔt = mΔv. The larger the force acting on the dummy, the steeper the changes in velocity (larger deceleration)" (TE, page 215).

- *Apply techniques of algebra and functions to represent and solve scientific and engineering problems.*
  - Lesson 6: This element is claimed as being used. The class develops a mathematical model and tests it in various conditions using a simulation. They are then asked, "Does the mathematical relationship we developed above hold for none, one, or both of the collisions you tested in the simulation?" (Lesson 6, slide FF).
- *Use simple limit cases to test mathematical expressions, computer programs, algorithms, or simulations of a process or system to see if a model "makes sense" by comparing the outcomes with what is known about the real world.*
  - Lesson 4: This element is claimed as being used. Students are asked, "What would happen to the time it takes the car to come to a stop when your independent variable is really small (but not zero) or really big? Explain your reasoning. Do your predictions match the prediction of the curve fit you selected for your data? If not, which curve fit better matches your real-world predictions?" (Braking Investigation Handout, page 4). Note that the mathematical model from the data is compared to students' predictions rather than "what is known about the real world." However, in the assessment opportunity notes of "What to do," the teacher is told to, "highlight the following ideas. According to the linear (-) curve fit, if we continue increasing the force, there will be a point where the stopping time becomes negative. Encourage students to think about whether negative time makes sense. Encourage students to think about whether it is possible that there is no force acting on the vehicle. They should say no. The inverse curve fit suggests that as we continue increasing the force, the time will get really small, but will never be zero. This curve fit also shows that while the force cannot be zero, very small forces will result in very long stopping times" (TE, page 94).
  - Lesson 5: This element is claimed as being used. Students consider cases such as the following: "Imagine you could reduce the friction acting on the cart to 1/1000th (one thousandth) of its current magnitude. Would it take longer to stop, or would it stop more quickly, and by what multiplication factor?" (Electronic Exit Ticket Key).

Constructing Explanations and Designing Solutions

- *Make a quantitative and/or qualitative claim regarding the relationship between dependent and independent variables.*
  - Lesson 4: This element is claimed as being used. Students graph data from investigations and are told, "'Scientists use mathematical tools to identify trends in their results. These

graphs are an example of these tools, and they show us possible curve fits for our data. Curve fits are considered mathematical models because they use mathematical equations to describe the relationship between the independent and dependent variables. Use the slide's prompt and graphs to discuss the roles of mass and speed in stopping time: Based on your results, how would you say the variable you investigated is related to time?' Listen for the following ideas: The larger the mass, the longer the time it takes for the cart to stop. The higher the speed, the longer the time it takes for the cart to stop" (TE, page 93).

- Lesson 9: This element is claimed as being used. Students are asked, "If we wanted to create a safety feature that reduced the average force applied to the person to a fourth of its previous value, how much longer would that force have to have been applied to the person?" (TE, page 187). A sample student response says, "Four times as long" (TE, page 187).

- *Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects.*
  - Lesson 9: This element is claimed as being used. Students use the "solve design problems" part of this element when they complete the Comparing Speeds handout. Question 4 states, "If you were designing the safety features for a vehicle and knew that it typically travels at faster speed, what design changes might you make about both the seatbelt and airbag's characteristics? Explain how your design choices would increase safety" (page 2). However, students are not asked to provide an explanation of phenomena. In this case, the colloquial definition of "explain" (meaning "communicate") is used but teachers and students are likely to think they are expected to construct explanations (the SEP).
  - Lesson 12: This element is claimed as being used. Students are told to, "Select one criterion or design solution that we have investigated in this unit. Apply the ideas from our Gotta-Have-It Checklist to explain how this criterion or design solution can be optimized to increase vehicle safety" (TE, page 234). Students therefore use the "solve design problems" part of this element to communicate about their solutions but are not asked to provide an explanation of phenomena. In this case, the colloquial definition of "explain" (meaning "communicate") is used but teachers and students are likely to think they are expected to construct explanations (the SEP).
- *Design, evaluate, and/or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.*
  - Lesson 3: This element is claimed as being used. Students discuss possible engineering solutions to real world problems, along with any issues that make those solutions less than optimal.
  - Lesson 10: This element is claimed as being used. "Explain that we will work in partners or small groups to design crumple zones for our cars after we identify our design criteria as a class" (TE, page 197). Students are asked, "What is the problem that we're trying to solve with a crumple zone?" (TE, page 197). In the Design Solution Comparison handout,

students are also asked, "What key science ideas do we have to support this design?" (page 2).

- Lesson 14: This element is claimed as being used. The teacher is told, "When designing solutions, we should encourage students to consider what specific criteria they want to prioritize. No solution will satisfy all possible criteria–a good solution weighs various possible criteria to make an informed choice about which is most important" (TE, page 262). Students are told to, "Use your answer to 4a to prioritize criteria to optimize your solution: Criteria: Who or what will you prioritize? What do you want the solution to accomplish? Trade-offs: Who or what may be negatively impacted by your solution? What might you have to give up?" (Design Challenge Organizer, page 3). Students are then told to, "Work with your team to design 1-2 possible solutions that meet the criteria you set in question 4b. Describe or draw below the solution that you decided on with your team" (Design Challenge Organizer, page 3).

Engaging in Argument from Evidence

- *Compare and evaluate competing arguments or design solutions in light of currently accepted explanations, new evidence, limitations (e.g., trade-offs), constraints, and ethical issues.*
    - Lesson 12: This element is claimed as being used. Students compare two written arguments and are asked, "Compare your evaluations of the two arguments. Which argument or design has the most merit from a science perspective, and why?" (Science Ideas Argument Comparison, page 3). Students are given an Argument Comparison Tool with the first column filled out to scaffold their use of the tool.
    - Lesson 13: This element is claimed as being used. "Have students work through one article at a time and evaluate each one in full before proceeding to the second article. Once both articles have been evaluated, ask students to go back to the second table and reconsider each question, since a new perspective might have emerged as they read each article. Give students 20 minutes to complete the Argument Comparison Tool in partners" (TE, page 245). Students are given a blank Argument Comparison Tool.

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

The reviewers found adequate evidence that students have the opportunity to use or develop the DCIs in this unit. Students use DCIs throughout the unit, although there is a mismatch between claims and student use of many of the ETS DCI elements.

PS2.A: Forces and Motion

- *Newton's second law accurately predicts changes in the motion of macroscopic objects.*
    - Lesson 1: The last part of this element is claimed as being used. Students discuss physical characteristics of traffic accidents, including safety features in cars (e.g., seat belts). In a Gallery Walk, a sample student response to possible Matter, Energy, Forces triangle connections is, "A few representations of motion which we recall from Afar are somehow related to forces, and which are a manifestation of energy transfer" (TE, page 42).

- Lesson 4: This element is claimed as being used. Students begin examining the relationship between mass and stopping time, force and stopping time, and initial speed and stopping time.
- Lesson 5: This element is claimed as being used. "At this moment, students have identified the relationship between force, mass, and acceleration and Newton's second law. Take this moment to call this out explicitly and name the second law of motion and that we have used this relationship to provide an explanation of the movement of objects" (TE, page 105).
- Lesson 6: This element is claimed as being used. Students use their understanding of F=ma to derive and apply other equations.
- Lesson 8: This element is claimed as being used. Students use their understanding of F=ma to derive and apply other equations.
- Lesson 9: This element is claimed as being used. Students apply their understanding of F=ma.
- Lesson 10: This element is claimed as being used. Students apply their understanding of F=ma.
- Lesson 11: This element is claimed as being used. Students apply their understanding of F=ma. They are asked, "How do the times over which the changes in velocity occur compare[sic] to the times over which the forces act on the crash test dummies?" (TE, page 213).
- Lesson 12: This element is claimed as being used. Students apply their understanding of F=ma.

- *Momentum is defined for a particular frame of reference; it is the mass times the velocity of the object. In any system, total momentum is always conserved. If a system interacts with objects outside itself, the total momentum of the system can change; however, any such change is balanced by changes in the momentum of objects outside the system.*
  - Lesson 6: This element is claimed as being used. The class derives the equation $m_1 * \Delta v_1 + m_2 * \Delta v_2 = 0$ and learn that $m * \Delta v$ is the change in momentum (e.g., slide LL). They talk about conservation of physical quantities, and practice using conservation of momentum equations.
  - Although this element is not claimed again until Lesson 15, it is referred to in most lessons after Lesson 6 as students apply an understanding of momentum.

ETS1.A: Defining and Delimiting an Engineering Problem

- *Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them.*
  - Lesson 2: The first part of this element is claimed as being used. However, no evidence was found for its use or development in the lesson.
  - Lesson 10: The first part of this element is claimed as being used. Students use criteria in their designs and discuss that the problem they're trying to solve is related to human

safety in cars. The idea that requirements set by society are important, though, is not discussed.

- *Humanity faces major global challenges today, such as the need for supplies of clean water and food or for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities.*
    - Lesson 1: This element is claimed as being used, other than the "such as" phrase. Students discuss statistics related to traffic accidents as well as engineered solutions that might help.
    - Lesson 2: This element is claimed as being used, other than the "such as" phrase. In this lesson, students observe consequences of distracted driving, but do not discuss ideas in this element.
    - Lesson 3: This element is claimed as being used, other than the "such as" phrase. Students read about pedestrian fatalities associated with different automobile driver speeds and discuss possible solutions.

ETS1.B: Developing Possible Solutions

- *When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts.*
    - Lesson 3: This element is claimed as being used, other than the "cost" and "reliability" words. When the class fills out the Engineering Design Tracker, the teacher is told, "Explain that a constraint might be something as simple as a solution being too expensive, or it might be much more complex. As we fill in the tracker's last column, we need to think about the constraints on the design solution and whether that constraint might not affect everyone equally" (TE, page 78). However, note that "constraints" is used in the Framework for K–12 Education and the NGSS as a feature of an optimal solution rather than as a drawback of a particular suggested solution, as it is used here.
    - Lesson 12: This element is claimed as being used, other than the "cost" and "reliability" words. Students are asked, "What constraints and expectations in real life might affect how we should apply science ideas to make vehicles safer?" (slide V)
    - Lesson 13: This element is claimed as being used, other than the "cost" and "reliability" words. Students compare arguments for and against certain innovations. In the Argument Comparison Tool, students are asked, "What constraints might exist in our community that would make it hard to accept this argument?" This gives students an opportunity to address the constraint part of the element. Another question asks, "How would accepting this argument affect you and others around you, both human and not human? For example, is one group's safety being prioritized, or are there others being put more at risk if this solution/argument is accepted?" Afterward, the teacher is told to say, "We've also considered how these engineering ideas can be shaped by both the science and societal wants and needs, such as the arguments we explored in this lesson" (TE, page 248).

- *Both physical models and computers can be used in various ways to aid in the engineering design process. Computers are useful for a variety of purposes, such as running simulations to test different ways of solving a problem or to see which one is most efficient or economical; and in making a persuasive presentation to a client about how a given design will meet his or her needs.*
    - Lesson 9: This element is not claimed but is built toward. The teacher is told to say, "Just imagine how many different experiments engineers might need to carry out, even in a simulation, to find the best combinations across all these different cases. This is an area where computer modeling and artificial intelligence can help automate the process for carrying out such simulations and narrowing in on optimal designs" (TE, page 185).
    - Lesson 10: This element is claimed as being used. Students create physical models and discuss how comparing the various physical models can help them in the engineering design process. Later in the lesson, students use computer simulations to test design considerations. The utility of computers in making persuasive presentations is not discussed.

ETS1.C: Optimizing the Design Solution

- *Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (tradeoffs) may be needed.*
    - Lesson 11: This element is not claimed but the last part of it is built toward. The teacher is guided to say, "reducing the rigidity of the crumple zone does increase the likelihood of serious, unsightly, and expensive damage to vehicles, even in lower speed collisions that don't have as much safety risk. Discuss how this is called a tradeoff where safety in higher risk scenarios is prioritized over preventing damage in lower risk scenarios. Foreshadow that the rest of the unit will talk about tradeoffs and how design decisions are navigated" (TE, page 215).
    - Lesson 12: This element is claimed as being used. Students are told to identify criteria for vehicle systems to ensure they are designed for safety, and are asked, "What possible unanticipated or negative effects might occur from optimizing the specific criterion or design solution that you explained? Considering these possible effects, should this criterion or design solution be prioritized over other criteria or designs?" (slide U) However, the ideas in the first part of this DCI element are not discussed or evident in the student performances.
    - Lesson 14: This element is claimed as being used. Students develop and use criteria to propose solutions to a problem. Students are told, "When you're giving feedback, try to focus your questions on criteria or trade-offs" (TE, page 264). However, the ideas in the first half of this DCI element are not discussed or evident in the student performances.
    - Lesson 15: A teacher note in the "Where We Are Going" section of the lesson says, "This unit is not covering the first half of ETS1.C, as this occurs in Electricity Unit" (TE, page 274). However, the full element is claimed in the "Elements of NGSS Dimensions" document for the other lessons described above.

Collisions and Momentum

EQuIP RUBRIC FOR SCIENCE EVALUATION

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

The reviewers found adequate evidence that students have the opportunity to use or develop the CCCs in this unit. However, there are several mismatches between CCC claims and evidence of student use of these concepts in the lessons.

Patterns

- *Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.*
    - Lesson 6: This element is not claimed but is supported. The teacher says, "In our Earth's Interior Unit, we discovered that if we look at what's happening in a system at a much smaller or much larger scale than we can directly observe, it helps us see different patterns, which then helps us explain cause-and-effect relationships for what we observed" (TE, page 123). The teacher is told, "This will help them reuse this idea more fluently to make sense of subsequent phenomena they will encounter in other science classes" (TE, page 123).
- *Patterns of performance of designed systems can be analyzed and interpreted to reengineer and improve the system.*
    - Lesson 11: This element is claimed as being used. Students analyze data from graphs of collisions with differently designed vehicles and discuss the design of crumple zones.
- *Mathematical representations are needed to identify some patterns.*
    - Lesson 2: This element is claimed as being used. In the lesson, students graph data from videos, creating and analyzing mathematical representations. However, they do not discuss whether or not they could see the patterns before they created the graphs.
    - Lesson 4: This element is not claimed but is built toward. The teacher is told to, "Say, Scientists use mathematical tools to identify trends in their results. These graphs are an example of these tools, and they show us possible curve fits for our data" (TE, page 93). In addition, the optional Data Analysis handout says, "Very often, results don't seem to show a clear trend or pattern, and that's where curve fitting comes in. It helps us find a smooth and coherent shape or curve that best represents our data. This makes it easier to see trends and patterns in our results, even if the measurements have some variations" (page 2).
    - Lesson 6: This element is claimed as being used. Students create geometric models of quantities and are asked, "What did the geometric representation help us visualize?" Sample student responses include, "It helped us see that if one variable is really small but the other is really big, it can result in the same amount of change" (TE, page 140).
- *Empirical evidence is needed to identify patterns.*
    - Lesson 1: This element is claimed as being used. Students are told to identify patterns from a graph (which presumably is created from empirical evidence), and the teacher is told in a side bar comment to, "Use this opportunity to highlight that the empirical evidence presented in the graphs was needed in order to accurately identify the patterns in the number of crashes over time" (TE, page 37). However, the lesson plan narrative itself doesn't discuss the idea of empirical evidence or provide support for how

teachers might develop this targeted CCC element with students. Later, when students develop questions for the DQB, the assessment guidance indicates that students are using this element through the look for: "Look for students to…connect questions to specific patterns revealed in the empirical data." It is implied that students think the patterns are from the real world and that making sense of them will benefit the real world, so students might be implicitly using this element.

