Lesson 11: How do the rigidity and length of the crumple zone influence the safety of the occupants during a collision?

Previous Lesson *We proposed and compared designs for a vehicle's crumple zone. We used a simulation to investigate how crumple zone length and rigidity influence the safety of the driver.*

This Lesson

Investigation

2 days

Images generated using CODAP (https://codap.concord.org/), developed at the Concord Consortium

We analyze crash test results from simulated collisions to identify how the rigidity and length of the crumple zone affect the forces acting on vehicle occupants. We apply the concepts about matter, energy, and forces to explain how the design of the crumple zone can enhance safety during a collision. We update our [material:PM.L3.HO1].

Next Lesson *We will compare arguments about speed limits, considering both science ideas and societal impacts. We will construct a Gotta-Have-It Checklist and use the list to develop explanations of how criteria and design solutions can increase vehicle safety.*

BUILDING TOWARD NGSS

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

What students will do

11.A Analyze patterns in graphical data from simulated collisions to make and support scientific claims about how the rigidity and the length characteristics of the crumple zone of a vehicle can be designed to optimize safety during a collision. (SEP: 4.6, 5.2; CCC: 1.3, 2.3; DCI: PS2.A.1)

What students will figure out

- A less-rigid and longer crumple zone results in lower peak forces over longer periods of time acting on the occupants during a car collision.

- Energy transfers to the crumple zone as matter deforms.
- The amount of deformation is related to the amount of energy transferred.
- When the crumple zone is too short, the peak force is very high and the time to stop is very short.

Lesson 11 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	3 min		**NAVIGATE** Use data from simulated car collisions to remind students where we left off.	A-B	
2	7 min		**ANALYZE AND INTERPRET FORCE ON A DUMMY DURING ONE COLLISION** Have students turn and talk to identify variables related to safety. Scaffold building connections between graphs of data from multiple collisions and graphs of data from a single collision.	C-E	*Survivability versus Rigidity*, https://s3.amazonaws.com/p.3simulation/collisions/crumple-zones.html (optional)
3	15 min		**ANALYZE FORCES OVER TIME ON THE DUMMY IN COLLISIONS WITH DIFFERENT CRUMPLE ZONE RIGIDITIES** Have students make predictions about the forces on the dummy in different collisions. Use data to compare these predictions and have students construct a claim on the relationship between crumple zone rigidity and force over time.	F-J	*Survivability versus Rigidity*, *Investigating Rigidity*, individual whiteboard, dry erase marker, *Modeling Identify Interpret Strategy* (optional)
4	15 min		**ANALYZE CHANGES IN MOTION OF THE VEHICLES WITH DIFFERENT CRUMPLE ZONE RIGIDITIES IN COLLISIONS** Have students compare patterns for three crumple zone rigidities between the change in velocity and the time to stop and the changes of acceleration over time. Discuss what is happening to matter during each collision.	K	*Investigating Rigidity*, https://s3.amazonaws.com/p.3simulation/collisions/crumple-zones.html (optional), Force and Motion Relationships poster
5	5 min		**REVISE OUR CLAIMS ABOUT THE ROLE OF CRUMPLE ZONE RIGIDITY ON VEHICLE SAFETY** Have students develop a claim about how increasing the rigidity of the crumple zone affects survivability in a collision.	L	*Investigating Rigidity*, https://s3.amazonaws.com/p.3simulation/collisions/crumple-zones.html (optional), https://codap.concord.org/app/static/dg/en/cert/index.html (optional)
					End of day 1
6	4 min		**NAVIGATE** Revise some of the ideas we developed about the role of the crumple zone during a collision. Have students share some of their ideas about the effects of increasing the crumple zone length.	M-N	

7	22 min		**ANALYZE CRUMPLE ZONE LENGTH AND DEFORMATION DATA** Discuss the relationship between the crumple zone deformation and the likelihood of survival. Distribute *Survivability versus Length* and have students analyze different data sets as they complete part 2 of the handout.	O-Q	*Survivability versus Length*, *Investigating Rigidity* from day 1 with written feedback
8	15 min		**CONSIDER CRUMPLE ZONES FROM MATTER AND ENERGY PERSPECTIVES** Facilitate a Scientists Circle discussion to come to a consensus about how to explain how crumple zones keep people safe from M-E-F perspectives. Then have students update their *Engineering Progress Tracker*.	R-S	*Engineering Progress Tracker*, https://openscied-static.s3.amazonaws.com/HTML+Files/Apply+and+Remove+External+Force+on+a+Solid.html (optional), computer (optional), M-E-F triangle poster, Crumple Zones and M-E-F poster, chart paper markers
9	4 min		**NAVIGATE** Guide students to consider the initial kinetic energy of a vehicle and how it affects safety in a collision. Complete an exit ticket about velocity and safety.	T-U	*Survivability versus Velocity*

