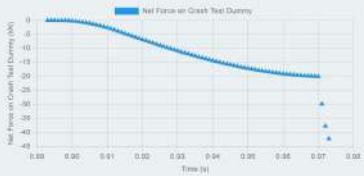
Lesson 9: How do safety features affect the forces over time on a person during a collision?

Previous Lesson *We watched a video of people in a collision and determined it was too fast to analyze. We used an animation to create collision timelines for the vehicle and crash test dummy with and without seat belt and airbag and added velocity info from simulation data.*

This Lesson

Investigation

2 days



We read about the role of force interaction on a crash test dummy and measures of injury. We make predictions about how force versus time would be affected on the dummy with safety features and compare these to the results from a simulation. We analyze the results and explain two safety features together to improve survivability. We brainstorm characteristics of seat belts and airbags that would improve survivability. We use a simulation to try to optimize these characteristics. We analyze graphs from the simulation and explain why survivability changes in collisions at different speeds with the same safety features.

Next Lesson *We will propose and compare designs for a vehicle's crumple zone. We will use a simulation to investigate how crumple zone length and rigidity influence the safety of the driver.*

BUILDING TOWARD NGSS

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

What students will do

9.A Develop an explanation for why designs of vehicle safety features improve survivability and why survivability changes in collisions at different speeds with the same safety features, using the relationships of Newton's second law and evidence derived from graphs produced by a collision simulation. (SEP: 6.1, 6.3, 4.6; CCC: 2.3; DCI: PS2.A.1)

What students will figure out

- The force applied to a part of the crash test dummy is directly proportional to the acceleration or the deformation in that part of the crash test dummy.
- The likelihood of injury increases as the magnitude of the force on different parts of the body increases (head, chest, neck).
- Reducing the peak force on a body reduces injury.

- Safety features of the vehicle, such as seat belts and airbags, increase the length of time that forces are applied to the body and reduce the magnitude of the peak forces applied over that time.
- When Δv is higher, peak force on the person is higher and likelihood of survivability goes down.
- Newton's second law can be rearranged to show that $F\Delta t = m\Delta v$.

Lesson 9 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	5 min		**NAVIGATE BY LOOKING BACK AT COLLISION TIMELINES** Use the collision timelines to motivate a look at safety features.	A-C	Vehicle Collision Timelines poster from Lesson 8
2	11 min		**READ ABOUT CRASH DUMMY TESTS** Read to learn how data are collected during crash dummy tests.	D	*Crash Test Measures*
3	8 min		**MAKE PREDICTIONS ABOUT CONTACT FORCE** Draw a force diagram and sketch a contact force versus time graph to make predictions about the forces causing injury to a driver during a car collision.	E-F	whiteboard, 2 whiteboard markers (different colors), paper towel or whiteboard eraser, Vehicle Collision Timelines poster from Lesson 8
4	11 min		**ANALYZE DATA FROM A COLLISION SIMULATION** Analyze simulated data to verify predictions about the additive effects of using airbags and seat belts on the driver's survival rate during head-on collisions.	G-J	*Effects of Safety Features*
5	8 min		**INTERPRET DATA FROM A COLLISION SIMULATION** Compare students' predictive graphs with the simulated data on how safety features alter the force acting on the driver over time during a collision.	K-L	*Effects of Safety Features*
6	2 min		**OPTIONAL HOME LEARNING** Optional: Provide each student a choice of reading one of two articles to explore more about car safety features or testing and record new questions on sticky notes.	M	2 3x3 sticky notes, permanent marker, *How Airbags Work*, *Biases in Modeling People*
					End of day 1
7	5 min		**NAVIGATE** Brainstorm characteristics of airbags and seat belts.	N-O	sticky note questions from the home learning, *How Airbags Work*, *Biases in Modeling People*

8	13 min		**PLAN AND CARRY OUT AN INVESTIGATION AND COMPARE RESULTS** Orient to a control condition.	P-R	*Safety Optimization Investigation*, sticky note questions from the reading, computer with access to https://s3.amazonaws.com/p.3simulation/collisions/seatbelts-airbags.html, *Simulation Use Guide*, https://s3.amazonaws.com/p.3simulation/collisions/seatbelts-airbags.html
9	5 min	☑	**ANALYZE DATA** Describe patterns we see across force versus time graphs related to attempts to optimize the safety features for vehicle collisions.	S	*Six Optimization Attempts*, Force and Motion Relationships poster from Lesson 6
10	7 min	☑	**MAKE PREDICTIONS AND ANALYZE DATA** Describe patterns in the data, identify an equation model that helps show how force and change in velocity are related, and use it to explain the difference in likelihood of survival for two collisions.	T-U	*Comparing Three Speeds*, Force and Motion Relationships poster from Lesson 6
11	7 min		**DEVELOP AND USE A MODEL TO EXPLAIN THE DATA** Rearrange an equation and consider how it helps us understand how force and time are related.	V-W	*Six Optimization Attempts*, Force and Motion Relationships poster from Lesson 6, index card, chart paper markers, transparent tape
12	7 min		**ADD TO THE ENGINEERING PROGRESS TRACKER AND BRAINSTORM VEHICLE BODY REDESIGNS** Add to *Engineering Progress Tracker*. Brainstorm ways that the body of the vehicle could be redesigned to increase safety in a collision.	X-Y	*Engineering Progress Tracker*