Cause and Effect

- *Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.*
    - Lesson 7: This element is claimed as being used. "Have students turn and talk about the second question on the slide: Is this evidence that one variable caused the other variable to change? There is no need to share with the whole class. Then say, Just because two variables are correlated does not mean one of them caused the other. Maybe it does, but there could be other factors involved that we haven't thought of. And several factors could contribute to one trend" (TE, page 154). However, this discussion only explicitly supports a middle school-level CCC understanding: *Relationships can be classified as causal or correlational, and correlation does not necessarily imply causation.* The teacher goes on to say, "Scientists use correlations to make educated guesses that then can then explore further with experiments and simulations" (TE, page 154), which might begin to build a foundation for student learning related to the claimed element. Similarly, at the end of the lesson the teacher is told to say, "Can we tell which is which? Not really, because correlation is not causation… But we can use these data to make an educated guess and investigate further. Scientists sometimes set up experiments or use simulations to test their ideas" (TE, page 156). However, there is no evidence that all students would use understanding of the claimed element.
- *Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller scale mechanisms within the system.*
    - Lesson 14: This element is claimed as being used. The teacher is told to say, "If we think about cause and effect within the system, then it can be much easier to identify places in the system where we can fix the problem we've identified. For example, if accidents on a specific road are caused by people driving too fast, then installing speed humps to reduce speed is likely to reduce accidents also. Alternatively, you can frame these prompts with a question by asking, Why might cause-effect relationships be a useful way to identify places where solutions could help improve our design problem?" (TE, page 262). The teacher is told to, "Look for answers such as these: Cause and effect means that a specific factor causes something else to happen or not happen. If we know what causes the problem, then it's easier to know how to fix it" (TE, page 262). Note that the idea of scale is not explicit in the student performance.
- *Systems can be designed to cause a desired effect.*

- Lesson 1: This element is claimed as being used. Students discuss design features (e.g., seat belts) that might help prevent or reduce negative consequences of traffic accidents.
- Lesson 3: This element is claimed as being used. Students fill out an Engineering Design Tracker, describing characteristics of different design solutions and their effects.
- Lesson 5: This element is claimed as being used. The teacher is told, "The progress tracker is a great opportunity to make consistent connections to CCC element 2.3, Systems can be designed to cause a desired effect, explicit to students. Consider taking time to have a discussion about this element and how it has been seen within the unit so far. Highlight the designs that students have added to their trackers and ask students to make connections between the systems and their specific desired effects" (TE, pages 110–111).
- Lesson 9: This element is claimed as being used. Students analyze data from different optimization attempts. "When the speed or mass of a vehicle changes or the size of a passenger changes, there is often a new combination of optimal characteristics for the seat belt and airbag. Just imagine how many different experiments engineers might need to carry out, even in a simulation, to find the best combinations across all these different cases. This is an area where computer modeling and artificial intelligence can help automate the process for carrying out such simulations and narrowing in on optimal designs" (TE, page 185).
- Lesson 10: This element is claimed as being used. The teacher is told to say, "The patterns we noticed in the way the body of the newer car responded to the collisions are features that engineers started designing into vehicles after 1952. The features they designed for were based on dividing the car body into three sections and designing those sections to have different structural characteristics" (TE, page 196).
- Lesson 11: This element is claimed as being used. Students are asked, "What design for crumple zone length do you think would increase safety? A longer crumple zone? A shorter crumple zone? Why?" (TE, page 217).
- Lesson 12: This element is claimed as being used. "Students have been engaging with CCC element 2.3, Systems can be designed to cause a desired effect, throughout this unit. Look for students to make this concept explicit in their explanations. If students are struggling, use probing questions such as: What is the desired effect when optimizing a design? How is this system being designed to cause a specific result or effect?" (TE, page 234).

- *Changes in systems may have various causes that may not have equal effects.*
  - Lesson 7: This element is not claimed but the teacher is told to tell it to the students. "Can we tell which is which? Not really, because correlation is not causation, and changes in systems might have various causes that might not have equal effects. But we can use these data to make an educated guess and investigate further. Scientists sometimes set up experiments or use simulations to test their ideas" (TE, page 156).
  - Lesson 12: This element is claimed as being used. Students discuss possible changes in speed limits and the various effects on society of these changes (e.g., TE, page 235).

Scale, Proportion, and Quantity

- *The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs.*
    - Lesson 14: This element is claimed as being used. The teacher is told to, "Point out that part of prioritizing [the design challenge] will be to think through the scale, proportion, and quantity at which the problem occurs. Say, If your group disagrees about which problem is more important or impactful, it may help to discuss the questions in a and b for a couple different problems. Some problems will clearly seem more widespread or more frequent, while others may seem more impactful because they're so specific--like a specific intersection near our school. It's up to you and your group how you consider scale, proportion, and quantity to help you define your design problem" (TE, page 258).
- *Some systems can only be studied indirectly as they are too small, too large, too fast, or too slow to observe directly.*
    - Lesson 8: This element is claimed as being used. The teacher is told, "This is an important moment where students are not just acknowledging that a phenomenon cannot be observed directly, but experiencing the struggle to do so. Highlight this thinking and support students in recognizing how the time scale is limiting direct observations. If students suggest using slow motion video, you can slow down the play speed of the video and show that the timing is still too fast to determine when events happen" (TE, page 163).
- *Algebraic thinking is used to examine scientific data and predict the effect of a change in one variable on another (e.g., linear growth vs. exponential growth).*
    - Lesson 3: This element is claimed as being used. Students create and analyze graphs to predict the change of variables on one another (e.g., distraction, speed). They therefore may implicitly use this element.
    - Lesson 4: This element is claimed as being used. Students create and analyze graphs and predict the change of one variable on another (e.g., the effect of changing mass on stopping time). They therefore may implicitly use this element.
    - Lesson 5: This element is claimed as being used. Students create and analyze graphs and predict the change of one variable on another. They therefore may implicitly use this element.

Systems and System Models

- *When investigating or describing a system, the boundaries and initial conditions of the system* need to be defined and their inputs and outputs analyzed and described using models.
    - Lesson 6: This element is claimed as being used. The teacher is told to, "Ask what would happen if we changed the boundary of our system to include both carts. Draw the two-cart system boundary. Listen for students to say that both forces would be acting on the two-cart system" (TE, page 134).
- *Models can be used to predict the behavior of a system, but these predictions have limited precision and reliability due to the assumptions and approximations inherent in models.*

- Lesson 14: This element is claimed as being used. Students are told that they'll "apply the physics models you develop to help you present your solution." The teacher is told to say, "How might we come up with valid assumptions and approximations for our models? How can we tell if an approximated value in our model is valid or reasonable?... A value is unreasonable if it doesn't make any sense. Reasonable values aren't too big or too small, but they're not necessarily exactly right either. 'Pretty close' is usually good enough when you're approximating." (TE, pages 266–267). The teacher is told, "Say, Many of us are going to have a hard time approximating anything close to exact values, but this is true for real science work a lot of the time. Modeling can be really useful if the values are even sort of close, especially if we're able to see a useful difference between two values. In this case, it helps us understand part of why airbags are safer to see these two force values next to each other--one is obviously smaller and safer than the other" (TE, page 267).

Structure and Function

- *The functions and properties of natural and designed objects and systems can be inferred from their overall structure, the way their components are shaped and used, and the molecular substructures of its various materials.*
  - Lesson 10: This element is claimed as being used. Students design crumple zones on vehicles and are told to analyze the designs that met criteria for success. They are asked, "What about its structure enabled it to do this?" (Design Solution Comparison handout, page 2). However, molecular substructures are not discussed.
  - Lesson 11: This element is not claimed but is alluded to. "Use the M-E-F questions to scaffold this discussion. Begin with the Matter perspective: 'What changes do we observe in the matter during a collision? What particle level changes are happening in the matter?' Guide students to make connections to vehicle crumple zones. Suggested guiding prompts are: 'How does changing crumple zone length change the matter? How does changing crumple zone rigidity change the matter?'" (TE, page 218).
- *Investigating or designing new systems or structures requires a detailed examination of the properties of different materials, the structures of different components, and connections of components to reveal its function and/or solve a problem.*
  - Lesson 9: This element is not claimed but is listed in a teacher sidebar: "This is a moment you can explicitly connect to this crosscutting concept… To do this, ask students the following: What properties of the system they considered so far? What additional properties of other other[sic] parts of the vehicle system would they want in a simulation as an engineer working on designing safer vehicles?" (TE, page 183). Based on the guiding questions, it is likely that the element listed is a typo, and that the other **Structure and Function** CCC element was intended here.

Stability and Change

- *Change and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible.*

- Lesson 2: This element is claimed as being used. The teacher is told, "In this lesson, students 'invent' position versus time graphs to answer their questions, motivating a quantification of a rate of change (speed) for the first time in the unit. Here, the time over which they think about rates of change is relatively long (several seconds). Later in the unit, they will model changes in a similar way but over very short periods of time (less than a second) to better understand the forces involved in the collision itself" (TE, page 61). Students model rates of change of speed during the lesson, but do not discuss irreversibility.

Suggestions for Improvement

General

- Consider ensuring a close match between claims and evidence of student use of the elements, either by adjusting the claims or supporting students to more fully use the elements.
- Consider supporting students to use more of the claimed elements in service of sense-making.

Crosscutting Concepts

- Consider more often making CCC lenses explicit for students and supporting them to develop deeper understanding in these ideas such that they might be able to use them again in the future.

I.C. INTEGRATING THE THREE DIMENSIONS

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

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

The reviewers found extensive evidence that student performances integrate elements of the three dimensions in service of figuring out phenomena and designing solutions to problems. Students have many opportunities in the unit to use multiple dimensions together to help make sense of phenomena and problems.

Each lesson lists three-dimensional goals for the student, such as, "Ask questions about patterns in vehicle safety over time that we have identified using empirical data and about factors that might have affected them (such as driver distraction, safety features, vehicle mass, and vehicle velocity). (SEP: 1.1; CCC: 1.5; DCI: PS2.A, ETS1.A.2)." These goals are listed as "what students will do" rather than "what students will learn."

Students are supported to engage in several three-dimensional learning experiences during the unit. For example:

- Lesson 9: Students analyze data from different optimization attempts. "When the speed or mass of a vehicle changes or the size of a passenger changes, there is often a new combination of optimal characteristics for the seat belt and airbag. Just imagine how many different experiments engineers might need to carry out, even in a simulation, to find the best combinations across all these different cases. This is an area where computer modeling and artificial intelligence can help automate the process for carrying out such simulations and narrowing in on optimal designs" (TE, page 185). Students integrate the following elements:
  - SEP: *Analyze data to identify design features or characteristics of the components of a proposed process or system to optimize it relative to criteria for success.*
  - CCC: *Systems can be designed to cause a desired effect.*
  - DCI: *Both physical models and computers can be used in various ways to aid in the engineering design process. Computers are useful for a variety of purposes, such as running simulations to test different ways of solving a problem or to see which one is most efficient or economical; and in making a persuasive presentation to a client about how a given design will meet his or her needs.*
- Lesson 10: Students design crumple zones on vehicles and are told to analyze the designs that met criteria for success. They are asked, "What about its structure enabled it to do this?" (Design Solution Comparison handout, page 2). Students integrate the following elements:
  - SEP: *Design, evaluate, and/or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.*
  - CCC: *The functions and properties of natural and designed objects and systems can be inferred from their overall structure, the way their components are shaped and used, ~~and the molecular substructures of its various materials~~.*
  - DCI: *Newton's second law accurately predicts changes in the motion of macroscopic objects.*
- Lesson 14: The teacher is told to. "Point out that part of prioritizing [the design challenge] will be to think through the scale, proportion, and quantity at which the problem occurs. Say, If your group disagrees about which problem is more important or impactful, it may help to discuss the questions in a and b for a couple different problems. Some problems will clearly seem more widespread or more frequent, while others may seem more impactful because they're so specific--like a specific intersection near our school. It's up to you and your group how you consider scale, proportion, and quantity to help you define your design problem" (TE, page 258). Students integrate the following elements:
  - SEP: *Define a design problem that involves the development of a process or system with interacting components and criteria and constraints that may include social, technical, and/or environmental considerations.*
  - CCC: *The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs.*

- DCI: *When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts.*

Suggestions for Improvement

Applying suggestions under Criterion I.B would help strengthen the evidence for this criterion.

I.D. UNIT COHERENCE

Lessons fit together to target a set of performance expectations.

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

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

The reviewers found extensive evidence that lessons fit together coherently to target a set of Performance Expectations (PEs). Students are supported to build toward most of the targeted PEs and are supported to see how lessons fit together coherently.

Connections are made within and between lessons to help students see logical sequencing. For example:

- Lesson 2: At the beginning of day 2 of the lesson, a suggested prompt is given that references what students were doing the previous day. "What insights did looking at distances give us into the system during our investigations of the videos?" (TE, page 60).
- Lesson 3: At the beginning of the lesson, the teacher is told to say, "'Many of you mentioned in your exit tickets [from Lesson 2] that we need to know how fast they were going because this will affect how quickly a driver can slow down.' Alternatively, before class you can choose a student who talked about speed in their exit ticket and ask them to share their response during class. Then ask, 'Who else thinks that the speed that the driver is going before the obstacle appears will make a difference?' Ask for a show of hands" (TE, page 73).
- Lesson 3: "The handout provides the information that the average reaction time is 0.75 seconds and assumes that a distracted driver will have a reaction time twice that long (1.5 seconds).

Point out to students that this is based on the information from the Distracted Driving Research we read for Lesson 2" (TE, page 75).