End of day 2

Lesson 11 • Materials List

	per student	per group	per class
Lesson materials	• *Survivability versus Rigidity* • *Investigating Rigidity* • individual whiteboard • dry erase marker • *Modeling Identify Interpret Strategy* (optional) • *Survivability versus Length* • *Investigating Rigidity* from day 1 with written feedback • *Engineering Progress Tracker* • https://openscied-static.s3.amazonaws.com/HTML+Files/Apply+and+Remove+External+Force+on+a+Solid.html (optional) • computer (optional) • *Survivability versus Velocity*	• https://s3.amazonaws.com/p.3simulation/collisions/crumple-zones.html (optional) • https://codap.concord.org/app/static/dg/en/cert/index.html (optional)	• https://s3.amazonaws.com/p.3simulation/collisions/crumple-zones.html (optional) • Force and Motion Relationships poster • M-E-F triangle poster • Crumple Zones and M-E-F poster • chart paper markers

Materials preparation (30 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 handouts in this lesson:

- *Survivability versus Rigidity* (1 per student)
- *Investigating Rigidity* (1 per student)
- *Survivability versus Length* (1 per student)

- *Survivability versus Velocity* (1 per student)

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

Prior to day 1
Make sure the Force and Motion Relationships poster from Lesson 6 and updated in Lesson 9 is visible in the classroom for students to reference.

Prior to day 2
Title a piece of chart paper "Crumple Zones and M-E-F".

Make sure the M-E-F triangle poster is visible in the classroom for students to reference.

Lesson 11 • Where We Are Going and NOT Going

Where We Are Going

During this lesson, students engage in a series of data analyses, some as a class, some with a partner, and some on their own. Students will investigate how the structure of the crumple zone, more specifically, its length and rigidity, can influence the forces and changes in velocity of the vehicle and the crash test dummy during a collision. They will investigate how the design and structure of crumple zones can affect the time and magnitude of the forces acting on the vehicle and connect this to likelihood of survival.

Because of this, this lesson is reinforcing 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)

This lesson continues the thread of engaging with the following crosscutting concept (CCC):

- **Cause and Effect: Mechanism and Prediction.** Systems can be designed to cause a desired effect.

Throughout this unit students have investigated multiple designs that affect vehicle safety. This lesson wraps up the arc of examining vehicle design features and how they affect safety. In Lesson 12 students will again use this element, but with regards to speed limits. This element is also assessed in the final transfer task in Lesson 15.

This lesson wraps up the arc of two science and engineering practice (SEP) elements that have been used across this unit:

- **Analyzing and Interpreting Data.** 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.
- **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.

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.

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 the vehicle and driver during a collision. Therefore, we do not cover how rigidity affects energy capacity of the crumple zone, only how rigidity affects the forces.

LEARNING PLAN for LESSON 11

1 · NAVIGATE

3 min

MATERIALS: None

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

Remind students where we left off. Say, *Last time, we investigated the role of the crumple zone, and we identified its rigidity and length as two important variables that help explain how a vehicle responds during a collision. We started to connect these things to the likelihood of survival, but we weren't able to explain those connections yet.*
Present **slide B**. Orient students to the graphs and what is shown on each axis. Give students a moment to look at the graphs before inviting them to share their wonderings and noticings.

Look for students to mention the following ideas:

- Increasing the rigidity will result in a decrease in survivability.
- There is a point where increasing the rigidity will not have a significant impact on survivability.
- Increasing the length will increase survivability.
- There is a point where increasing the length will not have an increased significant impact on survivability.

