Lesson 10: How are the bodies of cars designed to make collisions safer?

Previous Lesson *We read about force interactions on drivers during collisions. We made predictions and collected data from a simulation about how safety features affect force of contact versus time. We tried to optimize the characteristics of seat belts and airbags in a simulation. We used simulation results to explain why survivability changes in different vehicle collisions.*

This Lesson

Investigation

2 days

We make observations of a collision between two cars designed and built 50 years apart. We hypothesize that the car's crumple zone affects driver safety. We propose and compare designs for a crumple zone that can provide better protection for the driver. We use a simulation to investigate how two variables from the front of the car, crumple zone length and rigidity, influence the safety of the driver.

Next Lesson *We will analyze crash test results from simulated collisions to understand how the crumple zone's rigidity and length influence occupant safety. We will use ideas about matter, energy, and forces to explain how the crumple zone design enhances collision safety.*

BUILDING TOWARD NGSS

HS-ETS1-3, HS-PS2-2, HS-PS2-3, HS-PS2-1

What students will do

10.A Design and evaluate a solution to reduce the peak force (function/effect) in a collision through the choice and modification of type of material and the structure (causes) used in building, testing, and comparing physical models of alternate front-end crumple-zones. (SEP: 6.5; DCI: ETS1.B.2, ETS1.A.1; CCC: 2.3, 6.2)

10.B Analyze force and motion graphs of cart collisions with differing front-end crumple zone designs as well as driver survivability data in order to identify patterns in peak forces, time of impact, and design characteristics of the crumple zone (amount of deformation, thickness of material, and structure/length). (SEP: 4.6, 5.2; DCI: ETS1.A.1, PS2.A.1; CCC: 2.3, 6.2)

What students will figure out

- Using lower-rigidity materials in the crumple zone leads to a decrease in the (peak and average) magnitude of the net force acting on the vehicle during the collision.

- For lower-rigidity materials, the longer the crumple zone, the more time available to apply a force to the car to slow it down.
- The product of the magnitude of the net force and the time it acts on an object contributes to the object’s change in momentum.
- When the crumple zone is too short, the peak force is very high and the time is very short.

Lesson 10 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	3 min		**NAVIGATE** Reflect on what we have figured out about seat belts and airbags and consider other vehicle design features related to safety.	A-B	
2	11 min		**MAKE PREDICTIONS AND OBSERVATIONS OF CRASH TESTS** Have students make predictions and then show a video of a crash test between two cars: one designed and built in 1959 and another designed and built in 2009.	C-G	https://youtu.be/9iA31TWGJpM, M-E-F Triangle poster
3	12 min		**INTRODUCE THE CRUMPLE ZONE DESIGN ACTIVITY** Compare two different crumple zone designs and their force versus delta t graphs.	H-J	*Design Solution Comparison*, Control Condition Collision
4	16 min		**DESIGN CRUMPLE ZONES** Design and test various crumple zones with the objective of lessening the force on the car.	K-M	*Design Solution Comparison*, sanitized safety glasses with side shields, Crumple Zone Designs
5	3 min		**NAVIGATE** Students individually compare their own designs.	N	*Design Solution Comparison*
					End of day 1
6	3 min		**NAVIGATE** Identify the criteria from the design activity on day 1.	O	*Design Solution Comparison*
7	8 min		**CRUMPLE ZONE DESIGN GALLERY WALK** Complete a virtual gallery walk of various crumple zone designs and identify characteristics of the safest designs.	P	*Design Solution Comparison*, computer
8	15 min		**DISCUSS THE SAFEST DESIGNS** Conduct a Building Understandings Discussion to come to identify the characteristics led to the safest designs.	Q	*Design Solution Comparison*, Force and Motion Relationships poster from Lesson 6 and updated in Lesson 9, transparent

					tape, copy paper, chart paper markers, two different spring scales (optional)
9	4 min		**CONNECT TO PEOPLE AND SAFETY** Motivate the need to look at driver safety data.	R	
10	12 min		**TEST THE EFFECT OF CRUMPLE ZONE LENGTH AND RIGIDITY ON SURVIVABILITY IN A SIMULATION**	S-V	computer, https://s3.amazonaws.com/p.3simulation/collisions/crumple-zones.html
11	3 min		**NAVIGATE** Discuss why the force on the car would be related to the likelihood of survival.	W	