- Lesson 3: At the beginning of day 2 of the lesson, the teacher is told to, "Have students pull out their home learning notes [homework from day 1]. Present slide H. Move through the prompts as a class. Encourage students to refer to Calculating Reaction Distances [handout from day 1] in their notebook to support their claims related to the third question, as suggested in the fourth prompt in the table below" (TE, page 77).
- Lesson 3: An Engineering Progress Tracker is introduced (TE, page 78). Students come back to it in Lesson 5: "Remind them that this is a living document and that if they have thought of other solutions related to prior lessons, these can also be added at this time" (TE, page 110), in Lesson 9 (TE, page 187), and in Lesson 11 (TE, page 220).
- Lesson 3: At the end of the lesson, the Exit Ticket sets up the focus of Lesson 4. "We figured out that driving is more dangerous when the car is moving faster because it will travel farther during the time it takes the driver to react. So, the driver will brake later, making it harder to avoid an accident. But could the speed also affect what happens after they hit the brakes, changing the braking time and the braking distance?" (TE, page 79). Lesson 4 begins by telling the teacher, "Remind students that last class, they completed an exit ticket about their ideas of how the speed of a car would affect the distance and time it takes to stop. Ask them to turn and talk about their ideas using the slide's prompts: How did you think speed would affect the distance and time it takes to stop after the driver hits the brakes? What other factors might affect how long it takes to stop after the driver hits the brakes?" (TE, page 87).
- Lesson 5: The lesson begins by asking students these questions: "What did we figure out last class? How does this new information relate to the graphs we had drawn in our notebooks in Lesson 3? What clues have we been using from these graphs to make sense of the motion they are representing?" (Lesson 5, Slide A).
- Lesson 6: The lesson begins by reminding students about what they did in Lesson 1. "We have looked at how to prevent a collision and at factors that affect the ability to do so. But sometimes a collision still occurs. What factors did we identify in our initial consensus model that we said might affect the severity of the outcome of a collision? Cue students to refer to the Initial Consensus Model poster from Lesson 1 (displayed in the room) to individually review the factors in the model. Have a few students share what they see, then suggest that we start looking into the various factors" (TE, page 122). Then when students encounter a new question, the teacher is told to, "Show students the newly added Force and Motion Relationships poster that shows the equations established in Lessons 4 and 5" (TE, page 122).
- Lesson 6: In the beginning of Day 3, the teacher is told to, "Write this equation from the end of last class on the board: $m * \Delta v + m * \Delta v = 0$ Ask students to summarize what we did last time to test this equation" (TE, page 137).
- Lesson 7: Students connect their learning to that of prior lessons. "Make sure the Puzzling Patterns poster created in Lesson 1 is visible. Ask students to pair up and make sure each pair has a whiteboard. Present slide D. Direct each pair to choose one of the factors on the slide that we have investigated so far" (TE, page 154).

- Lesson 8: At the beginning of the lesson, the teacher is told to say, "Last class we added questions to our DQB. A lot of our new questions are about safety features that we noticed in the simulation. Then Say, The simulation is a really useful tool. But before we use it again, let's actually look at a collision to try and determine what the safety features might be doing and when they might be acting to keep people safer" (TE, page 163).
- Lesson 8: At the end of the lesson, students are asked the following question as an Exit Ticket. "Considering the evidence we assembled in our timelines and our mathematical relationships, what other variables might help us understand how how[sic] safety features affect risk to occupants in a collision?" (TE, page 172). Then at the beginning of Lesson 9, students are asked a nearly identical question without referring to their thoughts or discussion from the end of the prior lesson. "Considering the evidence we assembled in our timelines, what other variables might help us understand how safety features affect safety in a collision?" (TE, page 178). This is likely to be seen as a repeat and therefore be confusing to students. In contrast, the end of Lesson 9 gives students a question to think about and they are told they will share their ideas next time. Then the beginning of Lesson 10 refers to students' ideas from that question and the teacher is told to say, "Last time, after we explained seat belts and airbags, we started brainstorming ways to alter the design of a vehicle body to make it safer" (TE, page 195) before asking students to share out their ideas generated at the end of Lesson 9.
- Lesson 10: At the beginning of Day 2, the teacher is supported to help students connect back to Day 1. "Discuss the design criteria from last time. Students should mention that we designed various crumple zones with the goal of reducing the magnitude of the peak force in a collision by increasing the time of the collision" (TE, page 200).
- Lesson 11: At the beginning of Day 2, the slide reminds students of the prior class period. "Last class, we looked at how crumple zone rigidity affects the outcomes of a collision. What design for crumple zone rigidity did we figure out increases safety?" (slide L). The teacher is told to, "Have the students discuss the answer to the prompts to review from last class" (TE, page 217).
- Lesson 14: The teacher is told to say, "Last time, we identified some problems that still exist in our communities. Today we'll get to think more deeply about how to solve those problems. Look back at question 3 in your copy of the Design Challenge Organizer, and let's think more about how we can use our physics knowledge to help solve these problems" (TE, page 261).

The PEs below are claimed as being built toward in the unit (TE, page 1). Students are supported to adequately develop most, but not all, of the underlying elements of the three dimensions in these PEs (see evidence in Criterion I.B).

- **HS-PS2-1** *Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.*
- **HS-PS2-2** *Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system.*
- **HS-PS2-3** *Apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.*

- **HS-ETS1-3** *Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.*

Suggestions for Improvement

None

I.E. MULTIPLE SCIENCE DOMAINS

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

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

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

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

The reviewers found extensive evidence that links are made across science domains when appropriate. The phenomena and problems in the unit are related to only one scientific domain. Some references are made to students' prior learning in other domains and one explicit reference is made to help students see the utility of CCCs across science domains.

References are made to students' prior learning in the Earth and life sciences. For example:

- Lesson 10: Students are told to refer to the M-E-F triangle poster and are asked, "How is designing a car to crumple related to what we know about forces and elastic limits of a material?" and the teacher is told to, "Listen for students to make connections back to the Earth's Interior Unit" (TE, page 196).
- Lesson 13: The teacher is told, "These tradeoffs and considerations provide a feedback loop that is present in almost all areas of engineering design. Help students see that these tradefoffs[sic] are not just important in physics, but across disciplines. In order to make decisions about cars, we need to think about physics ideas, but we also need to think about human biology, and the chemical structure of materials that make up the car" (TE, page 246).
- Lesson 13: An optional suggestion for the teacher says, "If you choose to have students look at tradeoffs due to payload weight limits, consider making an explicit connection to HS-ESS3-6: Use a computational representation to illustrate the relationships among Earth systems and how

those relationships are being modified due to human activity. Help students see that more massive vehicles affect Earth's systems, and how that will affect humans, plants, and animals over time" (TE, page 246). As this is framed as an optional activity, it is less likely that it will be used in all classrooms.

The teacher is guided to help students consider using a CCC element explicitly across scientific domains. In Lesson 6, the teacher says, "In our Earth's Interior Unit, we discovered that if we look at what's happening in a system at a much smaller or much larger scale than we can directly observe, it helps us see different patterns, which then helps us explain cause-and-effect relationships for what we observed" (TE, page 123). The teacher is told, "Explicitly referencing work in the prior unit related to switching scales (down to the microscopic and up to all of Earth) can help students recognize the application of this crosscutting concept (CCC) across various domains….This will help them reuse this idea more fluently to make sense of subsequent phenomena they will encounter in other science classes" (TE, page 123).

Suggestions for Improvement

Consider supporting students to more often connect their ideas related to CCCs across science domains.

I.F. MATH AND ELA

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

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

The reviewers found extensive evidence that the materials provide grade-appropriate connections to the Common Core State Standards (CCSS) in mathematics and English language arts (ELA). The CCSS are listed in the lessons where they are used, and students are provided with opportunities to see how their mathematics and literacy activities support their science sense-making.

Students use mathematics throughout the unit, and explicit connections are made to mathematics standards. Related evidence includes:

- Unit Overview: "Making mathematical models is a Standard for Mathematical Practice, and specific modeling standards appear throughout the high school standards. This unit does not assume students are fluent with the mathematical practices listed below, rather students develop these practices as part of the sense-making. Thus, these standards are not so much prerequisites, as co-requisites. If students are simultaneously developing the skills and vocabulary in math class, you can help by making explicit connections to the mathematical standards below" (TE, page 22).

- A table is provided with "co-requisite concepts from students' math classes," including CCSS codes, standards language, and relevant lesson numbers from the unit. The end of each lesson also lists the related CCSS used in the lesson. For example, in Lesson 2, the teacher is told, "This is the CCMS-related idea that is used to support sensemaking in this lesson: The Number System. CCSS.MATH.CONTENT.HS.A-CED.2 Creating Equations: Create equations that describe numbers or relationships. Create equations in two or more variables to represent relationships between quantities; graph equations on coordinate axes with labels and scales. In this lesson, students graph position on a number line and then graph time on a number line. They decide that in order to get a sense of the relationship between the two quantities, they will graph them together with those lines as axes" (TE, page 67).
- Lesson 2: "Say, In math terms, we call this the slope of the line, or how much the y-axis changes every time the x-axis changes. Label the fraction as 'slope of the line over interval ΔX.' Then say, Let's take a closer look at what this slope is telling us" (TE, page 63).
- Lesson 2: In the formative assessment guidance, the teacher is told to, "consider reaching out to a math colleague to find out what students are expected to know about change over time in their math classes" (TE, page 64).
- Lesson 5: In an Exit Ticket, students are asked, "What are some ways in which you used mathematics in this lesson that you think could be helpful tools for explaining or predicting the motion of other objects in the world?" (Electronic Exit Ticket Key, page 3).
- Lesson 6: The teacher is told, "Students interpret the structure of an equation, identify ways to rewrite it, and rearrange it to highlight a quantity of interest. Talk with your students' math teachers to identify students' prior experiences with these related ideas from the Common Core State Standards (CCSS) for mathematics, further detailed at the end of this Teacher Guide" (TE, page 120).
- Lesson 6: "Students have been reasoning about area constructs as conserved quantities in Common Core mathematics throughout much of grade school before working with symbolic representations or bivariate graphs in later grades. These geometric representations may therefore draw on additional intuitions about why a product of two variables (named as momentum later in this lesson) would either be conserved or transferred in a particular process or event (like a collision)" (TE, page 138).
- Lesson 6: "What shapes have we used in math class to represent a quantity that is the product of two variables (a * b)? After a minute, have a few students report out. They will suggest a rectangle. Ask, Can someone tell us how the product of two variables can be represented by a rectangle? Listen for ideas about how a rectangle has a base and a height and their product represents its area. If this doesn't come out or needs clarification, say something like, Another way to visualize the product of two values or variables is using the area of a rectangle, where the rectangle's base and height represent the values or variables" (TE, page 138).

Students read, write, and speak throughout the unit, and explicit connections are made to literacy standards. Related evidence includes:

- Lesson 2: Students read an informational text.
- Lesson 8: At the end of the lesson, the teacher is told that students made connections to ELA using the following CCSS-ELA: "CCSS.ELA-LITERACY.RI.11-12.7 Integrate and evaluate multiple sources of information presented in different media or formats (e.g., visually, quantitatively) as well as in words in order to address a question or solve a problem. Students use a video, animation, and read two data tables (information presented quantitatively) to construct a timeline of events. The sources of information provided in different formats have to be integrated in order to address the question of what features of the vehicle system interact with the crash test dummy at different times, specifically airbag deployment and collision with the crash test dummy, and how a collision with safety features is different from a collision without safety features" (TE, page 172).
- Lesson 9: Students read a brief informational text. They discuss it as a class and the teacher is told to say, "In summary we learned that the greater the force of contact on a driver, the greater the risk of injury" (TE, page 78), supporting students to understand the utility of reading for their sense-making.
- Lesson 10: "These are the CCSS for ELA/Literacy-related ideas that are used to support sensemaking in this lesson: CCSS.ELA-LITERACY.SL.11-12.1 Initiate and participate effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on grades 11-12 topics, texts, and issues, building on others' ideas and expressing their own clearly and persuasively. This standard shows up because students work in partners to design and discuss various crumple zones. They then discuss in partners and later as a class the results of the data collected from the various collisions and their ideas around the relationship between length, rigidity, force, and time" (TE, page 206).
- Lesson 12: "As a class, read both arguments together. As the arguments are being read aloud, ask students to annotate any claims, science ideas, and data or evidence that the authors used in their arguments" (TE, page 227).

Suggestions for Improvement

None

Collisions and Momentum

EQuIP RUBRIC FOR SCIENCE EVALUATION

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

CATEGORY II

NGSS INSTRUCTIONAL SUPPORTS

- II.A. RELEVANCE AND AUTHENTICITY
- II.B. STUDENT IDEAS
- II.C. BUILDING PROGRESSIONS
- II.D. SCIENTIFIC ACCURACY
- II.E. DIFFERENTIATED INSTRUCTION
- II.F. TEACHER SUPPORT FOR UNIT COHERENCE
- II.G. SCAFFOLDED DIFFERENTIATION OVER TIME

II.A. RELEVANCE AND AUTHENTICITY

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

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

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

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

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

The reviewers found extensive evidence that the materials engage students in authentic and meaningful scenarios that reflect the real world. Multiple real-world phenomena and problems are used that help make instruction meaningful to students, and the teacher is supported to help students connect instruction to their lives and communities.

The phenomena and problems are relevant to students, and students experience them as directly as possible. For example:

- Unit Overview: The selection of the anchoring phenomenon for the unit included gathering evidence about student interests. “The vehicle collisions anchoring phenomenon was chosen from a group of phenomena aligned with the target performance expectations based on the results of a survey administered to almost 1000 students from across the country, and in consultation with external advisory panels that include teachers, subject matter experts, and state science administrators” (TE, page 12).
- Lesson 1: Students are supported to see why the anchoring problem is important. “Encourage students to think about not just the safety of the driver and passengers but also the safety of pedestrians, trees, and animals. Students might also think more broadly about safety, considering the impact of larger vehicles on emissions, for example, and the resulting impact on lands and waters” (TE, page 35).
- Throughout the unit, there are frequent examples of real-world applications of physics concepts. For example, Lesson 3 broaches car speed and Lessons 4 and 5 discuss braking distance. These concepts are presented in the context of vehicular safety, which is a real-world concern.
- Lesson 2: Students watch videos of the investigative phenomenon (a car with a distracted driver versus a non-distracted driver) (TE, page 54). In addition, this phenomenon is likely very relevant to many teenagers.

- Lesson 2: An optional extension activity gives students an opportunity to experience a phenomenon firsthand. "How could we test to see whether being distracted impacts our reaction time? Have students use https://www.justpark.com/creative/reaction-time-test/ to test their reaction times normally and when another student is distracting them; they will notice that being distracted does make a difference. You can also give them something to unwrap, like a book wrapped in paper, to simulate someone who is trying to eat and drive" (TE, page 60).
- Lesson 3: "In the Calculating Reaction Distances handout, speed is converted from m/s to mph before the data are graphed. The purpose of this conversion is to aid students in conceptually understanding how distracted driving impacts reaction distance, given that most speedometers on vehicles have the unit of mph. If it is more important for you that your students use metric units, feel free to keep data in m/s. However, if students graph in m/s it may be difficult for them to make connections to their real-world understanding" (TE, page 75).
- Lesson 5: "Say, 'OK, we've learned a new term, and we can now explain what the slope means. But why do we even care about this slope, and what else do we care about?' Students should respond that the slope is about applying braking force to stop in time, and the more braking force is applied for a given mass at a given speed, the faster we can slow down" (TE, page 105).
- Lesson 8: "Say, 'The forces of contact between the front of the vehicle and the person accounts for most injuries. We need to think about how we minimize that Force'… Say, 'It's important to create mathematical models so we can consider ways to prevent injury'" (TE, page 179).
- Lesson 10: Students watch a video of a collision (TE, page 195).
- Lesson 12: Students are asked, "What constraints and expectations in real life might affect how we should apply science ideas to make vehicles safer?" The teacher is told, "After students turn and talk, ask a few pairs to share their ideas. Highlight ideas that are connected to societal norms and impacts on the environment, animals, or people other than drivers" (TE, page 235).