Transition to the next slide by saying, *Let's see if we can use our physics ideas to explain why the crumple zone rigidity can affect the safety during a collision.*

2 · ANALYZE AND INTERPRET FORCE ON A DUMMY DURING ONE COLLISION

7 min

MATERIALS: *Survivability versus Rigidity*, https://s3.amazonaws.com/p.3simulation/collisions/crumple-zones.html (optional)

Consider the variables related to increased safety. Present **slide C**. In order to motivate the need to look at forces acting on the system, ask students to turn and talk with the prompt:

- *What variables have we investigated that can affect the survivability of the driver?*

You may need to remind students what it means for two variables to be correlated using the quick definition on the slide.

Listen for the following ideas:

- Forces acting on the system
- Changes of velocity over time
- The amount of time during a collision

Develop connections between graphs. Present **slide D**. Say, *We have identified some patterns about how increasing the rigidity of crumple zones can affect the likelihood of survival, but this does not tell us how crumple zone rigidity might be affecting some of the variables related to safety that we have investigated in the past.*

Point out to students that the top graph shows the data for multiple collisions, where every dot represents a collision of a car with a unique crumple zone rigidity. The top graph was created using the Review Your Trials table of the simulation, while the bottom graph for the individual trial was created using the data table for the individual trial. CODAP is used to adjust scales on the graphs. Suggest that we zoom in to some of these collisions to explore how crumple zone rigidity can actually affect one of the variables the class shared that might affect the safety of people in the vehicle, such as forces.

ADDITIONAL GUIDANCE	This is the first time students are explicitly making a connection between one graph and another, especially two graphs that have different variables plotted. Take some time to establish the connection between the two graphs presented on the slide to support data analysis during this discussion. It may be helpful to view the different locations of data in the simulation in the crumple zone restricted view (https://s3.amazonaws.com/p.3simulation/collisions/crumple-zones.html) to see that the cross-trial data are from multiple trials, while the others are adjusted versions of the graphs shown for each individual trial.

ADDITIONAL GUIDANCE	Crumple zone restricted view of simulation: https://s3.amazonaws.com/p.3simulation/collisions/crumple-zones.html The simulation settings used to create the data for this lesson are as follows. Each variable was set to the noted value unless it is the independent variable for that graph. • Vehicle mass: 1,500 kg • Crumple zone length: 1.0 m • Crumple zone rigidity: 200 kN • Initial velocity: 30 mph Note that airbags are not active in the crumple zone version of the simulation. This is to create cleaner graphs of the force on the dummy to be able to identify the changes in time and force more cleanly. The seat belt stiffness is set to 60 kN/m, which avoids hitting the steering wheel except for when the velocity is changed. If students wonder about this, say something like, *In Lesson 9 we investigated how seat belts and airbags work*

together to protect the occupants of a vehicle, but we also saw that the force graphs got more complicated when using both safety features. Therefore, in this lesson we are using data that only include the seat belt. We know that adding the airbag could further increase safety, but including it in our simulation would make our current investigation of crumple zones more difficult. Often, scientists need to isolate different parts of a system in order to clearly see how they work.

Analyze the force on the dummy during one collision. Present **slide E** and distribute *Survivability versus Rigidity*. Tell the class that the bottom graph shows the results of the forces over time on the dummy for collision B. The vehicle for this test had a crumple zone rigidity of 400 kN. Then pose the prompt on the slide:

- *What does the bottom graph tell us that the top graph does not?*

Suggest to students that we should think about some other data points on the top graph.

3 · ANALYZE FORCES OVER TIME ON THE DUMMY IN COLLISIONS WITH DIFFERENT CRUMPLE ZONE RIGIDITIES

15 min

MATERIALS: *Survivability versus Rigidity*, *Investigating Rigidity*, individual whiteboard, dry erase marker, *Modeling Identify Interpret Strategy* (optional)

Make predictions about the force over time on the dummy during a collision. Present **slide F**. Say, *We have analyzed the forces acting on the dummy over time for the collision at point B on the graph, which was neither the safest nor the most dangerous. Now, let's explore predictions for the forces in both the safest and the least safe collisions.*

Read the slide prompt aloud to orient students to this task:

- *Draw on an individual whiteboard your predictions about what the forces over time will look like for points **A** and **C**.*

Distribute a whiteboard and a dry erase marker to every student. Give them a couple of minutes for this.