End of day 2

Lesson 10 • Materials List

	per student	per group	per class
Control Condition Collision materials			• smart cart • smart cart track • quick-release magnetic bumper mount (see the *Pasco Quick-Release Mount* and *Vernier Quick-Release Mount* references) • steel double-wide mending plate (3.5” wide) • computer with data collection software (see https://youtu.be/1LLZEYo1Yzk or https://youtu.be/iJB1o6WOxqY)
Crumple Zone Designs materials		• steel double-wide mending plate (3.5” wide) • green index card (labeled with group letter) • yellow index card (labeled with group letter) • red index card (labeled with group letter)	• regular aluminum foil • heavy-duty aluminum foil • copy paper • cardstock • cardboard • transparent tape • masking tape • smart cart • smart cart track • quick-release magnetic bumper mount (see the *Pasco Quick-Release Mount* and *Vernier Quick-Release Mount* references) • computer with data collection software (see https://youtu.be/1LLZEYo1Yzk or

			https://youtu.be/iJB1o6WOxqY) ● camera
Lesson materials	● science notebook ● *Design Solution Comparison* ● sanitized safety glasses with side shields	● computer	● https://youtu.be/9iA31TWGJpM ● M-E-F Triangle poster ● Force and Motion Relationships poster from Lesson 6 and updated in Lesson 9 ● transparent tape ● copy paper ● chart paper markers ● two different spring scales (optional) ● computer ● https://s3.amazonaws.com/p.3simulation/collisions/crumple-zones.html

Materials preparation (120 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Make copies of the handout in this lesson:

- *Design Solution Comparison* (1 per student)

Make copies of the following handout only if you choose to do the the optional activity that requires them:

- *Two-Car Collision Forces* (1 per student)

Three-hole-punch all handouts so they can be added to students' notebooks.

Test the video and simulation in this lesson:

- https://youtu.be/9iA31TWGJpM
- Vehicle Collision Simulation: Crumple Zone restricted view, https://s3.amazonaws.com/p.3simulation/collisions/crumple-zones.html

Make sure the following are visible in the classroom for students to reference.

- The Force and Motion Relationships poster from Lesson 6 and updated in Lesson 9.
- The M-E-F Triangle poster

Day 1: Control Condition Collision

- **Group size:** whole-class demonstration
- **Setup:**
  - Put together a track system and magnetic bumper for the type of smart cart you are using, following the directions in either the *Pasco Quick-Release Mount* or *Vernier Quick-Release Mount* reference.
  - Review the directions for setting up the software to display force versus time and speed versus time graphs for the type of smart cart you are using:
    - Pasco system, https://youtu.be/1LLZEYo1Yzk
    - Vernier system, https://youtu.be/iJB1o6WOxqY
  - Collect the force versus time and velocity versus time data for the control condition. Save an image of the resulting graphs and swap it into **slide I**.
  - The materials identified in the rest of this lesson outline are listed with the assumption that you are using *Pasco Quick-Release Mount*.
- **Notes for during the investigation:** Make sure students understand that the test cart's original steel mending plate attachment serves as the control condition simulating a vehicle designed without a crumple zone. Before moving on to the design activity, explain:
  - which side of the steel mending plate to mount their crumple zone on
  - the need to minimize the amount of tape on the back side of their steel mending plate
  - that their crumple zone model should not touch the track when attached to the magnetic bumper

Day 1: Crumple Zone Designs

- **Group size:** 2-3 students
- **Setup:**
  - If student groups do not have their own phone camera available, provide a computer or photo camera to take photographs and upload them.
  - Create and share a virtual space for students to upload their designs and data. It may be helpful to use a table format so these are easier for students to analyze. An example is shown here:

Names	Structure before crash test	Structure after crash test	Crash test graphs

    - Each group needs 1 steel double-wide mending plate (3.5” wide).
    - Gather these supplies to make available for all groups:
        - regular aluminum foil
        - heavy-duty aluminum foil
        - copy paper
        - cardstock
        - cardboard
        - transparent tape
        - masking tape (or painter’s tape)
        - sanitized safety glasses with side shields (for each student)
    - Insert a picture of the supplies available to students on **slide J**.
    - Place the materials you construct in a location that is easily accessible for all students.
    - Prepare group identification tickets for each group, by labeling 3 index cards with the corresponding unique group letter (e.g., A) written on them in different colors (e.g., green, yellow, and red). Students will add their names to these cards.
- **Notes for during the investigation:**
    - Use the color of the index cards’ letters as consumable tickets to ensure that each group has at least one turn at testing their devices and/or that groups who have had fewer turns can go ahead of those who have had more turns. You can do this by having everyone use their green-labeled card first and turn it in after taking a photo of their before versus after crash test results. Those who still have a green card can jump in line in front of those with a yellow or red card.
    - Tell partner pairs to have one person upload the images to the virtual space and the other person work on removing their crumple zone from the cart so the line moves quickly and more students have a chance to try multiple designs.
- **Disposal:** A few minutes before the end of class, have students dispose of materials that cannot be reused.
- **Storage:** The steel mending plate attachments and unused building materials should be stored together.