The teacher is supported to anticipate sensitive issues that might arise. For example:

- Unit Overview: "Make space for students to process and validate their feelings and reactions. To help foster a safe environment during this unit, consider revisiting the Community Agreements as necessary to help guide respectful engagement around emotionally sensitive topics. The culminating project task in Lesson 14 was designed to give students and educators the chance to engage in 'transformative social and emotional learning.' Transformative SEL describes a process 'whereby young people and adults build strong, respectful, and lasting relationships that facilitate co-learning to critically examine root causes of inequity and develop collaborative solutions that lead to personal, community, and societal well-being.' Rather than provide students with a fictional scenario, the task is designed to support students in taking agency and providing them with the tools to speak up in their local and global community in hopes of a better future for everyone….We recognize that vehicle collisions can be traumatic, and recalling past experiences or learning about others' experiences can be triggering, so this unit was designed to support students and teachers using a trauma-informed approach….Particularly, when engaging with a trauma-related topic such as vehicle collisions, it is important not to ask students to share their personal experiences unless they volunteer to do so… Be aware that students who are struggling [with the emotional topic] may demonstrate a variety of behaviors including but not limited to fidgeting, withdrawal, disruption or distraction, rapid breathing, holding their breath, and change in body language or tonation [sic]. If you notice a student might be struggling, check in with the student. This may look like sharing what you are observing and/or asking if the student needs support. It is also important to be aware of your own past experiences and responses to this unit. Be mindful of your own emotions and reactions, and take a break or reach out to others for support, if needed. As needed, you can also utilize calming techniques (e.g. deep breathing) with your students as a whole group, individually to support yourself, and/or have emotionally-impacted[sic] students utilize these techniques at their desk." (TE, pages 24–25).

- Unit Overview: "Reach out to students' support system at home before the unit using the Pre-Unit Letter Home. This letter is a way to communicate with trusted adults and make them aware of the content of the unit. The letter also provides an opportunity for trusted adults to share important context with you about students' experiences and background that might be relevant" (TE, page 25).
- Lesson 1: "Please see the unit front matter, the teacher reference (Trauma-Informed SEL Supports) associated with this lesson, the Student Mindfulness Resource, and the callouts in the Teacher Guide for guidance around how to support social and emotional needs as you move through this unit. Refrain from asking students to share their personal experiences unless they volunteer to do so… At the front of the slideshow bundled with this lesson is a teacher-facing slide meant to alert you to sensitive content. When you see this slide in subsequent lessons, know that the lesson deals with the physics of crashes and fatalities and that some students may require additional support. After this slide is a student-facing slide titled 'Student Content Advisory'. Note that this slide is designed to be shown to students in advance of Lesson 1" (TE, page 33).
- Lesson 3: "In the reading, students learn about design solutions that affect some people more than others because of their race or socioeconomic status. Learning about solutions that feel unfair can be upsetting. Guide students toward the resources provided in Lesson 1 to ground themselves if they are upset. Make space for ideas about what is fair or right as they come up rather than suggesting that they don't belong in science class, and acknowledge that many societal problems can't be solved with physics and engineering" (TE, page 79).
- Lesson 12: The teacher is told, "Engaging in argumentation about speed limits may cause some individuals to have a strong reaction related to past trauma. It is important to acknowledge this possibility as a class and remember to be respectful when disagreeing. Remind students that when we engage in argumentation we are evaluating ideas, not the people expressing those ideas" (TE, page 228).
- Lesson 13: "If you choose the public transit arguments, students might bring up ideas about ability and access. Be sure to support students in identifying and examining their biases about ability. Tell students that when we believe or express that having a disability is worse than not having a disability, this is called ableism. It is important to note that this does not include things such as a disabled person talking about struggles they have because of their disability or complaining about pain associated with their disability. You can connect the discussion to how students understand other types of discrimination" (TE, page 244).

Instruction is connected to students' lives and communities. For example:

- Unit Overview: One of the suggestions "to extend or enhance the unit" is "Lesson 14: Spend more time having students research and develop their community design solutions" (TE, page 22).
- Lesson 1: "After students have had a chance to look at the handout, ask what they, their caregivers, or people in their community have done in the past to ground themselves and stay mindful when a topic is upsetting. They can jot down their ideas on the last page of the handout, under prompt 1. They may talk about meditation, meals with family, recreational activities, breathing exercises, spending time with pets, and so forth. Accept all ideas and consider making a public record of some of these ideas at the front of the classroom" (TE, page 36).
- Lesson 2: Students are asked, "What are some other, maybe more common distractions?" The teacher is told, "The goal at this moment is to support engagement by encouraging students to draw connections to everyday distractions in their own lives" (TE, page 53).
- Lesson 3: "Distribute the Speed Home Learning handout. Explain that students will ask a family, friend, or community member these questions: 1. What are the speed limits in different parts of our community? 2. Have they changed? How? Why do you think they were changed? 3. Should they be changed? Why or why not? If so, how? Instruct students to keep track of what they learn on the bottom of the handout to guide our discussion next time. You will not need to collect the handout" (TE, page 77). This home learning is debriefed the next day and used to help brainstorm engineering design solutions, positioning ideas from students' families and community members as being important in the classroom.
- Lesson 12: The teacher is told to say, "'Back in Lesson 3, we asked our families, friends, or community members about speed limits in our community. Use the prompts on the slide to have students turn and talk: Take out your Speed Home Learning handout from Lesson 3. Review your notes with a partner.' After a minute or so, have a couple pairs share ideas that they had about speed limits from their Speed Home Learning handout from Lesson 3" (TE, page 227).
- Lesson 12: In the "Science Ideas Argument Comparison" handout, students are asked, "Why is understanding the science behind speed limits important for members of our community?" (page 3).
- Lesson 12: Students complete a "Societal Impacts Argument Comparison" sheet and are asked, "What constraints might exist in our community that would make it hard to accept this argument? How would accepting this argument affect you and others around you, both human and not human? For example, is one group's safety being prioritized, or are there others being put more at risk if this argument is accepted?" (TE, page 235).
- Lesson 12: In the Exit Ticket, students are asked, "How might comparing two arguments, like we did in this lesson, help people in your community make decisions about something other than vehicle safety?"
- Lesson 13: "If driving is so risky, why do we even drive or ride in vehicles at all? What kinds of decisions do people in our community make related to cars and driving that could affect driving risk?" (TE, page 243).

- Lesson 13: "Explain that, like in the last lesson, the class is going to use the Argument Comparison Tool to dig into an issue relevant to our community involving risks for ourselves and others as we use our roads. Introduce which topic you have prepared materials for… Options of argument sets for use with the Argument Comparison Tool: Should we allow lift kits? (See Lift Kit Argument.) Should we increase truck payloads? (See Weight Limit Argument.) Should we prioritize public transit over personal vehicles? (See Public Transportation Argument.)" (TE, page 244).
- Lesson 13: "Explain that students will have the opportunity to interview a trusted member of their home or local community and gain perspectives about something in our community that might put some people more at risk than others because of cars or driving. Introduce the Community Interview here and go over the document with students" (TE, page 248).
- Lesson 14: "What ideas do you have about what we might do as drivers, passengers, and residents that could make driving safer for people in our community by raising awareness, changing driver behavior, or making our driving environment safer?" (TE, page 262).
- Lesson 15: At the very end of the unit, students are asked, "Has something you learned about during this unit changed the way you will make decisions as a driver, a passenger, a community member, or a pedestrian? If so, how?" (TE, page 277).

Suggestions for Improvement

Although connections to students' lives and communities are strong in the beginning and end of this unit, they are not present in the middle of the unit. Consider adding supports for the teacher to connect to students' lives or ways of knowing in additional lessons.

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. The teacher is frequently supported to elicit student ideas, justification, and reflection. In addition, there are many opportunities for students to get feedback on their thinking from both students and the teacher.

The materials support teachers to elicit and honor student ideas. Related evidence includes:

- Lesson 1: "Consider agreeing on a set of nonverbal signals to use as a class (e.g., head nods, thumbs up or down, ASL signs) for signaling nonverbal agreement, disagreement, and wondering or questioning as a way to ensure equitable participation by giving students additional modalities with which to express themselves" (TE, page 35).
- Lesson 1: "Have students assemble their chairs in a circle. Ask each group to spend no more than 1 minute sharing out the major patterns they noticed in the data. Record ideas on chart paper for a public record of 'Puzzling Patterns' we would like to be able to explain" (TE, page 38).
- Lesson 1: The teacher is told to say, "My role in this discussion is to press for evidence, regardless of whether the ideas are right or wrong. So, you might hear me ask, 'Where did you see that in the data?' That does not mean you're wrong! It's my job to push us as a class to articulate the evidence we have to support the patterns we noticed" (TE, page 40).
- Lesson 1: "As students share, areas of disagreement or uncertainty may emerge. If this happens, honor those student ideas by revoicing and/or recording them and create a convention, such as a question mark, to show that the class is uncertain" (TE, page 44).
- Lesson 3: "If students are thinking that the speed might change in a variable way (and they draw something nonlinear), ask them to voice their reasoning but do not shut them down. You can use multiple colors to illustrate different ideas… Give students a minute to sketch their predictions and a minute to share their ideas with their group or a partner. Then ask for a volunteer to share out. Ask the class if they drew something similar or different and elicit a couple of ideas" (TE, page 74).
- Lesson 5: "If controversy arises about the direction of the slope, ask students to share their thinking with another partner pair before sharing their ideas with the class" (TE, page 104).
- Lesson 7: "Elicit ideas. Listen for students to turn to examples to explain their thinking; for example, if there are more-massive cars over time and driving is more dangerous over time, that suggests that the more-massive cars might be causing the danger" (TE, page 154).
- Lesson 8: "Stir up controversy around when each safety feature became engaged with students by asking questions like: '_____ thought that the airbag deployed first. Are we sure about that? Does anybody disagree? How can we tell if that really was at the same time, or if one was slightly beforehand? You look like you might disagree _______, what are you thinking?'" (TE, page 164).
- Lesson 8: "After a minute or so, have a few pairs share their predictions. Accept all answers and probe reasoning. Highlight ideas on how the vehicle timing might be the same or different. Then say, Let's check our predictions using the animation" (TE, page 168).
- Lesson 10: The teacher is told, "Your role in this discussion is to invite them to share conclusions and claims and push them to support these with evidence. Here are several examples of helpful prompts during this kind of discussion: What can we conclude? How did you arrive at that conclusion? What's your evidence?" (TE, page 201).
- Lesson 11: "During this work, the class resolves disagreements where possible. Your role is to help students see where they agree and where they still disagree. Helpful prompts include: What ideas are we in agreement about? Would anyone have put this point a different way?

Who feels like their idea is not quite represented here? Are there still places where we disagree? Can we clarify these?" (TE, pages 218–219).

- Lesson 12: Students are asked to, "Compare your evaluations of the two arguments. Which argument or design has the most merit from a science perspective, and why?" (TE, page 230).
- Lesson 12: "Students work individually first so that all students are given the opportunity to synthesize the evidence and formulate their ideas. This part is important so that all students are prepared to defend their ideas, evaluate one another's ideas, and consider their ideas in the context of others' ideas" (TE, page 232).

Students are supported to reflect on their changing thinking over time. For example:

- Lesson 6: Students make predictions and then study graphs of data related to their predictions. They are asked, "What was surprising? What was not?" (TE, page 127). Sample student responses include, "The force got much bigger than we predicted" (TE, page 127).
- Lesson 8: "Remind students to record and/or modify our class thinking about this timeline in their science notebooks as it is developed by the class" (TE, page 164).
- Lesson 9: Students compare the results of a simulation to their predictions. The teacher is told to say, "Let's take a moment and reflect on what we learned today" (TE, page 181).
- Lesson 10: After viewing a simulation, students are asked, "How do the initial survivability results compare to your predictions?" (TE, page 205).
- Lesson 11: Students draw predictions and then compare results to their predictions (e.g., slide F).
- Lesson 12: "Direct students' attention to the Initial Consensus Model poster from Lesson 1. Give them a couple of minutes to individually consider the model and complete the sentence stem (mentally or written): I used to think ______, but now I know _____. Then have them turn and talk with a partner to share their reflections" (TE, page 233).
- Lesson 13: "Have them document one way in which their thinking was pushed today and who helped them see or consider a different perspective to the argument by responding to the three questions on the slide: Who was it? What was it? How did it help you figure something out?" (TE, page 248).

Students receive feedback from peers and the teacher and have opportunities to reflect on and react to the feedback. Related evidence includes:

- Lesson 3: "Move around the classroom while students are working. You can also collect students' handouts at the end of class to give more-focused feedback… Flag incorrect solutions and graphing errors but focus feedback on questions 4 and 5 on the handout" (TE, page 76).
- Lesson 3: "Provide written feedback to help students set expectations for what the tracker entries should look like. In this feedback, encourage students to expand on their ideas by asking questions like Why? and How?" (TE, page 79).
- Lesson 12: "When reviewing individual work after class, provide feedback on the level of detail and clarity. On Day 3 students will be completing Societal-Impacts Argument Comparison, which is very similar in structure to Science-Ideas Argument Comparison. They also complete the same

table for different arguments in the next lesson. Providing written guidance now can help students understand the expectations as they move forward" (TE, page 231).

- Lesson 12: "Say, In order to strengthen our shared understanding and our explanations, we are going to share our explanations and give and receive feedback from each other. Then you will have an opportunity to revise your explanation… Introduce and explain the TAG Feedback protocol: Tell something you like, Ask a question, Give a suggestion…. Ask students to use the feedback to revise their explanation" (TE, page 234). Note that students are sharing their design solutions rather than explanations so the instructions may be confusing for students who have learned about the SEP **Constructing Explanations** in the past.
- Lesson 14: "Tell students that they will have a 'lightning round' of peer feedback to share their work and guide their thinking going forward. Explain how to give TAG feedback: Tell something you like, Ask a question, Give a suggestion" (TE, page 259).
- Lesson 14: The teacher is told, "Say, Be ready to hand in one group member's copy of the Design Challenge Organizer at the end of class. I'll read through your progress on question 3 and give you my thoughts. If I have any resources or evidence that could be useful to you in coming up with solutions, I'll suggest those to you in our next class" (TE, page 260). The next day, the teacher is told, "Give students 4 minutes to review feedback in groups and to locate or browse through any resources you have provided" (TE, page 261).
- Lesson 14: After students brainstorm initial solutions to their problems, they are told, "Stand up with your Design Challenge Organizer, find a partner not in your project group. Share your work in question 5 and get TAG feedback" (slide N). Students are then told, "When you're giving feedback, try to focus your questions on criteria or trade-offs. When you're giving suggestions, focus on specific physics models" (TE, page 264).
- Lesson 14: As students work on their final presentations in teams, the teacher is told, "Encourage groups to assign one student from their group to pair up with a student from another group, exchange TAG feedback, and report this feedback back to their group. Say, As you work it will be useful to get quick feedback from other groups thinking about different problems. Send one representative from your group to pair up with someone from another group, and exchange TAG feedback about a specific section of your work. Tell something you like, Ask a question, Give a suggestion for improvement" (TE, page 269).
- Lesson 14: "Consider giving written feedback outside class on their work so far and assigning the rest of the Final Product for home learning or providing students with an extra class day" (TE, page 269).

Suggestions for Improvement

None

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. However, prior levels of proficiency expected of students are not described for individual elements of the three dimensions, and learning progressions are not described for all targeted learning goals.