End of day 2

Lesson 9 • Materials List

	per student	per group	per class
Lesson materials	• *Crash Test Measures* • whiteboard • 2 whiteboard markers (different colors) • paper towel or whiteboard eraser • science notebook • *Effects of Safety Features* • 2 3x3 sticky notes • permanent marker • *How Airbags Work* • *Biases in Modeling People* • sticky note questions from the home learning • *Safety Optimization Investigation* • sticky note questions from the reading • *Six Optimization Attempts* • *Comparing Three Speeds* • *Engineering Progress Tracker*	• computer with access to https://s3.amazonaws.com/p.3simulation/collisions/seatbelts-airbags.html • *Simulation Use Guide*	• Vehicle Collision Timelines poster from Lesson 8 • https://s3.amazonaws.com/p.3simulation/collisions/seatbelts-airbags.html • Force and Motion Relationships poster from Lesson 6 • index card • chart paper markers • transparent tape

Materials preparation (20 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 enough copies of *Six Optimization Attempts* for the number of students in your largest class. You will reuse these across classes.

Make an individual copy of each of these for every student:

- *Crash Test Measures*
- *Effects of Safety Features*
- *Safety Optimization Investigation*
- *Comparing Three Speeds*

The following readings are optional for home learning at the end of day 1. If you choose to use them, make enough copies so that each student can choose one of the two readings. Print enough copies of each reading for half of the students:

- *How Airbags Work*
- *Biases in Modeling People*

Please refer to the "Plan And Carry Out An Investigation And Compare Results" activity in this document for detailed instructions on how to use the simulation on day 2. Test the related simulation link:

- student view: https://s3.amazonaws.com/p.3simulation/collisions/seatbelts-airbags.html

Here is the copyedited version of the sentence:

Students will not use the simulation directly but will use data collected from it. If you want students to use the simulation themselves to generate the same data used in this lesson, provide *Simulation Use Guide* from Lesson 7 as a guide.

Make sure you can run the following video, as you will use it with the class during day 1:

- https://youtu.be/rjICpd7SkIA

After Lesson 8, you should have created a chart paper version of the vehicle collision timelines. Have this Vehicle Collision Timelines poster available for reference.

Make sure the Force and Motion Relationships poster from Lesson 6 is visible. You will be adding to this poster in this lesson.

Lesson 9 • Where We Are Going and NOT Going

Where We Are Going

This lesson begins the process of uniting the science and engineering performance expectations with examples and designs from the real world. Students encounter the reasoning behind why safety features inside the cabin can reduce risk for occupants, and they make connections between the momentum changes, force, and acceleration.

This lesson is designed to coherently build ideas related to the following disciplinary core idea (DCI):

- **PS2.A.1 Forces and 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 in prior lessons and will continue doing so through subsequent lessons. This lesson specifically engages students in the following science and engineering practice (SEP):

- **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.

This element will be included in this and the next two lessons as students examine vehicle design and safety. The last assessment moment in Lesson 11 is designed as a summative assessment moment on this element.

This lesson also engages students in the following science and engineering practice (SEP):

- **Constructing Explanations and Designing Solutions.** Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena and solve design problems, ~~taking into account possible unanticipated effects.~~

Students will further engage with this element and the related part of it that is crossed out in Lesson 12 and in the final transfer task in Lesson 15.

Students co-construct definitions for the following vocabulary: *peak force*. They also encounter these terms: *crash test dummy, accelerometer.* **Do not** ask students to define or keep track of any words until after your class has developed a shared understanding of their meaning.

Students co-construct the following version of Newton's second law: $F * \Delta t = m * \Delta v$. As with vocabulary, **do not** ask students to keep track of any equations or name any quantities until after your class has developed a shared understanding of their meaning.