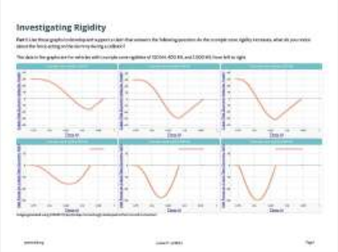
Compare predictions. Present **slide G**. Have students hold up their predictions on individual whiteboards. Use the following prompts to have students compare their predictions:

- *How are our predictions similar or different?*
- *What in your force graphs shows that A has a higher likelihood of survival than C?*

Look for students to show differences in the magnitude and time the force acts on the dummy and connect lower forces with higher likelihood of survival.

Suggest we check our predictions against the actual data graphs of force over time at data points A and C.

Compare predictions with data. Present **slide H**. Distribute *Investigating Rigidity* to every student. Say, *Using the graphs on this slide and on the handout, compare the predictions that you and other students made with the results from each collision.*



Discuss with the class the changes of the forces over time acting on the crash test dummy across the three graphs, highlighting the changes in peak force and time over which the forces act on the crash test dummy. Highlight that the places where the forces change are during the first part of the graphs, when the crash test dummy is colliding with the seat belt, not the second part, where the crash test dummy experiences a positive force from the seat back. Focus students on comparing this initial curved part of each graph.

Connect velocity and force data. Present **slide I**. Read the prompt on the slide:

- *How do the changes in velocity of the dummy relate to the forces acting on it? Why?*

Use the prompts in the table below to support student sensemaking.

Suggested prompts	Sample student responses	Follow-up questions
How do the times over which the changes in velocity occur compare to the times over which the forces act on the crash test dummies?	For every crash test, velocity changes during the time the force is acting on the dummy.	*Does this make sense? How does our understanding of forces support this?*
How do the differences in forces affect the changes in velocity? *OR* *How do the differences in forces affect the acceleration?*	The larger the force, the less time the velocity has to change. The change in velocity is the same, but it happens over different amounts of time.	*What on the graphs shows us this? (Look for students to say the slope is different.)*

ADDITIONAL GUIDANCE	This is an opportunity to use the velocity versus time graphs to explain why we compare only the time for the first part of the motion of the crash test dummy, from the start of the crash to when it starts moving backwards. In this set of velocity graphs, we can see that when the rigidity is higher, the peak negative velocity of the crash test dummy also increases. This means, after the crash test dummy begins to move backwards, it

will have a different change in momentum, making the forces and time incomparable with our models. It is beyond the scope of this unit to explain why this happens.

Develop a claim. Present **slide J**. Read the prompt aloud to instruct students to write a claim about the role of rigidity on the forces acting on the crash test dummy:

- *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.*

Give students a few minutes to develop their claims. While students are working, circulate to review their work and support them in their initial claims. Their claims do not need to be perfect at this point as they will have multiple chances to revise them within this lesson. See the assessment guidance below for suggestions on supporting students within the rest of this lesson.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment: Look for students to start to do the following:

- Support the claim by describing the relationship between crumple zone rigidity and the forces acting on the dummy. (SEP: 5.2; DCI: PS2.A.1)
  - One example is: As the crumple zone rigidity increases, the peak force on the dummy increases and the time the force is acting on the dummy decreases.

What to do: This initial claim is about describing the relationship among crumple zone rigidity and the force acting on the dummy. As students work on this, walk around the classroom. Use the following prompt if students are struggling making a connections between the data and the design of safer vehicles:

- *What is the safest condition among these three conditions--A, B, or C. Why?*

If students are still struggling with writing a claim, ask them to use the I^2 strategy steps to summarize the patterns across the data set (see *Modeling Identify Interpret Strategy* from Lesson 1). Suggest they consider how their summary helps them answer the question: As the crumple zone rigidity increases, what do you notice about the variable on the *y*-axis of the graphs during a collision and the time?