Descriptions of prior learning and some learning progressions are provided in the unit, but not all targeted learning goals have their learning progressions described. Related evidence includes:

- The Unit Overview section of the materials includes language about: "Where does this unit fall within the OpenSciEd Scope and Sequence?" For example: "This unit is the third in the OpenSciEd High School Physics course sequence. It is designed to build on student ideas about forces and matter interactions from the second unit of the course. In the first unit of OpenSciEd HS Physics, students developed ideas around energy transfer and conservation in the context of charged particles (electrons) colliding with other electrons (electricity) to transfer energy across great distances. In this second unit of the course, the development of the concept of forces was needed in order to explain earth science phenomena that involve energy transfer across scales of time and space" (TE, page 12).
- The Elements of NGSS Dimensions document describes how students use the SEP and CCC elements in each lesson but does not describe any development (new learning) of the elements.
- Unit Overview: Brief descriptions of the focal categories of the three dimensions and how they are used during the unit are provided. For example:
    - "Explanation and designing solutions is[sic] also intentionally developed in this unit, as is argumentation in a design context. In the final lesson set, students begin to apply their understanding of momentum and force, along with the engineering design solutions they have considered, to address global and local challenges associated with driving vehicles. They use an argumentation scaffold (the Argument Comparison and Evaluation Tool) across Lessons 12-15 to deliberate about complex socio-ecological explanations

and proposed solutions" (TE, page 15). In this bullet, only use, and not development, of the focal categories (not elements) of the three dimensions is described.
    - "Over time by applying empirical data to engineering thinking, students come to see that systems are designed to cause specific effects, and that decisions that we make can cause changes in our own communities, thus cause and effect intentionally developed over the unit" (TG, page 15). In this bullet, development of a focal element is described.
- Unit Overview: The section "How does the unit build three-dimensional progressions across the course, and the program" describes some examples of learning in the unit. However, many of the descriptions only list the usage of elements rather than a description of their development. Related evidence includes:
    - "In P.2 Afar students start thinking about force as a vector, and extend that idea in this unit to recognize they can have negative direction and that velocity is also vector quantity. In this unit, they uncover mathematical relationships between forces and time, acceleration, and momentum (mass and velocity) that help them make predictions about peak force on vehicle occupants during a collision" (TE, page 19).
    - "In the first unit of the course, students construct explanations about how energy moves through systems, and design a community solution. In the second unit, students construct explanations about what will happen to the future of the Afar region of Ethiopia. In this unit, students think deeply about the design solutions at multiple grain sizes, both within a vehicle (i.e. airbags), and at a societal level (i.e. policy requiring airbags in vehicles). In addition, students think deeply about the implications of design tradeoffs in new ways, including how the constraints associated with certain design solutions might have implications for some groups of people more than for others" (TE, page 19). Only use in this unit, and not development, is described in this bullet.
    - "In the third unit of the eighth grade sequence, students use a series of sentence starters to scaffold engagement in practices through the lens of cause and effect. The structure of those sentence starters was echoed again in the second unit of this physics course (P.2 Afar), when students collaboratively build a cause-effect model for understanding how interactions on a nuclear scale can cause patterns on a global scale. In this unit, the scaffold of these sentence starters has moved further into the background, and students are expected to begin applying cause-effect thinking to design solutions" (TE, page 19).
    - "In the first two units of the course, students have been identifying patterns in data. Typically, one or two causes can be attributed to these patterns. In this unit, students are analyzing complex data with many overlapping patterns that must be teased apart, each with multiple causes" (TE, page 19). This bullet only states student use of different CCC elements, rather than how those elements are built upon in this unit.
- Unit Overview: A table is listed of SEP and CCC categories and in which units in the program they are built. However, individual elements are not listed. "This unit uses and builds upon high school level science and engineering practices (SEPs) and crosscutting concepts (CCCs) that students should have previously developed in OpenSciEd High School Biology and Chemistry, and will continue to build in future units" (TE, page 20).

- A list of common student prior ideas is provided. Some relevant ideas that students may come into the unit with include the following: "1. A continuous force is needed for continuous motion. 2. Forces get things moving but can't stop them. 3. Direction of motion implies direction of force. 4. Rest is the natural state of objects. 5. Equal and opposite refers only to forces that are in balance, and ceases to be true when unbalanced forces cause motion. It is valuable to think of ideas like these not as misconceptions that need to be erased but as productive ideas that we can use to build understanding. Not only does this help some students feel more comfortable talking about science and build a scientific identity, it improves science learning across the board" (TE, page 21).
- Lesson 2: The teacher is told, "In this lesson, students 'invent' position versus time graphs to answer their questions, motivating a quantification of a rate of change (speed) for the first time in the unit. Here, the time over which they think about rates of change is relatively long (several seconds). Later in the unit, they will model changes in a similar way but over very short periods of time (less than a second) to better understand the forces involved in the collision itself" (TE, page 61).
- Lesson 3: The teacher is told, "They quantify criteria and constraints in the OpenSciEd High School Chemistry course and in OpenSciEd Unit P.1: How can we design more reliable systems to meet our communities' energy needs? (Electricity Unit)" (TE, page 72). However, the teacher is not prompted to remind students themselves of these connections.
- Lesson 3: "This lesson is designed to coherently build ideas related to the following crosscutting concept (CCC): Scale, Proportion, and Quantity: Algebraic thinking is used to examine scientific data and predict the effect of a change in one variable on another (e.g., linear growth vs. exponential growth). and following science and engineering practices (SEP): Using Mathematics and Computational Thinking: Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations. In this lesson, students are engaging with simple algebraic relationships (distance = speed * time) and speed versus time graphs to explain reaction distance. In the next couple lessons, the relationships become more complex. In Lesson 4, use speed versus time graphs to predict how variables will affect braking time. Then they develop F = (m * Δspeed)/Δt within the braking lab to make sense of how stopping time is affected by changing other variables by using curve fitting. In lesson 5, the equation is simplified to F = m * a, and students are told to use these algebraic relationships in the Electronic Exit Ticket assessment. In lesson 6, students use multiple types of mathematical representations to make sense of momentum conservation, which is then assessed within the transfer task in Lesson 7" (TE, page 72).
- Lesson 5: "How would we say we could calculate this acceleration using graph terms, like, if we were just referring to this change in terms of the x- and y axes?....Allow students to respond, and remind them that in middle school they learned how to calculate this slope as rise over run" (TE, page 104).
- Lesson 6: "They have previously worked with graphs to identify trends and quantities over time in OpenSciEd Unit P.1: How can we design more reliable systems to meet our communities' energy needs? (Electricity Unit) and in nonlinear exponential models derived from data in OpenSciEd Unit P.2: How forces in Earth's interior determine what will happen to its surface?

(Earth's Interior Unit). The highly scaffolded analysis of velocity versus time graphs and force versus time graphs built into day 1 of this lesson lays the groundwork for needing less scaffolding to interpret these types of graphs in future lessons (e.g., Lessons 9 and 10)" (TE, page 120).

- Lesson 6: "The idea that models have limitations but can still provide useful approximations is a fundamental part of the high school-level science and engineering practice (SEP) elements 2.2 and 2.4. In this lesson, these elements are applied at a middle school level, so we have not claimed them here. Students build off prior work in this unit and across other units related to idealized conditions and limited data to develop explanatory models of phenomena" (TE, page 120).
- Lesson 6: "If students completed OpenSciEd Unit 8.1: Why do things sometimes get damaged when they hit each other? (Collisions Unit) in a prior grade, they collected firsthand evidence that the forces in any collision are equal in strength and opposite in direction, even when the masses are not equal (Newton's third law). This is one reason why we are not collecting such data firsthand in this unit; the other is that Newton's third law is a learning target for middle school. Slide Q and Slide R and the related force graphs in the Collisions D-F Forces handout are designed to quickly reestablish that force symmetry relationship" (TE, page 120).
- Lesson 6: "Give students half a minute to talk with a partner to identify some other conserved physical quantities. Listen in and then say, I heard ideas about conservation of energy and mass. We definitely used those ideas in earlier units. And now we have found a quantity that is being conserved" (TE, page 138).
- Lesson 7: "Say, When two variables change in the same way over time, scientists call that a correlation. Give students a moment to add the word correlation to their Personal Glossary" (TE, page 154). This term is reintroduced as being new even though it is part of the expected prior learning for students from the middle school grades. There is a missed opportunity to make an explicit connection to prior learning.
- Lesson 8: "While it may be tempting to give students access to the simulation or pull up the data here instead of using Simulation Velocity Data, doing so would give away force and acceleration data that we want students to dig into at a later time. Providing force and acceleration data too early could take the focus away from what impacts the velocity data has in relation to the forces in the collision. By the end of this lesson, we want students to reason out what the force data would be in relation to the changes in velocity, helping to make a stronger conceptual connection to the relationship among these variables before moving forward" (TE, page 169).

In the Unit Overview, suggestions for modifications to the unit are provided. For example:

- "This is the third unit of the High School Physics Course in the OpenSciEd Scope and Sequence. Given this placement, several modifications would need to be made if teaching this unit earlier in the Physics course. These include the following adjustments: If taught earlier in the school year, supplemental teaching around the nature of energy transfer through systems, and how to represent it may be required. If taught earlier in the school year, supplemental teaching around the basics of forces. If taught as part of an AP Physics course, be prepared to provide students with additional support around equations that are not treated in depth" (TE, page 21).

- "The following are example options to shorten or condense parts of the unit without eliminating important sensemaking: Lesson 4: Instead of conducting the Braking Lab, you could provide students with demonstrations and the sample data to do the analysis" (TE, page 22).
- "To extend or enhance the unit, consider the following: Lesson 3: Consider having students use the collision avoidance view of the Vehicle Collision Simulator to experiment with the relationships established" (TE, page 22).

Suggestions for Improvement

- Consider describing for teachers the intended learning progressions for more of the targeted learning goals, rather than only how elements are used in various ways throughout the unit.
- In Lesson 3 when the term "constraints" comes up, consider prompting teachers to remind students of their prior discussions of constraints in prior instruction, such as in unit P.1.

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

The reviewers found adequate evidence that the materials use scientifically accurate and grade-appropriate scientific information. A majority of the information in the unit is scientifically accurate and grade appropriate. Some minor misleading ideas were identified in the unit.

Scientific background information is provided for the teacher. For example, in the Unit Overview, the teacher is told, "To learn more about the physics of vehicle collisions: https://driving.ca/features/feature-story/motor-mouth-the-physics-of-car-crashes-prove-bigger-is-better; https://www.epermittest.com/drivers-education/physics-collisions" (TE, page 24).

Support for addressing students' initial ideas that may be scientifically inaccurate is provided. For example, in Lesson 1, the teacher is told, "Students will have ideas about vehicle collisions, distracted driving, and so forth. Some may bring in ideas about forces and momentum. Accept all of these ideas without judgment right now, even if they are scientifically inaccurate. If a student puts an idea on the table that feels very inaccurate, you can respond with one of the following: Wow, that's an interesting idea! Does anybody disagree? Let's follow up on that, for sure. How could we investigate the claim

_____ made? Let's add that to our ideas for investigations later. What an interesting idea. Could you reframe that as a question for our Driving Question Board?" (TE, page 34).

Some potentially confusing or misleading ideas are present in the materials. Related evidence includes:

- Throughout the unit, the dependent and independent variables are inconsistently displayed on graphs, which might be confusing. For example, in Lesson 4, students make a prediction about how speed, force, and mass affect stopping time. The handout for this task says, "Make predictions of how increasing and decreasing each independent variable will affect the time it takes for the car to stop." This wording suggests that time is the dependent variable. Yet the sample graph on the handout shows time on the horizontal axis, which is traditionally reserved for the independent variable.
- Lesson 7: The teacher gives an inaccurate or misleading definition of correlation to students. "Say, When two variables change in the same way over time, scientists call that a correlation. Give students a moment to add the word correlation to their Personal Glossary" (TE, page 154). This might lead to a misconception in which students think that all correlations are positive, meaning that if one variable increases, so does the other. In fact, two variables can be correlated if one variable increases and the other decreases.
- In several lessons, the unit of measure for rigidity is listed in kN rather than in kN/m^2. For example, Lesson 11 says, "The vehicle for this test had a crumple zone rigidity of 500 kN" (TE, page 212). This is inaccurate and may be confusing for students as they are told to compare rigidity and forces as two separate variables, and students are also using kN to quantify forces.
- Lesson 12: "Determine that we are evaluating these arguments to understand whether we should lower speed limits. Any variation of this answer is acceptable, but look for students to identify that the question should start with the word 'should.' Make this explicit by saying, This is a 'should we' question. There are a lot of important 'should we' questions out there that we can use science and engineering to address" (TE, page 238). This may be confusing for teachers (and students) as teachers are also told, "As students complete this tool, remember that one key goal is to elevate these nature of science ideas:… Science addresses questions about the natural and material world: Scientific knowledge indicates what can happen in natural systems—not what should happen. The latter involves ethics, values, and human decisions about the use of knowledge" (Argument Comparison Keys, page 1).

Suggestions for Improvement

Consider addressing the areas of potential confusion identified in the evidence above.

II.E. DIFFERENTIATED INSTRUCTION

Provides guidance for teachers to support differentiated instruction by including:

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

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

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

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

The reviewers found extensive evidence that the materials provide guidance for teachers to support differentiated instruction. Supports are provided throughout the unit for differentiating instruction for multilingual learners, students with disabilities, and struggling students. However, most such supports are not specifically related to the targeted learning goals in the three dimensions.

Guidance is often provided in the unit that might be helpful for multilingual learners and students who need language supports. Related evidence includes:

- Unit Overview: “Most often in this unit, students will have experiences with and discussions about science ideas before they know the specific vocabulary word that names that idea. After students have developed a deep understanding of a science idea through these experiences, and sometimes because they are looking for a more efficient way to express that idea, they have co-developed that definition and can add the specific term to a personal glossary at the back of their notebooks. These ‘definitions we codevelop’ should be recorded using the students’ own words whenever possible….The definitions we co-develop and encounter in this unit are listed in this document and in each lesson to help prepare and to avoid introducing a word before students have earned it. They are not intended as a vocabulary list for students to study before a lesson, as that would undermine the authentic and lasting connection students can make with these words when they are allowed to experience them first as ideas they’re trying to figure out” (TE, page 27).
- Lesson 2: “The conventions we use to describe kinematics are not always intuitive and require students to develop a new literacy. Consequently, we should think of the use of these conventions much as we think of the introduction of new vocabulary. As with vocabulary, it is best to motivate a need for a new convention before providing the convention itself, so it will be ‘earned.’ In the case of subscripts, for example, consider spending a moment asking what we

could do to differentiate quickly between the positions. If students suggest using numbers or letters (i.e., 1, 2, 3; A, B, C), use their suggested representations. When we start to keep track of times as well, they will quickly see the need to add something to indicate whether we are referencing a position or a time. At that point, you can tell them that scientists use X and t to reference time and position, and subscript these letters with numbers" (TE, page 55).