When working with the lab materials, the following safety precautions are necessary.

- Students must conduct the experiment under the supervision of qualified personnel who can respond quickly to any unforeseen circumstances.

- Students involved in setting up the equipment and conducting the experiment must be properly trained in handling the sensor carts and understand the experimental procedures.
- Wear appropriate personal protective equipment (PPE) including sanitized safety glasses with side shields during the setup, experimentation, and takedown segments of the activities.
- Secure loose clothing, wear closed-toe shoes, and tie back long hair.
- Clear the workspace of any obstacles or hazards that could interfere with the experiment or cause accidents during the collision.
- Make sure that all parts of the carts are properly secured and stabilized before conducting the collision test. Follow manufacturer guidelines for setup and operation.
- Immediately clean up anything that falls on the floor, so it does not become a slip or fall hazard.
- Maintain a safe distance from the collision area during the activity to avoid injury from flying debris or malfunctioning equipment.
- Following the activity, inspect all equipment for any damage or wear and tear. Repair or replace any damaged components before further use.
- Wash hands with soap and water once all equipment is put in appropriate storage areas.

Lesson 10 • Where We Are Going and NOT Going

Where We Are Going

During this lesson, students engage in a series of data analyses: some on their own, some as a group, and some as a class. They investigate how the structure of a crumple zone--specifically, its length and rigidity--can influence the changes in velocity of a vehicle and the driver during a collision. They investigate how the design and structure of the crumple zone can affect the time and magnitude of the forces acting on the vehicle.

Because of this, this lesson reinforces ideas related to the following disciplinary core idea (DCI):

- **PS2.A.1 Forces in Motion:** Newton's second law accurately predicts changes in the motion of macroscopic objects. (HS-PS2-1)

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.

Students encounter some words that guide their sensemaking in this lesson: *rigidity* and *crumple zone*. They may choose to add these words to their Personal Glossary. **Do not** ask students to define or keep track of any words until after your class has developed a shared understanding of their meaning.

Where We Are NOT Going

This is not a lesson about work. Although the idea of work can be used to derive the forces acting on an object, here instead we focus on Newton's second law to make sense of the changes in motion and forces acting on a vehicle and driver during a collision.

LEARNING PLAN for LESSON 10

1 · NAVIGATE

3 min

MATERIALS: science notebook

Present **slide A.** Give students a half minute to read the student content advisory.

Consider additional safety features. 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.* Present **slide B**. Initiate class discussion by reading the slide's prompt aloud:

- *What are some ways in which the body of the vehicle could be redesigned to make a collision safer?*

Have students share out. Accept all responses. Here are a few examples:

- Add a cushion-like material to the front or back of the car (e.g., a spring, airbag, padding).
- Add repulsive magnets to the front or back of the car.
- Make the car out of stronger materials.

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.

2 · MAKE PREDICTIONS AND OBSERVATIONS OF CRASH TESTS

11 min

MATERIALS: science notebook, https://youtu.be/9iA31TWGJpM, M-E-F Triangle poster

Make predictions about old versus new cars. Present **slide C**. Say, *I have a video of two cars, one built in 1959 and one built almost 50 years later. The older car has a more rigid body than the newer one.* 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.

Say, *Assume that safety features like seat belts and airbags are the same in both cars, and focus only on the body of the vehicle. Which car do you think will be safer in a collision, and why?* ✱

Have students turn and talk about their predictions. After 1-2 minutes, elicit 2-3 ideas. Listen for students to say something like "The new car will be safer because it will slow down the collision and reduce peak forces" or "The old car will be safer because it is more rigid and will protect the people inside from the forces." Accept all ideas.

Record observations from a video. Present **slide D.** Say, *Let's see what we notice in a video showing the results of a crash test between both of these vehicles.* Show the video https://youtu.be/9iA31TWGJpM.

ADDITIONAL GUIDANCE	**Social Emotional Learning (SEL):** Some students may have experienced trauma related to car collisions. Emphasize before showing the video that it is from an experiment with crash test dummies in order to prevent students from assuming that there are people in the vehicles. As you project the video, be mindful of any changes in students such as body language adjustments, intonation, and distraction. If a student seems to exhibit any changes, consider asking them privately and quietly if they would like to step out and see the counselor or take a moment to themselves for a break in the hallway or bathroom.