Building toward: 11.A.1 Analyze patterns in graphical data from simulated collisions to make and support scientific claims about how the rigidity and the length characteristics of the crumple zone of a vehicle can be designed to optimize safety during a collision. (SEP: 4.6, 5.2; CCC: 1.3, 2.3; DCI: PS2.A.1)

4 · ANALYZE CHANGES IN MOTION OF THE VEHICLES WITH DIFFERENT CRUMPLE ZONE RIGIDITIES IN COLLISIONS

15 min

MATERIALS: *Investigating Rigidity*, https://s3.amazonaws.com/p.3simulation/collisions/crumple-zones.html (optional), Force and Motion Relationships poster

Analyze data sets of changes of velocity and forces over time. Say, *Last lesson, we used velocity and force data to explore how the rigidity of our crumple zone designs affected the force acting on the cart. Let's look at these data for the simulated collisions and see how they support or refute our claims.*

Present **slide K**. Orient students to the graphs on part 2 of the *Investigating Rigidity* handout and have them complete the prompts in pairs. Give students about 10 minutes to complete the task.

ALTERNATE ACTIVITY	If you have time and your students are comfortable with analyzing across multiple graphs at this point, consider having them create the graphs and test other rigidity conditions using the crumple zones restricted view of the Vehicle Collision Simulator (https://s3.amazonaws.com/p.3simulation/collisions/crumple-zones.html).

Once students have completed part 2 of the *Investigating Rigidity* handout, have students share their responses to the prompts.

Suggested prompt	Sample student response
a. *How do the differences in the* ***vehicles' velocities*** *over time help explain the changes in the crash test dummies' velocities over time?*	The more time the vehicle takes to stop, the more time the dummy has to stop.
b. *Choose any of the mathematical models present on the Force and Motion Relationships poster to describe one of the patterns that you identified in question a of part 2.*	$F\Delta t = m\Delta v$. The larger the force acting on the dummy, the steeper the changes in velocity (larger deceleration).
c. *How do the patterns in these data help explain the impact of rigidity on the changes in velocity and net force experienced by the vehicle during a collision?* ✱	The lower rigidity has a less steep slope on the velocity versus time graph. This shows that it had more time to stop. The lower rigidity means lower forces on the vehicle.

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING PATTERNS

Encourage students to use some of the patterns they identified in the graphs to support their ideas. Use some of the following prompts:

- *What attribute of the graph shows you that pattern?*
- *Where do you see lower forces on the graph?*
- *What does the slope of the velocity versus time graph tell us?*

5 · REVISE OUR CLAIMS ABOUT THE ROLE OF CRUMPLE ZONE RIGIDITY ON VEHICLE SAFETY

5 min

MATERIALS: *Investigating Rigidity*, https://s3.amazonaws.com/p.3simulation/collisions/crumple-zones.html (optional), https://codap.concord.org/app/static/dg/en/cert/index.html (optional)

Develop a claim. Present **slide L**. Say, *Now that we have looked at how rigidity can affect the forces acting on the system, I think we are ready to revise our ideas about how the crumple zone affects vehicle safety.*

Read the prompt aloud to instruct students to write a claim:

- *In part 3 of the Investigating Rigidity handout, use your analysis of the graphs from the simulated vehicle collisions to develop and support a claim about how to design the crumple zone rigidity to optimize safety during a collision.*

Give students the remaining time to complete this task in part 3. Collect *Investigating Rigidity* to provide students with individual written feedback.

ADDITIONAL GUIDANCE	Some students may question the balance of prioritizing safety versus durability of a vehicle. After all, 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 *trade-off*, 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 trade-offs and how design decisions are navigated.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment

- Use the graphs to connect the increased time for the vehicle to stop to the increased time for the crash test dummy to stop. (SEP: 4.6; DCI: PS2.A.1)
- Use the patterns on the graphs to identify that differences in time and force are relevant to the impact of rigidity on the changes in velocity. (SEP: 4.6; CCC: 1.3; DCI: PS2.A.1)
- Make a claim that connects the design characteristic of rigidity for crumple zones and safety in a collision. (SEP: 4.6; CCC: 2.3; DCI: PS2.A.1)
    - One example is: The design with the lowest rigidity will be the safest.
- Support the claim by describing the relationship between crumple zone rigidity, the changes in velocity of the vehicle and dummy, and the forces acting on the vehicle and dummy. (SEP: 5.2; DCI: PS2.A.1)
    - One example is: As the crumple zone rigidity decreases, the peak force on the car and the dummy decreases and the time the force is acting on the car and dummy increases. As the

crumple zone rigidity decreases, the velocity of the vehicle and the crash test dummy changes over a longer time period. These changes in force and velocity increase the likelihood of survival.