- Lesson 3: "If the reading is overwhelming for some students, consider organizing the class into groups and asking some students to read about one design solution while others read about another" (TE, page 78).
- Lesson 5: "Some students may not be familiar with the term steep to describe the angle of the slope in the graphs. If so, ask the class to recall where they have heard the term steep in everyday language. Students might mention a steep hill or steeping tea. Point out that these examples refer to an incline or to an item increasing in intensity. Consider comparing two graphs from Lesson 4 that have a more steep versus a less steep slope and asking students to identify the steeper slope before moving forward" (TE, page 103).
- Lesson 10: "Pause to make sure students know what you mean by rigid; consider using an example, such as showing how a piece of cardboard is harder to deform than a piece of paper" (TE, page 195).
- Lesson 10: "This is especially beneficial to emergent multilingual students. For this reason, partner talk or small-group talk should precede whole-class discussion whenever possible to give students an opportunity to share their ideas with one or two peers before going public" (TE, page 200).
- Lesson 10: "For students who are learning English or who need support following whole-class discussion, it can be helpful to use gestures in addition to talk. For example, as you work to define rigidity, hold the physical materials in your hands and try to bend them. Ask students whether each material is rigid or not rigid" (TE, page 202).
- Lesson 11: "It may be helpful to establish a shared language for when the crumple zone deforms 100%. One option is 'bottomed out', but privilege students' language" (TE, page 217).
- Lesson 12: "Argument 1A: Maintaining Speed Limits and Argument 2A: Lowering Speed Limits are readings written at the 11th grade reading level (lexile level 1210-1400). Alternative versions are provided at a 9th grade reading level (lexile level 1010-1200): Argument 1B: Maintaining Speed Limits and Argument 2B: Lowering Speed Limits and at a 6th grade reading level (lexile 610-800): Argument 1C: Maintaining Speed Limits and Argument 2C: Lowering Speed Limits" (TE, page 227).

Supports are provided throughout the unit for students who struggle. For example:

- Lesson 1: "For students who require additional scaffolds to identify the key patterns in the Key Ideas callout box, you can offer three additional prompts, one by one: 1. Where does the line trend down? 2. Where does the line trend straight across? 3. Where does the line trend upward?" (TE, page 37). However, note that this support focuses on data analysis rather than with the targeted **Patterns** CCC element.
- Lesson 4: "If students struggle to graph the changes of speed over time, allow them to use their own words to describe these changes. For example, you can provide sentence stems such as: If I

double (the mass of the car/the braking force/the initial speed of the car), the time it will take for the car to stop will be: twice as long, half as long, longer, shorter" (TE, page 90).

- Lesson 4: The alternate activity box says, "If students need extra support with data collection strategies, consider making time to read the *Data Analysis Reading* together or providing it as a resource" (TE, page 92). However, the Data Analysis reading has a high lexile level and 13 graphs for students to make sense of. It is therefore possible that this resource will be challenging to use for the intended target audience.
- Lesson 5: "If students do not make connections between the steepness of the slope and the changing speed of the car right away, pause and give them a few minutes to puzzle over it with a manipulative, such as a toy car. Recreate the motion of one of the speed versus time graphs from Lesson 2 and ask students to observe the changes in motion of the car over time" (TE, page 103).
- Lesson 6: "Some students may need more support in making the jump to thinking more abstractly about the motion and forces when using the smart cart. Optional Collision Introduction provides an additional activity that scaffolds students through semsaking[sic] about the data when the smart cart collides with a wall and stops as opposed to bouncing, which is more similar to the stopping they investigated in Lesson 4. The slides for this extra transitional activity are provided at the end of the slide deck on slides C1-C4 and are used in place of slide D. This activity is meant to provide an alternative framing that is more concrete, more hands on, and clarifies the individual steps of the work in a coherent way" (TE, page 123).
- Lesson 7: "Depending on the comfort of your class's ability to read and compare graphs, another option is to first organize students into five 'expert groups' to analyze the same data set together" (TE, page 155).
- Lesson 8: "For students who need additional support, consider providing a timeline template with a list of the key events as a graphic organizer scaffold" (TE, page 167).
- Lesson 8: "If students are struggling to make comparisons across the timelines, highlight the physical difference in the distance between times on the timelines. Consider calculating the change in velocity for the dummy between each interaction noted on the timeline. If students are still struggling to compare these, divide to calculate the acceleration to get single numbers to compare" (TE, page 171).
- Lesson 14: "It may help students who are struggling to make the physics modeling more concrete by showing them an example that pertains more closely to models that have relevance for their chosen problem or solution. For these purposes, use Physics Models Used in Design Solutions" (TE, page 268).

Some supports are provided during the unit for students with disabilities. Related evidence includes:

- Lesson 1: "Data Jigsaw E: Registered Vehicles has graphs that use color to differentiate between two data sets on each graph. These colors have been selected to be colorblind friendly and have different enough shades that they should be discernible when printed in black and white. If they do not appear different enough in copies, consider projecting those graphs or providing them electronically so students can view them in color" (TE, page 38).

- Lesson 1: "Use representations like color coding and lettering. Although color coding is a usefulway[sic] to quickly reference the trends, also including letters helps ensure accessibility for any student who may be colorblind. If you know you have colorblind students, consider a color palette that uses orange, blue, black, or dark brown, as these tend to be more easily distinguished by people who are colorblind" (TE, pages 43–44).
- Lesson 8: "The colors chosen to represent the ideas for this timeline are color blind friendly, meaning that students who are color blind should still be able to distinguish between the different shades of colors. If you know you have color blind students, using similar colors and/or using different shapes to represent the vehicle and the person/crash test dummy separately will be helpful so they can differentiate between them. There are many websites that have information about what colors are useful for different color blindness. Consider using a palette that uses orange, blue, black, or dark brown" (TE, page 163).

Supports are provided to help the teacher differentiate instruction. However, these supports are rarely targeted to learning goals in the three dimensions. Related evidence includes:

- Lesson 4: "When assigning variables to lab groups, consider differentiating based on the complexity of the data collection task. The mass data collection is the least complex, focusing on the use of an electronic scale. The force data collection uses the tumble buggy to read the braking force while the cart is dragged. The speed data collection can be either the most complex or most simple, depending on whether you have them do this using the smart cart or choose to do this for them ahead of time" (TE, page 91).
- Lesson 13: "Consider providing an alternate representation of the two readings and instructions in a virtual space so that students can enable a text-to-speech program that can read the selections to them. This can reduce barriers to accessing the text. A read-aloud could also be done for the whole class as students annotate the text, and then students could shift to completing the tables in partner pairs. This would increase access for all students" (TE, page 245).
- Lesson 14: "If students found Argument Comparison Tool to be a useful tool in Lesson 13, Scaffolded Argument Tool has a similar structure, with sentence starters to aid students in applying these ideas to a design problem or solution setting. If some students have to complete the project work independently or if a group has less time to spend on the project than they will need, scaffolding the project thinking with the Scaffolded Argument Tool may be the right choice" (TE, page 254).

Some extensions or adaptations are provided for students who have already met the learning goals. However, these extensions rarely support students to extend their learning related to the three dimensions. For example:

- Lesson 4: The alternative activity box says, "If students feel comfortable reading and interpreting speed versus time graphs after Lesson 3, they may not require this much scaffolding. Feel free to move more quickly through slide D and the *Braking Variables Predictions*, or skip them, based on your students' needs."

- Lesson 5: "To extend students' sensemaking about braking and avoiding collisions, you can have students work with the collision avoidance restricted view version of the vehicle collision simulator (http://collision-sim.inquirium.org/collision-avoidance.html). Consider having students try to recreate the scenarios they read about and adjust the parameters to test their design solutions" (TE, page 108).
- Lesson 8: "To extend the sensemaking about the changes in velocity over time, consider providing students with the velocity vs. time graphs for the vehicle and crash test dummies for each collision" (TE, page 171).
- Lesson 10: "If time permits, consider engaging students in a force diagram extension activity. See the Two-Car Collision Forces handout for the activity and the Two-Car Collision Forces Key for possible responses" (TE, page 196).
- Lesson 11: "Extension opportunity: Provide students with a laptop with access to https://openscied-static.s3.amazonaws.com/HTML+Files/Apply+and+Remove+External+Force+on+a+Solid.html in order to investigate the role of fields in energy transfer during a collision" (TE, page 219).

Some suggestions are provided for adaptations if students begin the learning with significantly higher or lower levels of prior proficiency than expected. For example, in Lesson 4 the teacher is told, "If students have not completed OpenSciEd Unit P.2: How forces in Earth's interior determine what will happen to its surface? (Earth's Interior Unit) before this unit, you will need to include extra support in building understanding of balanced and unbalanced forces and the concept of net force" (TE, page 88).

Suggestions for Improvement

Consider more often providing support for differentiated instruction related to the learning goals in all three dimensions.

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. Teachers are guided to clearly see the unit storyline and to help students see linkages between all lessons. However, support is not provided to ensure that students will see how their learning in all targeted elements of the three dimensions were part of their sense-making. In addition, it is unlikely that teachers will be guided to give students sufficient time to complete all of the stated tasks.

The teacher is given information to help them understand the overall flow of learning in the unit, and teacher moves are provided that help students see connections between lessons. For example:

- The Unit Overview provides teachers with information about the focus of the three lesson sets (TE, page 1).
- A Unit Storyline is provided (TE, pages 3–10) that provides the following summary information about each lesson: Lesson Question, Phenomena or Design Problem, What we do and figure out, and How we represent it.
- A graphical representation of how the lessons fit together is provided for teachers (TE, page 14).
- Each lesson begins with a “Learning Plan Snapshot” to help teachers understand the flow of activities in the lesson (e.g., TE, page 30).
- Each lesson includes a “Where We Are Going” and “Where We Are NOT Going” section. This can help ensure that teacher modifications stay within the intended scope of the materials. For example, in Lesson 3, the teacher is told, “They will not be using vectors in this lesson and will be thinking about speed rather than velocity until Lesson 4” (TE, page 72).
- Several explicit teacher moves are a common part of the Navigation sections in each lesson. These teacher moves include: Look Back: How did we get here?, Take Stock: Where are we now?, and Look Forward: Where are we going? For example, the Navigate by looking back section of Step 1 in Lesson 9, says to ask students this: “Considering the evidence we assembled in our timelines, what other variables might help us understand how safety features affect

safety in a collision?" (TE, page 178). The task gives students the opportunity to activate prior knowledge, linking that knowledge across lessons.

- The DQB routine guides teachers to use a technique to elicit and track student questions throughout the unit.
- Lesson 4: There are inconsistent teacher directions that might be confusing to students if followed verbatim. At the very end of day 2, the teacher is told, "Before wrapping up, tell students that next time, we will consider how these relationships we figured out might relate to vehicle safety" (TE, page 94). At the very beginning of day 3, the teacher is told, "Say, Last time, I asked you to consider how the results of your investigations might relate to vehicle safety. Let's refresh our memory" (TE, page 95).
- Lesson 11: The teacher is told, "This is the first time students are explicitly making a connection between one graph to another, especially two graphs that have different variables plotted. This video helps students understand the connection between the two graphs presented on the slide to support data analysis during this discussion" (TE, page 212). The corresponding slide also says, "Watch the Building connections between graphs video" (slide C). However, such a video was not located, so these instructions are likely to be confusing to the teacher and students.
- Lesson 14: "It is not a goal of this project to tie together all models built in the unit. While some problems or design solutions may connect to more than one core physics model, the focus of the project is on applying one model to a specific real-world application, not tying together multiple models" (TE, page 256).

Some supports are provided to help students see how their learning is useful for sense-making. However, these supports are not provided in relation to all learning goals; in particular, supports related to CCC and SEP learning goals are rare. Related evidence includes:

- Lesson 12: "Say, 'We have developed a lot of science ideas so far, but let's start with one important idea. Have students turn and talk about the prompt: If you had to choose, which science idea that we have developed in this unit is most important for explaining how vehicle systems can be designed to increase safety?'…. Ask students to collect unit artifacts to review such as their Engineering Progress Tracker and other notes or handouts. Give them about 5 minutes to look through these and public artifacts, such as posters, and to use sticky notes to draft an initial Gotta-Have-It Checklist for explaining how vehicle systems can be designed for safety" (TE, page 232).
- Lesson 14: "Point to the posters showing physics models developed throughout the unit and say, We've developed quite a strong understanding of these various modeling tools in these posters. Now it's time to put those models to work and think through how physics can save lives!" (TE, page 268).
- The unit has several "Progress Tracker" entries. The Unit Overview document says that these trackers are "embedded in OpenSciEd units and are thinking tools designed to help students keep track of important discoveries that the class makes while investigating phenomena and figure out how to prioritize and use those discoveries to develop a model to explain phenomena." There are tracker opportunities in Lessons 3, 5, 9, 7, 9, 12, and 14. A sample tracker prompt from Lesson 9 is, "Add to the *Engineering Progress Tracker*. Display slide U. Give

students 4 minutes to add to their tracker." The progress tracker has a column labeled "How do science ideas explain why this solution could keep people safe?" Students may therefore see their science learning of DCIs as helpful for problem solving, but similar supports are not provided for SEPs and CCCs.

It isn't clear that the teacher directions provide enough time for students to engage with the material fully and coherently. For example, in Lesson 4, the materials suggest that the entirety of Step 4, including the initial teacher-led discussion, forming small lab groups, students reading and processing the lab procedure, practicing the protocols with new equipment, repeated trials, recording data in tables, transferring data to a computer spreadsheet, and writing answers to debriefing questions takes 25 minutes on Day 1 and 28 minutes on Day 2. Similarly, in Lesson 6 in just steps 11–14 (not the full lesson), there are 27 equations and 14 content-rich diagrams. The cognitive demand of students is large, as students will have to keep track of several abstract ideas in their working memory for quite a while processing new information. However, only 58 minutes is allotted for these steps.

Suggestions for Improvement

Consider reviewing the time allotment printed for each step and adjusting to ensure the time allotments are practicable. This adjustment would be particularly helpful for any cognitively demanding activities.

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 adjust supports over time. There is some evidence of scaffolded differentiation in the unit. However, many of the claimed SEP elements in the unit are only used by students one time, so they are not supported to increase their proficiency and independence in the SEP over time.

Related evidence includes:

- Unit Overview: One of the suggestions "to extend or enhance the unit" is "All lessons: Remove scaffolds provided with science and engineering practices (SEPs) as a way to give students more independent work with the elements of these practices" (TE, page 22).