Share observations. Present **slide E.** Have students turn and talk with a partner about their observations.

Discuss observations of the crash test. Present **slide F**. Use the slide's two screenshots as a reference. Listen for these ideas:

- The material in the front of both cars crumpled.
- Parts of the passenger area (safety cell) crumpled in the older car.
- Very little (or almost none) of the passenger area (safety cell) crumpled in the newer car.

If students don't make those observations, use the following prompts:

- *How far back in the vehicle system does the deformation go? Where does it stop?*
- *What do you notice about the material around where the driver is sitting in both cars? Is the amount of deformation there the same?*

It may be helpful to mark the place on the slide where the deformation appears to stop for the newer versus the older vehicle.

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.*

Motivate the need to investigate the crumple zone. Display **slide G**. Read the text at the top of the slide aloud and then emphasize the following:

- Engineers knew prior to this that the passenger compartment needed to be relatively rigid to prevent it from crushing in on the occupants.
- However, they also thought the parts of the vehicle body that extend in front of and behind the passenger compartment also needed to be rigid.
- It was so counterintuitive to many engineers that it might be better to design those parts to crumple that only some car

manufacturers started adding them into their designs in the 1960s, and the majority didn't adopt them into their designs until the 1990s.

Ask the question on **slide G** and discuss it as a class, *Why would crumple zones increase passenger safety?* Possible responses may be about change in matter, forces, or energy. Accept all answers.

Suggest that we consider our M-E-F triangle poster and reference the left side of it. Connect observations from the video to ideas developed in Lesson 9 using the prompts in the table below:

Suggested prompt	Sample student response
What evidence did we see in our prior lesson that the contact forces on a vehicle during a collision were correlated to the forces that act on the person inside it?	When we increased the speed of the vehicle in the simulation, it increased the forces on the vehicle. And we saw this was correlated to higher-magnitude forces on the test dummy and higher risk of fatality.
How is designing a car to crumple related to what we know about forces and elastic limits of a material?	(Listen for students to make connections back to the Earth's Interior Unit.)
So, would designing something to crumple increase or decrease the magnitude of the forces that a vehicle experiences during a collision?	(Accept all predictions.)

ALTERNATE ACTIVITY	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.

3 · INTRODUCE THE CRUMPLE ZONE DESIGN ACTIVITY

12 min

MATERIALS: Control Condition Collision, *Design Solution Comparison*

Orient to the crash testing track. Present **slide H**. Gather the class around the smart cart track. Point out that the cart currently has no crumple zone on the front, only a rigid metal plate, so we can consider this a control condition. Tell students that you are going to launch the cart at the barrier at the end of the track.

Either project the force versus time and velocity versus time data for this collision as you run it, or tell students that you will project the data from this condition on the next slide (**slide I**). Launch the cart at the barrier.

After launching the cart, either continue to display the graphs produced from the collision or project **slide I**. Discuss the two related questions in the table below as a class.

The values (in bold) in the sample responses reflect the data on **slide I** and will be different if you are projecting the graphs produced from the collision condition you just ran. ✱

Suggested prompt	Sample student response
What do we notice?	The shape of the force graph is similar to what we saw in Lesson 6. The change in velocity graph has a shape similar to what we saw in Lesson 6. The peak magnitude force is around **20 N**. The velocity decreases by about **0.9 meters per second**, from about 0.6 meters per second to about -0.3 meters per second. The time the collision lasted (Δt) is around **0.1 seconds**.
What should adding a crumple zone do to both graphs?	Result in a lower maximum force. More time to slow down in the velocity graph. The force spread out over more time.

Identify the problem and the design criteria. Present **slide J**. 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. Discuss these criteria using the prompts in the table below.

Suggested prompt	Sample student response
What is the problem that we're trying to solve with a crumple zone?	How to make cars safer through the design of crumple zones.
What criteria are we using to evaluate these design solutions?	Peak force reduction. Length of time that forces are applied.
How would comparing all of our results help us understand how crumple zones work?	How they're built (structure). What they do in a collision (changes). Why they do that (mechanisms related to M-E-F).

Distribute the *Design Solution Comparison* handout to each student. Give them a few minutes to answer the questions in Part A on their own.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment:

- Students identify the problem relating the structure of crumple zones and how/why they affect passenger safety (DCI: ETS1.A.1; CCC: 2.3, 6.2)
- Students identify the criteria we will use to evaluate alternative solutions (cause) that include one or more of the following effects: peak force reduction and/or increase in the length of time forces are applied (DCI: ETS1.A.1; CCC: 2.3)
- Students describe how comparing the results from all of our physical models will help us better understand how/why crumple zones work and are designed to reduce the peak force (SEP: 6.5; DCI: ETS1.B.2, ETS1.A.1; CCC: 2.3, 6.2)

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.