- Use patterns in the graphs to support their claim about improving safety. (SEP: 4.6, 5.2; CCC: 1.3, 2.3)
    - One example is: When the rigidity was lower, the shape of the force vs. time graph of the car and the dummy were more spread out on the time axis and less tall on the force axis.

What to do
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.
If students are struggling with the use of data to support their claim, ask them:

- *For each collision, how do the changes in velocity and forces in the car compare to the changes in velocity and force in the person?*

If students are struggling with the use of science ideas to connect their claim with the evidence, ask them, *Which changes in forces or motion might help explain why increasing the rigidity of the crumple zone results in lower survivability?*

The feedback that you provide will be instrumental in helping students complete the summative assessment on day 2 of this lesson.

Building toward: 11.A.2 Analyze patterns in graphical data from simulated collisions to make and support scientific claims about how the rigidity and the length characteristics of the crumple zone of a vehicle can be designed to optimize safety during a collision. (SEP: 4.6, 5.2; CCC: 1.3, 2.3; DCI: PS2.A.1)

ALTERNATE ACTIVITY

If you have time, consider having students create the graphs and test out other length conditions using the crumple zones restricted view of the Vehicle Collision Simulator (https://s3.amazonaws.com/p.3simulation/collisions/crumple-zones.html) in order to form their claims on *Investigating Rigidity*. Note that the graph scales will not match, so students might need extra guidance interpreting the graphs or using CODAP (https://codap.concord.org/app/static/dg/en/cert/index.html) to match the scales.

End of day 1

6 · NAVIGATE

4 min

MATERIALS: None

Remind the class where we left off. Present **slide M**. Read the text and prompts on the slide:
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?*
- *Why?*

Have the students discuss the answer to the prompts to review from last class.

Transition to thinking about crumple zone length. Present **slide N**. Ask the students to turn and talk about the prompts on the slide:

- *What design for crumple zone length do you think would increase safety?*
    - *A longer crumple zone?*
    - *A shorter crumple zone?*
- *Why?*

Have a few pairs share. Accept all answers. Say, *Let's explore data about the length of the crumple zone!*

7 · ANALYZE CRUMPLE ZONE LENGTH AND DEFORMATION DATA

22 min

MATERIALS: *Survivability versus Length*, *Investigating Rigidity* from day 1 with written feedback

Consider the relationship among crumple zone length, crumple zone deformation, and likelihood of survival. Present **slide O**. 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 these new data.*

Distribute *Survivability versus Length* to every student. Give them a couple of minutes to look at the graphs in part 1 and turn and talk about the prompts on the slide:
Focus on the data inside the box that show when the deformation of the crumple zone is 100%.

- *How is the crumple zone length related with the survivability of the crash test dummy?*

After a few minutes, have students discuss their thinking as a class. Look for students to say:

- Likelihood of survival is less than 100% when the deformation is 100%.
- Likelihood of survival increases as the length of the crumple zone increases.

ADDITIONAL GUIDANCE	It may be helpful to establish a shared language for when the crumple zone deforms 100%. Two options are “bottomed out” or “maxed out”, but privilege students' language. If students are having a difficult time conceptualizing this, demonstrate different percentages of deformation with foil crumple zones similar to what the students used in the previous lesson.

Discuss crumple zone lengths that lead to safer outcomes. Continue with this discussion by having students turn and talk with the prompts on **slide P**:

*Focus on the data inside the box that show when the deformation of the crumple zone is **less than** 100%.*

- *How is the crumple zone length related with the survivability of the crash test dummy?*

After a few minutes, have students discuss their thinking as a class. Look for students to say:

- Likelihood of survival is 86% when the deformation is less than 100%.
- Likelihood of survival stays the same even though the length of the crumple zone continues to increase.

Complete individual analysis of crumple zone length. Present **slide Q**. Return to students their *Investigating Rigidity* handout with written feedback. Say, *I've provided feedback on your last claim; please review it. Then we will work individually to analyze data about the crash test dummy and the vehicle that can help us explain how the crumple zone deformation affects the safety during a collision.* Orient students to the data sets in part 2 of *Survivability versus Length* and ask them to complete the questions of this section.

Collect the *Survivability versus Length* handout for individual review when students are done.