Where We Are NOT Going

Although students have explored the relationships between past equations in the context of safety features, they have not expanded this learning to crumple zones. Crumple zones may seem counterintuitive to some students because damage to a crumple zone in a collision can give the idea that it can lead to more injury instead of less. Because of this, the lesson does not try to make a quick extension to the front of the vehicle; this will be the focus of Lesson 10.

This lesson will also not discuss the distribution of force over space and explain why an airbag works to extend both the time and the space of the collision in order to reduce peak forces. This concept is out of grade band.

Students begin to gain ideas about the role of rigidity on the risk level of occupants in a collision, but this idea will not be fully constructed and applied to all safety features until the end of Lesson 12. Students will continue to work through the end of Lesson 12 with this idea of rigidity and how the optimized rigidity is affected by speed and mass.

LEARNING PLAN for LESSON 9

1 · NAVIGATE BY LOOKING BACK AT COLLISION TIMELINES

5 min

MATERIALS: Vehicle Collision Timelines poster from Lesson 8

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

Consider what variable to investigate next. Display **slide B**. Point to the Vehicle Collision Timelines poster from Lesson 8, and instruct students to use it as they review the question on the slide on their own.

- *Considering the evidence we assembled in our timelines, what other variables might help us understand how safety features affect safety in a collision?*

After a minute, discuss it as a class. Accept all ideas.

Motivate a reading on crash dummy tests. Project **slide C**. Say, *Engineers test vehicle safety using life-size plastic dolls called "crash test dummies". What data would you want to collect from a crash test dummy to better understand how safety features can prevent injury?*

Engage in a quick 2-minute brainstorm with students in a whole-group discussion. Accept all ideas.

2 · READ ABOUT CRASH DUMMY TESTS

11 min

MATERIALS: *Crash Test Measures*

Read about how data are collected during crash dummy tests. Project **slide D**. Say something like, *Let's see what types of data engineers collect during test crashes.* Distribute *Crash Test Measures* to each student. When students have finished reading, they can begin discussing the three questions at the bottom of *Crash Test Measures* with a partner. Then, take two minutes to debrief the answers as a class.

Suggested prompt	Sample student response
How is measuring acceleration related to the net force acting on the head of the crash dummy?	(Students should say that acceleration is directly proportional to the net force acting on the body, referencing Newton's second law.)

How is deformation related to the net force acting on the chest of the crash dummy?	(Students should say that the degree of deformation is directly proportional to the force acting on the body during a collision.)
What do the patterns in the data tell you about the relationship between injury and the magnitude of the net force applied to that part of the body?	The data show that the degree of injury, whether you experience minor or major injuries, is directly proportional to the net force applied to the body.

Say, *In summary, we learned that the greater the force of contact on a driver, the greater the risk of injury.*

3 · MAKE PREDICTIONS ABOUT CONTACT FORCE

8 min

MATERIALS: whiteboard, 2 whiteboard markers (different colors), paper towel or whiteboard eraser, science notebook, Vehicle Collision Timelines poster from Lesson 8

Sketch a force diagram to identify contact forces on a driver during a collision. Project **slide E**. Say, *So we know that during a car collision, there is a net force acting on the body that causes injury, but this net force is the result of multiple forces acting on the body . We could model the forces in the vertical interactions, but let's focus on those in the horizontal direction. Let's briefly rewatch in slow motion the collision we analyzed in Lesson 8.*

Mention that the video they are about to watch is already in slow motion. Play https://youtu.be/rjICpd7SkIA. Say, *As you watch, jot down a list of forces acting on the crash test dummy that is not using safety features.*

After watching the video, ask*, What are the horizontal force interactions acting on the dummy at the moment the vehicle makes contact with something in a collision?* If needed, probe further: *What points of contact did we see that are related to some of the injury risks described in our handout? For now, let's think about the forces at play without safety features.*

Listen for these student responses:

- The steering wheel or dashboard pushes on the head.
- The steering wheel pushes on the chest.

Sketch a force diagram of the contact forces acting on the driver as students share their ideas. Students might say the force of gravity and/or the force of the seat pushes up on the person. If so, remind them that these forces are acting in the vertical direction, whereas the change in motion is in the horizontal direction.

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. The net force pushing on the dummy's head and neck by the front of the car during a collision is called the "contact force". The highest magnitude of force pushing a driver forward or backward during a collision is called the "peak force".*

Sketch a predictive graph to show contact force versus time. Project **slide F**. Distribute to each student an individual whiteboard, 2 whiteboard markers, and a paper towel or whiteboard eraser. Prompt students to create the axes for an *x*-*y* graph, placing "net force on dummy (kN)" on the *y*-axis and "time (s)" on the *x*-axis.