Building toward: 10.A.1 Design and evaluate a solution to reduce the peak force (function/effect) in a collision through the choice and modification of type of material and the structure (causes) used in building, testing, and comparing physical models of various front-end crumple-zones. (SEP: 6.5; DCI: ETS1.B.2, ETS1.A.1; CCC: 2.3, 6.2)

4 · DESIGN CRUMPLE ZONES

16 min

MATERIALS: Crumple Zone Designs, *Design Solution Comparison*, sanitized safety glasses with side shields

Go through the safety protocols. Before students begin their data collection, display **slide K** and review the general safety protocols for the activity.

Review instructions for design building. Present **slide L**. Show students the materials available to them. Partners or groups are to work together to design, build, and document their own crumple zones using the materials provided. Explain that we will all work with the test cart that was used during the Control Condition Collision demonstration, but each partner or small group will have their own steel mending plate attachment to swap onto the front of the cart for their crumple zone models.

ALTERNATE ACTIVITY

A picture of the supplies you will be providing students should be on **slide K** or you can show students what you have placed at the materials supply station.

As students create their designs, they should log their ideas in Part B of the *Design Solution Comparison*. Ask whether they have questions about this part of the design work.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment:

- Students design physical crumple zone models that are made to collapse in order to reduce the peak force (SEP: 6.5; DCI: ETS1.B.2, ETS1.A.1; CCC: 2.3, 6.2)
- Students evaluate their designs using the data from the graphs as well as the observational data for whether or not (or how much) the peak force is reduced (function/effect) in each of their physical models (SEP: 6.5; DCI: ETS1.B.2, ETS1.A.1; CCC: 6.2)

What to do: Use the table on the *Design Solution Comparison* handout for formative assessment. If students struggle with interpreting the graphs, ask them to focus on identifying what the peak forces are in each case and remind them of our design criteria.

Building toward: 10.A.2 Design and evaluate a solution to reduce the peak force (function/effect) in a collision through the choice and modification of type of material and the structure (causes) used in building, testing,

	and comparing physical models of alternate front-end crumple-zones. (SEP: 6.5; DCI: ETS1.B.2, ETS1.A.1; CCC: 2.3, 6.2)

Review instructions for design testing. Present **slide M**. When one of their designs is complete, students should take a photo of it with their index card and get in line for using the test cart. When it is their turn, they should attach their crumple zone model to the test cart. You (the teacher) will run the collision test.

After the test, students should take these two photos:

- their graphed results with the corresponding index card
- their car and its deformed bumper with the corresponding index card

Students should then upload all three photos for their design into the shared virtual space and turn in the index card they just used as a record of having completed that round of testing.

Students can create and test as many designs as they have time for. However, priority for using the testing cart should go to those students who haven't had as many tests. Use the different index cards (green first, yellow second, red last) to signify the number of rounds they've completed.

5 · NAVIGATE

3 min

MATERIALS: *Design Solution Comparison*

Compare results. Present **slide N**. Have students reflect on their designs and consider the questions in their handout (and on the slide):

- *Which of **your** designs best met our design criteria? What is your evidence?*
- *What about its structure enabled it to do this?*

Collect the *Design Solution Comparison* before students leave.

ADDITIONAL GUIDANCE	Remember to review the virtual space in order to identify extreme cases and which designs you will want the class to focus on next time. To save time, rather than having students review all of the designs, identify 3-5 designs/graphs to focus on as a class; make sure one has an ideal design that stretches out the collision time and reduces the peak force, one has a design that maxes out the peak force, and one is in between. You can move these to the top of the virtual space or simply identify them as "to be discussed" by the class.

If students' designs do not allow for this, you need to include designs from another class or designs of your own.

End of day 1

6 · NAVIGATE

3 min

MATERIALS: science notebook, *Design Solution Comparison*

Reorient to the design challenge. Present **slide O**. 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.