ASSESSMENT OPPORTUNITY	**What to look for/listen for in the moment** • Use the graphs to connect the increased time for the vehicle to stop to the increased time for the crash test dummy to stop. (SEP: 4.6; DCI: PS2.A.1) • Use the patterns in the graphs to identify that differences in time and force are relevant to the impact of length of crumple zone on the changes in velocity. (SEP: 4.6; CCC: 1.3; DCI: PS2.A.1) • Make a claim that connects longer design characteristics of the crumple zone length and increased safety in a collision. (SEP: 4.6; CCC: 2.3; DCI: PS2.A.1) • Support the claim by describing the relationship between crumple zone length, the changes in velocity of the vehicle and dummy, and the forces acting on the vehicle and dummy. (SEP: 5.2; DCI: PS2.A.1) • Use patterns in the graphs to support their claim about improving safety. (SEP: 4.6, 5.2; CCC: 1.3, 2.3)

See *Survivability versus Length Key* for leveled example student responses and suggested supports.

What to do: Use the suggested actions and support on *Survivability versus Length Key*.
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.

Building toward: 11.A.3 Analyze patterns in graphical data from simulated collisions to make and support scientific claims about how the rigidity and the length characteristics of the crumple zone of a vehicle can be designed to optimize safety during a collision. (SEP: 4.6, 5.2; CCC: 1.3, 2.3; DCI: PS2.A.1)

8 · CONSIDER CRUMPLE ZONES FROM MATTER AND ENERGY PERSPECTIVES

15 min

MATERIALS: *Engineering Progress Tracker*, https://openscied-static.s3.amazonaws.com/HTML+Files/Apply+and+Remove+External+Force+on+a+Solid.html (optional), computer (optional), M-E-F triangle poster, Crumple Zones and M-E-F poster, chart paper markers

Introduce matter and energy perspectives to crumple zones. Present **slide R**. Say, *We analyzed how the design of crumple zones can affect safety from a force perspective. Let's use some other M-E-F perspectives to explain why these design characteristics affect forces.*

Gather students in a Scientists Circle around the M-E-F triangle poster. Lead the students in a discussion to put the ideas about crumple zones together using the M-E-F perspectives. ✱ As students discuss, record their ideas on the prepared Crumple Zones and M-E-F poster. Guiding prompts and key ideas are listed below.
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?*

Look for students to mention particle-level changes, such as changing the space between particles and bond breaking, to describe the changes in matter in the crumple zone.
Guide students to make connections to vehicle crumple zones. Suggested guiding prompts are as follows:

- *How does changing crumple zone length change the matter?*
- *How does changing crumple zone rigidity change the matter?*

✱ STRATEGIES FOR THIS CONSENSUS DISCUSSION

A Consensus Discussion is different from other kinds of discussions because the purpose of the discussion is to converge on one or more ideas that the whole class agrees upon. In this discussion, your classroom community is pressing toward a common (class-level) explanation, model, or model representation. 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 the following:

- *What ideas are we in agreement*

Listen for the following ideas:

- The longer the crumple zone, the more matter, and thus, more bonds.
- The more rigid the material, the harder it is to change the distance between particles.

Say, *Let's explain how these changes in matter help explain how the crumple zone can affect safety during a collision.* Transition to the energy perspective. Use the following prompts from the M-E-F poster:

- *Before the collision, how do we know there is energy in the system?*
- *During the collision, where is energy being transferred?*

Guide students to make connections to vehicle crumple zone length. Look for students to mention that we know the vehicle has kinetic energy before the collision, and that it transfers to the matter in the crumple zone.

A suggested guiding prompt is as follows:

- *How does changing crumple zone length change how energy transfers?*

Look for students to mention that the longer the crumple zone, the more bonds and particles there are to transfer the energy from the moving vehicle.

You can also optionally connect to crumple zone rigidity, but this is a more-complex connection. See the guidance callout below for more information.

Then connect the matter and energy perspectives. Say, *We know that energy transfers and matter changes happen together.*

- *How are the changes in matter we described related to the energy that transfers from the moving vehicle to the crumple zone?*

ALTERNATE ACTIVITY	**Extension opportunity:** Provide each student with a computer 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.