- Claimed SEP element: *Compare and evaluate competing arguments or design solutions in light of currently accepted explanations, new evidence, limitations (e.g., trade-offs), constraints, and ethical issues.*
    - Lesson 12: "During this lesson a large amount of time is spent on this process in a whole-group context. This is because students will continue to utilize comparison using these ideas and related scaffolds over the next three lessons to analyze arguments and design solutions. Students will eventually be expected to consider these prompts individually as they compare two design solutions on the Pedestrian Solutions transfer task in Lesson 15" (TE, page 230). Students compare two written arguments and are asked, "Compare your evaluations of the two arguments. Which argument or design has the most merit from a science perspective, and why?" (Science Ideas Argument Comparison, page 3). Students are given an Argument Comparison Tool with the first column filled out to scaffold their use of the tool.
    - Lesson 13: "Have students work through one article at a time and evaluate each one in full before proceeding to the second article. Once both articles have been evaluated, ask students to go back to the second table and reconsider each question, since a new perspective might have emerged as they read each article. Give students 20 minutes to complete the Argument Comparison Tool in partners" (TE, page 245). In this lesson, students are given a blank Argument Comparison Tool.
- Claimed SEP element: *Analyze data to identify design features or characteristics of the components of a proposed process or system to optimize it relative to criteria for success.*
    - Students analyze data throughout the unit, although this particular element is not claimed until Lesson 9. Early in the unit, graph analysis is done as a whole class in a facilitated way, as in Lesson 2 on page 65.
    - Lesson 9: Students compare four simulation set ups with graphs and are asked, "What patterns do you see in these four attempts to optimize the safety features?" (TE, page 185).
    - Lesson 10: In the "Where we are going" section at the beginning of the lesson, the teacher is told, "Students have engaged with a lot of analysis of graphs of velocity versus time, starting in Lesson 3 and continuing through subsequent lessons. They have also analyzed graphs of force versus time starting in Lesson 6 and continuing through subsequent lessons. Because of this, support for engagement in the science and engineering practices (SEPs) 9.4.6 and 9.5.2 should be less scaffolded than in prior lessons, and you can expect students to fluently interpret these graphs" (TE, page 194).
    - Lesson 10: Students compare data from various tests of design solutions. Students are asked, "What do the safest designs have in common in terms of what they were made of or how they were designed?" (TE, page 200).
    - Lesson 11: Students are prompted to "Analyze and annotate the following graphs to explain how the design of the crumple zone length affects safety of the crash test dummy" (Survivability vs. Length, page 3).
- Claimed SEP element: *Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations.*

- Lesson 3: Students create and use graphs of phenomena to support claims about breaking distance and reaction time.
- Lesson 4: Students graph data from investigations and are asked, "'What relationship have you discovered between mass, speed, and braking force that predicts the stopping time of a vehicle?' Invite volunteers to share. Listen for mentions of how the variables relate mathematically. Use the results in the table to test the proposed relationship. Ask whether other groups found the same or a different relationship… 'How can we represent the relationship we have identified as an equation?' Guide the class through writing out the equation in words first. For example: Stopping time = mass * initial speed / braking force. Say, 'Equations are often made smaller by using variable symbols instead of words. Which words can we replace with symbols in our equation?'" (TE, page 96).
- Lesson 5: Students derive Newton's 2nd law (F=m/a) and use it to analyze real world situations.
- Lesson 6: Students are asked, "What does our mathematical model predict the final velocity of cart D would be? Show how you solved for this unknown using one of our momentum equations. Why does your use of this equation provide a reasonable approximation of the outcomes for the system you defined?" (Different Momentum Cases Handout, page 5).
- Lesson 10: "Rewrite the last equation on the board: FΔt = mΔv." The left side of the equation is labeled as "The two variables that are changing." The right side of the equation is labeled as "The change in momentum of the vehicle was constant in every case where we brought its velocity to 0." Students are asked, "What does this tell us about how the average net force on an object and the time that force is applied are related to the change in momentum?" (TE, page 202).
- Lesson 11: Students are prompted, "Choose any of the mathematical models present in the Force and Motion Relationships poster to describe one of the patterns that you identified in question a of Part 2" (TE, page 215). The suggested student response is, "FΔt = mΔv. The larger the force acting on the dummy, the steeper the changes in velocity (larger deceleration)" (TE, page 215). Students are expected to complete this task somewhat more independently than in previous lessons.

Suggestions for Improvement

Consider supporting students to deepen their proficiency and independence in all learning goals over the course of the unit.

Collisions and Momentum

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

Collisions and Momentum

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 DCIs and CCCs to make sense of phenomena and design solutions. Students have many opportunities to create individual artifacts of their learning, showing multiple dimensions in service of defining and solving real world problems. In addition, there is a reasonable match between assessment prompts, assessment targets, and learning goals.

Related evidence includes:

- Throughout the unit, assessment opportunities are embedded into the learning and called out for the teacher, allowing them to collect evidence about students' progress in all three dimensions.
- Lesson 2: "Then ask students to respond to the slide's prompts A-C on a sheet of paper. Collect these papers before the end of class to check their interpretations of this kind of graph. A. What does a steeper slope mean about the motion of the object? B. What would it mean about the motion of the object if the slope were zero (a flat line)? C. What would it mean if the slope were negative?" (TE, page 64).
- Lesson 6: "Collect Collision A and B Predictions at the end of the period. If students' predictions do not include the look-fors above, have them determine the Δv calculations for the six velocity graphs on Collisions D-F Velocities on day 2, and collect that handout to evaluate their progress in the lesson-level performance expectation (LLPE) by the end of class" (TE, page 125).
- Lesson 7: Students are given an assessment task that uses a real-world context. Students are told, "In this assessment, you will use the results from their published paper to evaluate whether the outcomes of each collision can be predicted using what you learned about momentum conservation" (Assessment Bus Collision, page 1).
- Lesson 13: "Work through one article at a time and evaluate each one in full before proceeding to the second article. Once both articles have been evaluated, ask students to go back to the second table and reconsider each question, since a new perspective might have emerged as they read each article" (TE, page 245). The teacher is told, "Use the detailed guidance given in the teacher references (Lift Kit Argument, Weight Limit Argument, or Public Transportation Argument) to assess students' argumentation related to societal and ethical impacts for the topic you have selected for your class. (SEP: 6.5, 7.1; DCI: ETS1.B.1; Connections to Engineering,

Technology, and Applications of Science: Influence of Science, Engineering, and Technology on Society and the Natural World)" (TE, page 246).

- Lesson 14: Students engage in a transfer task that uses similar but slightly different problems than were used in a majority of the unit. Students are told to choose a related problem that is significant to their community. Examples given include: "The mass in a lifted truck is too high up for a regular car's crumple zone to do its job" and "Drivers in areas with more poverty are more likely to drive a car without airbags" (Final Product Example Summary, page 1).
- Lesson 15: The summative assessment uses a slightly different phenomenon/problem than that used in a majority of the unit: pedestrian collisions with an automobile with different kinds of "pedestrian catchers" on the front.

Suggestions for Improvement

Ensuring a closer match between assessment prompts, assessment targets, and learning goals would strengthen the evidence for this criterion.

III.B. FORMATIVE

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

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

The reviewers found extensive evidence that the materials embed formative assessment processes throughout that evaluate student learning and inform instruction. The unit supports teachers to provide feedback for students based on both the overall class performance as well as the individual student performances.

Throughout the unit, assessment opportunities provide "what to do" guidance for the teacher. Related evidence includes:

- Lesson 2: "What to do: Do not use this assessment moment to assign a score, but rather to decide whether the class needs more practice interpreting position versus time graphs… If only a few students are struggling, consider meeting with them one-on-one to analyze the graphs and videos in detail before the next class" (TE, page 64).
- Lesson 2: "What to do: As students graph, move around the classroom and support those who are struggling. Point to the steps they moved through to plot the first series of points for the undistracted driver. Use probing questions to help them articulate the steps we took as a class and why: What did we do when we did this together? What were we trying to figure out when we did that?" (TE, page 66).

- Lesson 4: "What to do: It may be difficult to distinguish between difficulty using the mathematical representation versus difficulty grasping the relationship between braking force and stopping time. To discern between these, encourage students to describe their predictions in their own words and see whether these align with their explanations for the last prompt on the handout" (TE, page 98).
- Lesson 5: "What to do: If students struggle determining the stopping time in question 1, reshow the video and consider using a whiteboard or a piece of chart paper to draw and predict the movement of the cart after it leaves the screen. For question 1, if students selected 2 seconds, check to make sure that students are considering the time it takes to stop from the initial speed, not the speed at which the green line has ended on the graph. This could result in an inaccurate answer but not an inaccurate science idea being conveyed. If students struggle with questions 2-4, conduct more practice examples as shown at the end of Lesson 4. Guide students in considering what happens if you double, halve, or triple any variable in the equations they have used thus far. If students cannot think of another application of the math for question 5, revisit this at the beginning of Lesson 6 and brainstorm some ideas as a class" (TE, page 112).
- Lesson 6: Students are given an answer key for one of their handouts and are told to self-assess and to "identify the parts of the process you're confident about and the parts you'd like additional practice or help with" (TE, page 145). The teacher is told, "This is an opportunity to use the self-assessment feedback to target areas where some students are requesting additional help" (TE, page 146). However, the "what to do" guidance for teachers only relates to science disciplinary concepts rather than to all three dimensions. "If the self-assessment indicates that students are not yet confident with the elastic/inelastic distinction from this lesson, review the home learning at the start of lesson 7 and use manipulatives (such as toy cars) to emphasize that in the grocery cart collision, the front cart bounced off the cart that hit it, propelling it forward; in the vehicle collision, both cars were moving, and the smaller car bounced backward off the larger car; but in the train collision, there was no bouncing. These terms will be important shared vocabulary in exploring collisions going forward" (TE, page 146).
- Lesson 7: During an interim assessment, the teacher is told, "Move around the classroom and refer students who are struggling to their science notebook, previous handouts, and Progress Tracker if they need additional scaffolding. Collect the assessments at the end of class to provide feedback" (TE, page 153). In the Answer Key document, example feedback is provided for three different levels of student responses (page 8). However, the feedback suggested for students who show "Organized understanding" (full proficiency) focuses on helping students learn the claimed CCC element, rather than helping students go beyond the expected performance. "Ask students to be explicit about what they included in their system, and then ask them to imagine how their approach might be different if they had bounded the system differently" (page 8).
- Lesson 10: "What to do: Consider reviewing students' individual answers to Part A of the Design Solution Comparison (collected at the end of day 1) and providing feedback. If they struggle with identifying the criteria, remind them of the previous lessons on seat belts and airbags and how these worked to reduce forces and increase the time forces are applied" (TE, page 198).
- Lesson 11: "As students work on this, walk around the classroom. Use some of the following prompts to quickly gather evidence of student thinking: How would you design the crumple

zone of a vehicle to make it safer? Why would that make it safer? Use the following prompts if students are struggling making a connections[sic] between the data and the design of safer vehicles: Ask, What is the safest condition among these three conditions (A-C), why? As you continue the lesson, offer targeted support as students are working on part 2 of Investigating Rigidity. Ask them to explain the patterns they see and connect them to the relationship between velocity and force over time and the rigidity" (TE, page 214).

- Lesson 11: In the Length vs. Survivability Answer Key, example feedback is provided for three different levels of student responses, although with "Classroom Level Guidance for What to do Next" (pages 5–6).
- Lesson 14: "At the end of class, collect at least one sample response for question 3 from each group, then give written feedback on this work before the next class as described in Design Challenge Organizer Key" (TE, page 259).
- Lesson 14: Students have team Exit Tickets and are told, "On one copy of question 6, jot down ideas on which physics models could help explain what makes the problem dangerous or how your solution helps make people safer. Hand in this work for teacher feedback" (slide P).

Additional explicit formative assessment guidance is provided in the unit. For example:

- Lesson 9: "Poll to gather formative data on student predictions" (TE, page 180). However, no formative assessment guidance is given. The teacher is just told to "accept all answers," so it is unclear how this could be used as formative data.
- Lesson 9: In the Comparing Speeds Answer Key, the teacher is told, "What to do: Point students back to the data and ask students to identify what the magnitude of the peak force is, when the forces are first applied and when they stop. Reference the versions of Newton's second law you have posted in the class, and ask students which of these variables stays the same between each condition and which changes. Ask students which of the changing variables is most directly related to injury based on their reading from day 1: Crash Test Measures" (pages 1–2). However, no indication is given about in what circumstances the teacher should take these actions (e.g., as a result of what kind of student performance).
- Lesson 11: "Collect Investigating Rigidity to provide students with individual written feedback" (TE, page 215). Later, the teacher is told, "Return Investigating Rigidity with written feedback to students. Say, I've provided feedback on your last claim, please review it" (TE, page 217).
- Lesson 14: "Your experience with formative assessment work done by your students may suggest that certain individuals will have trouble understanding the work that their group does prioritizing criteria or modeling physics related to their solutions. If you are not collecting and assessing all students' individual work, do not assume that these students have mastered the project objective. Instead, use the class time when groups are working to inspect the written work of these students and verbally check for understanding" (TE, page 255).
- Lesson 14: "Collect one copy of the Design Challenge Organizer from each group in order to give written feedback according to the assessment guidance above and in Design Challenge Organizer Key" (TE, page 260).

Suggestions for Improvement

Consider more often providing formative assessment guidance related to all three targeted dimensions.

III.C. SCORING GUIDANCE

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

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

The reviewers found adequate evidence that the materials include aligned rubrics and scoring guidelines that help the educator interpret student performance. Throughout the unit, scoring guidance is provided. However, several mismatches exist between the scoring guidance and the assessment targets.

Throughout the unit in the formal assessment opportunities, teachers are given lists of "what to look for/listen for in the moment" related to parts of all three dimensions, along with a three-dimensional learning goal that students are building toward. However, it is not always clear to what extent students are expected to be proficient in various tagged assessment targets in particular performances. Related evidence includes:

- Lesson 2: "Look for students to correctly analyze the distracted driver video by graphing position versus time for clip #2. Then in the debrief, listen for them to explain that: The graphs reveal a pattern for the distracted driver that looks different than the pattern in the undistracted driver data. (CCC: 1.4) The graphs show that the distracted driver moved farther during the time between the appearance of the obstacle and the brake lights. (CCC: 7.2) This suggests that being distracted increases the time it takes to react to something (reaction time). (DCI: ETS1.A.2) A longer reaction time means that the car travels farther before braking (reaction distance) and is more likely to hit the obstacle. (SEP: 4.1)".... "Building toward: 2.A.2 Analyze videos of two drivers encountering a sudden obstacle by graphing change in distance over time in order to describe and predict how being distracted can affect the risk of a potential vehicle collision. (SEP: 4.1; CCC: 1.4, 7.2; DCI: ETS1.A.2)" (TE, page 66). However, the students were prompted, "What differences did you notice that could explain why being distracted increases the likelihood of a vehicle collision?" and it is unlikely that the prompt would elicit the sample student answer coded as measuring the CCC element *Mathematical representations are needed to identify some patterns*.
- Lesson 4: "Students should use the speed-time graph to predict how increasing the braking force or decreasing the mass and initial velocity of the vehicle will result in a steeper negative slope (faster decrease in speed), whereas increasing the mass and initial speed or decreasing the

braking force will lead to a less steep slope (slower decrease in speed). (SEP: 5.2, 6.1; CCC: 3.5; DCI: PS2.A.1) Building toward: 4.A.1 Use mathematical representations of the relationship between mass, initial speed, force, and stopping time and algebraic thinking to make a quantitative claim that predicts how much changing braking force will affect the time it takes a vehicle to stop. (SEP: 5.2, 6.1; CCC: 3.5; DCI: PS2.A.1)" (TE, page 90).