7 · CRUMPLE ZONE DESIGN GALLERY WALK

8 min

MATERIALS: *Design Solution Comparison*, computer

Analyze data and evaluate designs. Present **slide P**. Have students work in partners to look in the class's virtual space at the data collected and identify the designs that best met our design criteria. Then have them write in Part C of their handout what they notice about the graphs **and** the actual designs. ✱

As students work, circulate and probe with questions like the following:

- *What do the safest designs have in common in terms of what they were made of or how they were designed?*
- *What do you notice in the graphs of the safest designs?*

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment:

- Students analyze force and motion graphs of cart collisions with differing front-end crumple zone designs in order to identify the designs with the lowest peak force (function/effect). (SEP: 4.6, 5.2; DCI: PS2.A.1; CCC: 2.3, 6.2
- Students analyze force and motion graphs of cart collisions with differing front-end crumple zone designs in order to relate lower peak forces (function/effect) to longer time of collision (cause) (SEP: 5.2; DCI: ETS1.A.1, PS2.A.1; CCC: 2.3)
- Students identify patterns in design characteristics of the crumple zone (amount of deformation,

✱ ATTENDING TO EQUITY

Universal Design for Learning: It is important to organize activities in ways that create opportunities to support student *engagement* in meaningful, accountable talk by emphasizing socially safe activity structures. 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.

thickness of material, and structure/length) that led to the lowest peak force (SEP: 4.6; DCI: ETS1.A.1, PS2.A.1; CCC: 2.3, 6.2)

What to do: Collect the *Design Solution Comparison* again at the end of the class period in order to check student understanding. Encourage students to look not only at the graphs but also at the physical designs in order to consider the material and structure of the design.

Building toward: 10.B.1 Analyze force and motion graphs of cart collisions with differing front-end crumple zone designs as well as driver survivability data in order to identify patterns in peak forces, time of impact, and design characteristics of the crumple zone (amount of deformation, thickness of material, and structure/length). (SEP: 4.6, 5.2; DCI: ETS1.A.1, PS2.A.1; CCC: 2.3, 6.2)

During this unit, there will be instances described in which students immediately engage in whole-class discussion. Insert a partner talk prior to the whole-class discussion if you believe this would benefit your students' ability to communicate and *express* their ideas.

8 · DISCUSS THE SAFEST DESIGNS

15 min

MATERIALS: *Design Solution Comparison*, science notebook, Force and Motion Relationships poster from Lesson 6 and updated in Lesson 9, transparent tape, copy paper, chart paper markers, two different spring scales (optional)

Convene in a Scientists Circle. Ask students to bring their *Design Solution Comparison* to a Scientists Circle. Tell them they can add to their ideas on their handout throughout the discussion. Present **slide Q**. Conduct a Building Understandings Discussion focused on which designs best met the criteria. ✱ Start by focusing on the graphs.

KEY IDEAS

Purpose: The purpose of this discussion is to press students to identify evidence from the graphs for each pattern they report out, so the class comes to agreement on the ideas listed below.

Listen for these ideas:

- When time of impact increases, peak force magnitude decreases.
- Crumple zones that are longer result in longer times of impact, and therefore lower-magnitude peak forces.
- Crumple zones that are more rigid lead to higher-magnitude peak forces.

Suggested prompt	Sample student response
Which of our designs best met our criteria?	(Answers will vary depending on the designs created by the class.)
What do all of these designs have in common in terms of the force data we collected?	They have lower peak forces. They occur over a longer period of time.
How does this relate to what we learned about seat belts and airbags?	They also increased the time of collision. As time increased, force decreased.

Cue students to the Force and Motion Relationships poster from Lesson 6 and updated in Lesson 9. Refer to the poster's four equations, reminding the class that these are equivalent:

- $\Delta t = m(\Delta v / F)$

✱ STRATEGIES FOR THIS BUILDING UNDERSTANDINGS DISCUSSION

A Building Understandings Discussion is useful after an investigation because its purpose is to focus students on drawing conclusions based on evidence. 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?*
- *Does any group have evidence to support Group A's claim?*
- *What data do we have that challenges Group B's claim?*

✱ ATTENDING TO EQUITY

Supporting emergent multilinguals: 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

- $F = m(\Delta v / \Delta t) = ma$
- $a = F/m$
- $F\Delta t = m\Delta v$

Establish that the mass and velocity are relatively the same for the cart in each test run. Say, *When we brought the cart to a complete stop with a crumple zone, we changed its momentum by the same amount by bringing its velocity to 0. However, some bumpers did this with less force than others. Let's revisit our equations to figure out what's going on.*

Rewrite the last equation on the board:

	$F\Delta t$ =	$m\Delta v$
The two variables that are changing		The change in momentum of the vehicle was constant in every case where we brought its velocity to 0.

Help students make sense of this form of the equation with the prompts in the table below.

Suggested prompt	**Sample student response**
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?	The force multiplied by the time it is applied is equal to the change in momentum.
If we change the momentum of an object by a certain amount, but want to do that over a short time, what has to happen to the magnitude of the net force applied to it?	It needs to increase.
If the materials we use for a crumple zone reduce the amount of force they apply by half, then how much time will that force need to be applied in order to bring a vehicle to a stop?	It would need to double.