Connect back to forces. Bring the force perspective to the discussion. Suggested guiding prompts are as follows:

- *What forces are acting on the matter of the crumple zone?*
- *How does changing the crumple zone rigidity change how forces act on the system?*
- *How does changing the crumple zone length change how forces act on the system?*

Connect the force perspective to the matter and energy perspectives. Suggested guiding prompts are as follows:

- *How does changing rigidity change the matter in order to affect the forces?*
    - Point to the connection between matter and forces on the poster: "Fields generated by matter result in forces".

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?*

- *How do the forces affect how energy transfers from the moving vehicle to the crumple zone?*

KEY IDEAS

Matter perspective

- The crumple zone changes shape.
- Bonds between the particles of the crumple zone are breaking when the material deforms.
- Adding length adds matter to the crumple zone.
- Increasing rigidity strengthens the bonds between particles (or increases the matter if rigidity is changed through thickness).

Energy perspective

- Vehicles have kinetic energy before collisions, and that energy needs to be transferred somewhere.
- The energy is transferred when the matter changes happen in the deformation of the crumple zone.
- Optional: Some of that energy is also transferred to the surroundings as sound and heat.
- Changing length changes how much energy can be transferred while the crumple zone deforms.

Connecting matter and energy perspectives

- The amount of matter in the crumple zone (length) determines how much energy can be transferred into the crumple zone. More matter means more energy is transferred into the crumple zone.

Force perspective

- Rigidity is how difficult it is to deform a material, which determines the force on the vehicle.
- If the crumple zone bottoms out, the more-rigid materials of the rest of the vehicle cause higher forces.

Connecting force and matter perspectives

- The force on the vehicle is determined by the rigidity because of the strength of these fields between particles.

Connecting force and energy perspectives

- The force determines how quickly the energy is transferred. Higher forces cause the vehicle to stop in less time.

ADDITIONAL GUIDANCE	Connecting rigidity to energy transfer is beyond the expected scope of this lesson. This is because we do not cover the work-energy theorem. The connection between length and energy can be explained through the quantity of bonds, as opposed to distance traveled. It is important for students to connect rigidity with the force that is applied to the vehicle, but they will not have the models to connect higher forces to more energy transferred over a distance.

ALTERNATE ACTIVITY	As an extension to this discussion, consider returning to the rigidity graph on **slide A** and posing the question, *What do you think is happening when the rigidity is super low to cause this dip in likelihood of survival?* Students should be able to connect to their understanding of bottoming out short crumple zones and conclude that super-low rigidity could also cause bottoming out, which would make the risk of the collision higher. This is not a key idea of the lesson since further explanation is connected to the work-energy theorem. However, it could still offer an extension of sensemaking without digging deeper into the explanation in terms of energy.

Update *Engineering Progress Tracker*. Display **slide S**. Ask students to return to their seats and individually update their *Engineering Progress Tracker*.

9 · NAVIGATE

4 min

MATERIALS: *Survivability versus Velocity*

Transition to thinking about initial kinetic energy of the vehicle. Display **slide T**. Read the text on the slide:
Crumple zone design determines how much and how quickly kinetic energy is transferred to stop a vehicle.

- *How would increasing the kinetic energy of a vehicle before a collision affect the likelihood of survival?*

Have students turn and talk about the prompt. If you have time, have a few pairs share, otherwise move on to the exit ticket on the next slide.

Consider kinetic energy. Display **slide U** and distribute *Survivability versus Velocity* to each student. Pose the prompts on the slide and handout:

- *What effect does increasing velocity have on likelihood of survival?*
- *What can a driver do before a collision to reduce their risk of injury?*

Ask students to answer the prompts on their handout. Let them know that they will share their answers next time.

Additional Lesson 11 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN MATH	**Functions** **CCSS.MATH.CONTENT.HS.F-IF.4** Interpreting Functions: For a function that models a relationship between two quantities, interpret key features of graphs and tables in terms of the quantities, and sketch graphs showing key features given a verbal description of the relationship. Students will be interpreting key features of graphs from multiple data sets. This includes changes in velocity and force on the crash test dummy and vehicle in simulated car collisions with varying crumple zone lengths and rigidities.

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA	**CCSS.ELA-LITERACY.W.9-10.1.C** Use words, phrases, and clauses to link the major sections of the text, create cohesion, and clarify the relationships between claim(s) and reasons, between reasons and evidence, and between claim(s) and counterclaims. Students will use evidence to develop and revise a claim that explains how the rigidity and length of the crumple zone design can result in increased safety during a car collision.