- Lesson 5: The following are listed as what to look for: "Once drivers have applied braking force, we see negative acceleration. (DCI: PS2.A.1) The shift in applying braking force occurs due to the change in conditions of the road (wet and rainy). (SEP: 2.6) The graph of the dry conditions shows a shorter acceleration period (a steeper slope over a period of time). (DCI: PS2.A.1) The graph of the wet conditions shows the acceleration occurring at a later time period than in the dry conditions and a longer acceleration period (a less steep slope over a period of time). (SEP: 2.6; DCI: PS2.A.1) Both graphs explain that the driver is going slightly over 45 miles per hour before applying braking force, accelerating, and bringing the object to a stop. (SEP: 2.6; DCI: PS2.A.1) Wet conditions increase the reaction time needed by drivers, making the yellow light time available for reacting shorter (DCI: PS2.A.1) To compensate for this, drivers increase their braking force, but the braking force is not enough to overcome the reduced friction between the tires and the road, and the acceleration occurs over a longer period of time. (DCI: PS2.A.1) To counteract this, drivers would need to either increase the reaction time or create a change in the system to reduce the rate of acceleration (reduce the steepness of the slope over a longer period of time) without running the light. (SEP: 2.6; CCC: 2.3; DCI: PS2.A.1)" (TE, page 110). However, SEP **2.6** asks students to develop or use a model to generate data, but students do not generate data in this activity, so the scoring guidance is misleading. Although the high school-level SEP element is claimed, student performance instead shows evidence of the following middle school-level SEP element: *Develop and/or use a model to predict and/or describe phenomena.*
- Lesson 7: The teacher is told to look for the following student performance as evidence of CCC element **2.1**. "Students are looking for correlations, but when challenged they can articulate why they should not make causal claims" (TE, page 155). However, this look for is only evidence of a corresponding middle school-level CCC element: *Relationships can be classified as causal or correlational, and correlation does not necessarily imply causation.* Note also that the prompt (on slide G: "Can we say anything about which factor is causing these trends?") that relates most closely to the issue of correlation is given to students after this assessment opportunity is described rather than as part of the assessment opportunity itself.
- Lesson 12: "Look for students to do the following: Identify multiple criteria and design solutions within vehicle systems that can be designed to affect safety. (CCC: 2.3; DCI: ETS1.C.1)" (TE, page 233). However, students are not told to show evidence of understanding or application of the claimed DCI element: *Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (tradeoffs) may be needed* in this performance.

Answer keys are provided for the teacher for many of the handouts throughout the unit, such as the Lesson 4 Braking Variables Predictions Answer Key. Related evidence includes:

- Answer keys are also provided for students in Lesson 6. The teacher is told, "Distribute the Momentum Self-Assessment Key to each student. Say, 'This is a key for the questions you started working on. At the end, you'll reflect on your confidence in using our equations to solve the practice problems. How could we use all of this to help us as learners so we're well prepared for doing this kind of thinking on our next summative assessment?'" (TE, page 145).
- In the answer keys, only one "right" answer is often shown versus support for understanding where students are along a progression. Exceptions are listed below:
    - Lesson 7: The answer key for the assessment lists "look-fors" and example student answers for three levels of student performance (e.g., page 8). However, the "look-fors" and example student answers do not show evidence of the claimed CCC element.
    - Lesson 11: The answer key for the assessment lists "look-fors" and example student answers for three levels of student performance (Length vs. Survivability Key, page 5).
    - Lesson 14: The answer key for the Design Challenge Organizer lists "look-fors" and example student answers for three levels of student performance (Design Challenge Organizer Key, page 4). Note the rubric for question 4 in the answer key does not match the "look fors" in the Teacher Edition. The former says that students are only using SEP **6.5**, but the latter says that students are only using SEP **1.8**, even though both say they are assessing the same two questions (4a and 4b). This difference might be confusing for teachers.
    - Lesson 15: The answer key for the Pedestrian Solutions Summative assessment lists "look fors" for three levels of student performance (Pedestrian Solutions Key, e.g., page 3). Example student answers for three levels of student performance are also provided for question 7 (Pedestrian Solutions Key, page 6).
- Lesson 9: In the answer key for the Comparing Speeds handout, only "look-fors" are given without any sample student answers. In addition, inaccurate scoring guidance is given to the teacher. In Question 1, students are asked, "What dependent variables are changing in each graph and what was the independent variable for these conditions?" and the teacher is told that this particular individual prompt elicits students' performance related to **the following two SEP elements:**
    - *Analyze data to identify design features or characteristics of the components of a proposed process or system to optimize it relative to criteria for success.*
    - *Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects.*

  Note also that this answer sheet and the "Assessment Opportunity" box both say the assessment is building toward students developing an explanation rather than solving a design problem, even though students are only told (in Question 4) to solve a problem and then communicate scientific information about the solution and not to develop an explanation. The scoring guidance is therefore likely to be confusing or misleading for teachers.

Student-facing scoring guidance is described as an option in Lesson 14. "Consider giving written feedback outside class on their work so far and assigning the rest of the Final Product for home learning or providing students with an extra class day. If time allows, consider giving students a chance to present their work more formally to one another, using a co-created rubric to evaluate one another's work. As a class, students might identify the solutions with the most potential to impact change and provide suggestions for how to advocate for these solutions (city hall, parent groups, etc.)" (TE, page 269).

Suggestions for Improvement

- Consider ensuring a close match between scoring guidance and assessment prompts.
- Consider more often showing a range of student performance in scoring guidance and sample answers.
- Consider more often providing students with scoring guidance to aid in their self-assessment.

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. Students have several opportunities to represent their ideas on assessments using multiple modalities. However, some assessments only use a single modality.

The unit offers multiple opportunities for students to represent their responses to in-lesson task prompts using talking about their learning (illustrated by numerous turn-and-talk opportunities), creating visual representations (as evidenced by several opportunities to draw and redraw models, graphs, and figures such as timelines), writing short and more complex answers (as provided by the numerous sample student answer sections in each lesson). Students are also given some choices to represent their understanding and ideas, although a majority of individual student artifacts are only collected in written form. Related evidence includes:

- Lesson 1: "Use any combination of drawings, symbols, and/or words to explain how and why the solution(s) and/or factor(s) you chose might impact outcomes in a potential vehicle collision. Consider what happens in the system both before and during the event" (TE, page 42).
- Lesson 10: In the Design Solution Comparison handout, students are told they can "write or draw" the response to one prompt.

- Lesson 14: Students are given a choice of which problem to solve and are told they can "describe or draw the problem you decided on with your team" (Design Challenge Organizer, page 2).

Support is provided to ensure students are demonstrating their understanding in relation to the learning goals. For example:

- The vocabulary in the assessments is consistent with high school-level learning expectations and abilities.
- Lesson 3: "Students can use a calculator to do these calculations. Allowing alternatives for using tools such as a calculator can remove barriers for students in expressing their understanding by keeping the focus on the learning goal. Use of such tools can help provide a match between a student's abilities and the demands of the task. You might also consider allowing students to use a digital graphing tool such as a graphing calculator, or spreadsheet software such as desmos.com, to create their graphs" (TE, page 75).
- Lesson 3: At the end of the "Calculating Reaction Distances" handout, students are asked, "Is it clear how you got to the solutions? If not, take a moment to make your work more visible. Is it clear what the solutions are? If not, take a moment to circle or underline your solutions. Does each solution make sense as a possible outcome in the real world? Take a moment to read through and flag data that do not make sense. Re-do the calculation to make sure it is not an error" (TE, page 75).
- Lesson 7: "To warm up for the assessment, ask students to turn and talk about the prompt: How does knowing the mass of the vehicles involved help us predict what will happen to each car after a vehicle collision?" (TE, page 153).
- Lesson 11: A confusing prompt is given to students. They are told, "On part 1 of your handout, develop an initial claim using the results from these car collisions to explain how the rigidity of the crumple zone can be designed to increase safety during a collision." The teacher is told to say, "We have analyzed these graphs and noticed patterns about forces and time. Use these graphs to construct a claim about how changes in the crumple zone rigidity affect the forces acting on the crash test dummy on part one of your Investigating Rigidity handout" (TE, page 213). These two different prompts appear to refer to the same student performance. The student handout itself says, "Complete this sentence to develop your claim: As the crumple zone rigidity increases…" (Investigating Rigidity, page 1). Therefore, three different possible prompts are presented to students: one about the possible design of crumple zones, one about a cause-and-effect relationship between rigidity and forces, and one about an observed correlation between rigidity and forces. Sample student answers for all three prompts are provided in the "Assessment Opportunity" section for the teacher even though the student only has one of the prompts in writing. A similar issue is present in part 3 of the handout. The student prompt in the handout is, "Write your claim that answers the question: What design of crumple zone rigidity will result in increased safety during a collision? What evidence from the graphs support your claim?" (Investigating Rigidity, page 4). This prompt is similar to that on the corresponding slide (slide K). However, the teacher is told to say, "In your handout, develop an explanation using

evidence from the data we analyzed about how the rigidity of the crumple zone affects survivability in a collision" (TE, page 215).

- Lesson 12: "As students work through the argument comparison, they may need support in understanding the questions in addition to the prefilled example responses. Use the following guidance to help build their understanding. Write the argument claims here. Explain that this space is meant to be an area where students can quickly write up a description of the argument or design that was made. This allows us to better define the argument or design solution and gives us a place to record what each design or argument is about in case they need to reference it later" (TE, page 229).
- Lesson 15: "This task was designed to offer multiple representations of the designs to students. Information is available about each of the designs in narrated video form with a transcript and also as a reading for each design embedded in the assessment. This provides learners the ability to access information through both auditory and visual representations. In addition, consider using a text reader and pushing out the texts digitally in an editable form to increase access for students" (TE, page 275).

Suggestions for Improvement

- Consider including additional non-linguistic ways to prompt student responses in assessment and providing more opportunities in formal assessment for students to choose the modality of their response.
- In Lesson 11, consider ensuring that assessment prompts are consistent across the materials.

III.E. COHERENT ASSESSMENT SYSTEM

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

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

The reviewers found extensive evidence that the materials include pre-, formative, summative, and self-assessment measures that assess three-dimensional learning. Teachers are supported to understand how different assessments could work together to support student learning, although there is an emphasis on DCIs (to the exclusion of SEPs and CCCs) in some parts of the assessment system, especially student self-assessment.

Assessment System Guidance

- In the Overview document, there is a detailed description of the materials' intent regarding assessment, along with examples. A table starting on page 38 tells teachers where certain types of assessments occur per lesson, along with a description of the "Purpose of Assessment" for that lesson. Types of assessments listed include pre-assessment (one), formative assessment (at least one and often two per lesson), summative assessment (five), and self-assessment (engineering tracker three times, self-assessment discussion multiple times). For example, the purpose of the Lesson 4 Formative assessment is listed as, "At the beginning of Lesson 4, students use what they know so far in conjunction with their prior knowledge about forces to make predictions about how changing variables will affect braking time. They use speed versus time graphs to do this. This builds off of the work they have done with graphs in Lessons 2 and 3 and leads towards continued use in Lessons 6, 7, 10, and 11. This is a good moment to see where students are struggling with representing their claims in graphs and provide additional support if needed before they engage supporting claims with graphs on the Braking Exit Ticket later in Lesson 4 and in later lessons" (Unit Overview, page 38).

Pre-Assessment:
- Lesson 1: "This lesson is an opportunity to pre-assess students' ideas about how force, mass, and velocity might affect changes in motion in a system" (TE, page 34).
- Lesson 1: "Throughout this unit, students will engage with CCC element 2.3, *Systems can be designed to cause a desired effect*, many times. Use the initial model work during this lesson as a way to assess students' prior knowledge on this element" (TE, page 42).

Self-Assessment:
- Lesson 6: The teacher is told, "Distribute the Momentum Self-Assessment Key to each student. Say, 'This is a key for the questions you started working on. At the end, you'll reflect on your confidence in using our equations to solve the practice problems. How could we use all of this to help us as learners so we're well prepared for doing this kind of thinking on our next summative assessment?'" (TE, page 145).
- Lesson 12: "As students return to their seats, have them use green and red sticky dots to mark the Gotta-Have-It Checklist poster with one idea they are confident about and one they are still figuring out" (TE, page 233).
- Unit Overview: The teacher is told that the Engineering Progress Trackers can be used for student self-assessment, but students are unlikely to be able to ascertain information related to their SEP and CCC learning goals.

Formative assessment
- See related evidence under Criterion III.B.

Summative assessment
- Lesson 7: Students are given an assessment task that uses a real-world context. Students are told, "In this assessment, you will use the results from their published paper to evaluate

whether the outcomes of each collision can be predicted using what you learned about momentum conservation" (Assessment Bus Collision, page 1).

- Lesson 11: In relation to two SEP elements, the teacher is told, "These elements have been used across this unit in multiple lessons. This lesson is the final lesson that engages students with these elements. Therefore, the final assessment moment in this lesson is designed to be an individual, summative assessment of these elements" (TE, page 210). In the related "Assessment Opportunity" section, the teacher is told, "This is the last lesson in the unit where students will be assessed in the practices of engagement with analyzing and interpreting data, and using mathematics and computational thinking practices that they have developed across multiple lessons. We suggest using it as a summative assessment moment" (TE, page 218).
- Lesson 15: Students are given an end-of-unit transfer task to assess NGSS PE **HS-PS2-3**.

Suggestions for Improvement

Consider supporting a robust system of assessments for all three dimensions.

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

The reviewers found extensive evidence that the materials provide multiple opportunities for students to demonstrate performance of practices connected with their understanding of DCIs and CCCs. Teachers are frequently prompted to give students feedback after assessments, and students have opportunities to demonstrate their performance again on most of the targeted elements after receiving feedback. However, teacher feedback prompts are heavily focused on DCIs and SEPs rather than on all three dimensions equally.

Related evidence includes:

- Lesson 3: "Move around the classroom while students are working. You can also collect students' handouts at the end of class to give more-focused feedback… Flag incorrect solutions and graphing errors but focus feedback on questions 4 and 5 on the handout" (TE, page 76). Although CCC-specific feedback guidance is not given to teachers, students have opportunities to use the targeted CCC again in the subsequent two lessons.
- Lesson 11: The teacher is told, "Provide written feedback to students. Also take note of which students will need extra support during the graph analysis and claim making in Day 2 of this

lesson….The feedback that you provide will be instrumental in helping students complete the summative assessment on day 2 of this lesson" (TE, page 216).

- Lesson 12: "Say, In order to strengthen our shared understanding and our explanations, we are going to share our explanations and give and receive feedback from each other. Then you will have an opportunity to revise your explanation" (TE, page 234).
- Lesson 12: The teacher is told, "When reviewing individual work, provide comments on where students could strengthen their answers by adding more details or being specific about connections to the reading. Next lesson, students will be engaging in this activity again with other arguments. Return the written feedback to students before you do this activity" (TE, page 237).
- Lesson 14: The teacher is told, "Say, Be ready to hand in one group member's copy of the Design Challenge Organizer at the end of class. I'll read through your progress on question 3 and give you my thoughts. If I have any resources or evidence that could be useful to you in coming up with solutions, I'll suggest those to you in our next class" (TE, page 260). The next day, the teacher is told, "Give students 4 minutes to review feedback in groups and to locate or browse through any resources you have provided" (TE, page 261).

Suggestions for Improvement

Consider more often prompting teachers to include feedback about students' CCC performance such that students will consider that CCC feedback in advance of their next related assessment opportunity.

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 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

Collisions and Momentum

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)