Write this statement on the board:

- The product of the magnitude of the net force and the time it acts on an object contribute to the change in momentum that object experiences.

in your hands and try to bend them. Ask students whether each material is rigid or not rigid.

Ask students for examples of where we saw evidence of this in the prior lesson for something other than the vehicle. They will say we made similar claims about the relationship for the person in the vehicle.

Bring students' attention to the physical designs of the crumple zones using the slide's third question:

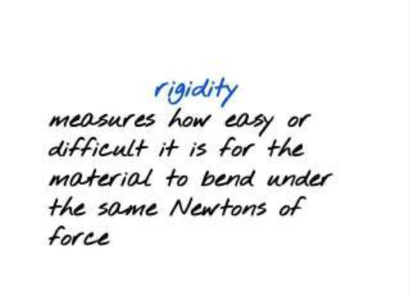
- *What do you notice about what they have in common in terms of their materials/designs?* ✱

Continue the discussion with the prompts in the table below.

Suggested prompt	Sample student response
How did the design of the bumpers enable them to increase the time over which the contact force was applied?	They crumpled longer. They had more space to crumple. They gave the vehicle more time to slow down.
Did any materials seem to work better than others?	The materials that were able to deform rather than stay intact worked better.
What if we used foil or paper that was 4 times as thick? Do you think that would crumple as easily or less easily?	It would be harder to crumple.
So, what would that do to the time?	Decrease the time.
If something is harder to crumple or deforms less under the same amount of force, it is considered more rigid. So, what would more rigid materials do to the peak forces? Why?	Increase the forces, because there is less time of collision.
Do you think any design that increases the time or distance over which forces are applied, will decrease the peak forces in a collision?	I think so. Probably.

Give time for students to add words to their personal glossaries such as *rigidity* and *crumple zone*. If students are still struggling with defining rigidity, consider using two different spring scales to show the difference in the ease of compressing/stretching each. An example student definition is: *rigidity is the stiffness or sturdiness of a material, and more rigid materials are harder to bend*.

Then say, *Until the crumple zone was invented, engineers thought designing vehicles to have more rigid fronts and backs was safer because those didn't deform as easily. But they didn't reason this through the way we have. Sure, those deform less, but that means the peak forces produced in a collision are higher, which is something we're trying to avoid.*



9 · CONNECT TO PEOPLE AND SAFETY

4 min

MATERIALS: None

Consider connections to safety. Have students remain in the Scientists Circle. Present **slide R**. Say, *So, in the design of our cars, we've been testing ways to reduce the magnitude of the forces on the* ***car****, which we thought was an important design criterion. But let us consider why that would have anything to do with safety for the driver or passengers.* Discuss the questions on the slide.

Suggested prompt	Sample student response
How do we think these crumple zones affect the forces on the people in the vehicle?	They reduce the forces on the people.
How is this related to passenger safety?	It reduces injury.

Problematize the lack of a person in the crumple zone tests. Say, *The force sensor only measured the force on the front of what might be thought of as the safety cell. Also, our safety cell didn't have things like seat belts, airbags, a dashboard, or a roof, let alone a crash test dummy. So, what type of data did we look at from the simulation in the previous lesson to support our claims about passenger safety?* Accept all responses.

Suggest that we return to the simulation and use a version where we can adjust the characteristics of the crumple zone to see if it contributes to the related measures we took for the inside of the vehicle in the last lesson work together to impact the related safety outcomes.

10 · TEST THE EFFECT OF CRUMPLE ZONE LENGTH AND RIGIDITY ON SURVIVABILITY IN A SIMULATION

12 min

MATERIALS: computer, https://s3.amazonaws.com/p.3simulation/collisions/crumple-zones.html

Orient to the simulation. Display **slide S**. Display the simulation: https://s3.amazonaws.com/p.3simulation/collisions/crumple-zones.html. Go over the variables that can be adjusted in this version of the simulation.

<table>
<tr>
<td>Vehicle Collision Simulator: Crumple Zones</td>
<td>
Before displaying the simulation, Select “Reset Simulator” at the bottom right so the review trials table doesn’t show any data yet.


Display the simulation and then select “New Trial” to view the input settings page. Note which variables can be changed.
Select “Run” and show students where Likelihood of Survival is in the outcomes list on the left side of the screen.
Select the “Home” tab at the top and show how the trials populate in the Review Your Trials table.
If necessary, also overview the manage work option on the right of the home page.

Note that in this lesson, the class will not need to review the trial data tables or graphs. These will be used extensively in the next lesson.
For more information on the simulation, see Simulation Use Guide and Collision Simulation Information from Lesson 7.
</td>
</tr>
</table>

Tell students that for today we will just focus on the crumple zone length and rigidity inputs and the likelihood of survival outcome, which is provided as a percentage.

Ask, *What would a high or low percentage for likelihood of survival tell us?* Students should say that a higher percentage means the driver has a better chance of surviving, and a lower percentage means they may be hurt or killed.

Make a claim about the crumple zone. Display **slide T**. Explain the chart. Remind students that we will test both the length and the rigidity of the crumple zone. Ask them to quietly select the letter from the slide for the length and rigidity combination that they believe will result in a safer design for the driver. Encourage them to use their experiences in our crumple zone design testing to inform their choice.

After about a minute, ask students to share out their responses. In addition, ask them which scenarios they believe will result in the lowest chance of survival.

ASSESSMENT OPPORTUNITY	**What to look for/listen for in the moment:What to look for/listen for in the moment:** Listen for students to connect the design characteristics of the crumple zone in the simulation (thickness of material and structure/length) (cause) with driver survivability data (effect). (SEP: 4.6; DCI: ETS1.A.1; CCC: 2.3, 6.2) **What to do:** If students struggle to make sense of the table on the slide, ask them to think back to their own crumple zone designs. Ask them the following questions: *Were longer or shorter crumple zones safer? Were more rigid or less rigid crumple zones safer?* Then show where their responses would be in the table. **Building toward: 10.B.2** Analyze force and motion graphs of cart collisions with differing front-end crumple zone designs as well as driver survivability data in order to identify patterns in peak forces, time of impact, and design characteristics of the crumple zone (amount of deformation, thickness of material, and structure/length). (SEP: 4.6, 5.2; DCI: ETS1.A.1, PS2.A.1; CCC: 2.3, 6.2)

Test crumple zone designs. Display **slide U**. Based on how students responded, test a few of their combinations with the simulation as a class (https://s3.amazonaws.com/p.3simulation/collisions/crumple-zones.html). Use the settings described below to create the different combinations.

Vehicle Collision Simulator: Crumple Zones	To test each trial, select the "New Trial" button on the home page. Then select the desired crumple zone length and rigidity using the sliders and run the trial. Leave the vehicle mass at 1500 kg and the vehicle speed at 25 mph for each trial. As you go, rename each trial with the conditions (e.g. short and low). For length, use the following values: ● Short = 0.1 m ● Medium = 0.8 m ● Long = 1.5 m For rigidity, use the following values: ● Low = 50 kN ● Medium = 1000 kN (note that this is not the middle value) ● High = 3000 kN

Trial	Survival	Vehicle Mass (kg)	Crumple Zone Length (m)	Crumple Zone Rigidity (kN)	Vehicle Speed (mph)
Short and Low	79%	1500	0.1	50	25
Short and Medium	79%	1500	0.1	1000	25
Short and High	79%	1500	0.1	3000	25
Medium and Low	88%	1500	0.8	50	25
Medium and Medium	80%	1500	0.8	1000	25
Medium and High	79%	1500	0.8	3000	25
Long and Low	100%	1500	1.5	50	25
Long and Medium	80%	1500	1.5	1000	25
Long and High	79%	1500	1.5	3000	25

Display **slide V** to show all the combinations. Pose the questions on the slide:

- *How do the initial survivability results compare to your predictions?*
- *How are these results related to crumple zone design and peak force on the vehicle?*

11 · NAVIGATE

3 min

MATERIALS: None

Preview the next lesson's focus. Display **slide W**. Read the text at the top of the slide, The forces we were studying were on the vehicle--more specifically, on the crumple zones--not on the person. Pose the two questions on the slide together prompt:

- *Why would the force on the car be related to the likelihood of survival? What information are we still missing in order to answer this question?*

Accept all responses but highlight those that connect to data about what we figured out also happens to the crash test dummy. Say, *Let's figure out how to connect this all together next time we meet.*

Additional Lesson 10 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA	**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.

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN MATH	**CCSS.MATH.CONTENT.HS.N-VM.1 Represent and model with vector quantities:** Recognize vector quantities as having both magnitude and direction. On days 1 and 2 of this lesson, students analyze force versus time graphs. They need to recognize that the negative values for force are related to the direction that the force is applied. **CCSS.MATH.CONTENT.HS.A-CED.4 Create equations that describe numbers or relationships:** Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations. On day 2, students analyze Newton's second law of motion and substitute for acceleration to see the relationship between force and time.