Say, *It's important to create mathematical models so we can consider ways to prevent injury. Let's make some predictive graphs of forces. Look back at our timeline from Lesson 8*. Point students to the Vehicle Collision Timelines poster from Lesson 8. Continue, *Think about the slow-motion video we just rewatched. Make the start of the collision--the first instant when the front of the vehicle makes contact in a head-on collision--the left end of the* time *axis on the graph. On your whiteboard, with your partner, draw your prediction for how net force acts on the dummy over time* ***without*** *safety features.* Allow students 1 minute to sketch their prediction.

Then say, *Let's now consider how we might mitigate these forces* ***with*** *safety features. Let's use a different color to overlay that on the same graph. What would it look like for the net force versus time? You may consider how the net force will be different from that in your first prediction. How would the timing be different? When would the force start and stop, and by how much? In the second color, show your prediction of the net force applied to the dummy during a collision with one safety feature--either a seat belt or an airbag.*

Give students 1 minute to sketch their prediction. Ask, *How did the safety feature alter your sketch of the net force?*

4 · ANALYZE DATA FROM A COLLISION SIMULATION

11 min

MATERIALS: *Effects of Safety Features*

Test predictions with simulation data. Say, *I have some data collected with the vehicle collision simulator we used in Lesson 7 that can help us test our predictions. Let's take a look at the force versus time graphs from this simulator.* Display **slide G** and distribute *Effects of Safety Features* to each student. Say, *How do the simulation data in part A of your handout compare to our predictions?* Give students 2 minutes to turn and talk with a partner.

Point to the data spikes at the right side of both the seat belt and airbag force graphs and ask students, *What do you think is happening here to make the force increase so much like this?* Look for students to identify that the crash test dummy must be running into the steering wheel. If they do not identify this, ask for them to compare the shape of those data spikes to the shape of the no-safety-features force graph and point out that they are the same shape.

Consider the risk of hitting the steering wheel. Display **slide H**. Point out that the crash test dummy did hit the steering wheel in all three cases. Pose the prompt on the slide:

- *Why do you think the likelihood of survival is higher for the seat-belt-only case?*

Look for students to have initial ideas about the amount the crash test dummy slowed down before hitting the steering wheel or the velocity it had when it hit. It is OK if they aren't sure at this time; encourage them to hold on to this question for later.

Sketch a predictive graph to show the additive effects of both safety features. Display **slide I**. Ask, *What should the graph look like if these safety features were used **together**, like they are in modern vehicles? You might imagine that accounting for two safety features would change the graph in different ways, such as when the curve starts and stops and the characteristics of the peak net force. Take 1 minute to sketch in part B of your handout your force diagram and the predicted net contact force versus time graph based on having both safety features.* Give students 2 minutes to record their predictions.

Poll to gather formative data on student predictions. Project **slide J**. Take the poll on the slide:

1. When both safety features are used, the magnitude of peak net contact force on the dummy will ...
    a. Decrease
    b. Not change
    c. Increase
2. When both safety features are used instead of one, the total time these contact forces are applied to the driver will ...
    a. Decrease
    b. Not change
    c. Increase

Accept all answers.

5 · INTERPRET DATA FROM A COLLISION SIMULATION

8 min

MATERIALS: *Effects of Safety Features*

Analyze simulated data when both safety features act on the crash test dummy. Say, *Now it is time to test our predictions.* Project **slide K** and give students a moment to sketch the actual shape and fill in the data table on the *Effects of Safety Features* handout. You may need to highlight where 0 kN is on the *y*-axis of the graph, since it is not on the top like in the other graphs.

ADDITIONAL GUIDANCE	Students may wonder about the constant positive force at the end. If they do, take a moment to talk about what motion the crash test dummy would go through if it doesn't hit the steering wheel. It would start to move backwards and then hit the seat. Explain that the positive force is the seat back bringing the crash test dummy to a final stop.

Display **slide L** and ask the students to answer in part C of their handout the questions that are shown on the slide. Give students about 3 minutes to answer the questions, then discuss as a class.

Suggested prompt	Sample student response
What features of the resulting graph were predictable? Which were unexpected?	(Answers will vary. Students may reflect on characteristics of the graph.) The shape change--the curve is wider. The peak is lower/higher than expected.
What does the combination of safety features do to increase likelihood of survival?	Driver safety increases and the survival rate improves because the crash test dummy doesn't hit the steering wheel. The peak force experienced by the crash test dummy is lower.

6 · OPTIONAL HOME LEARNING

2 min

MATERIALS: 2 3x3 sticky notes, permanent marker, *How Airbags Work*, *Biases in Modeling People*

Optional: Orient students to home learning. Present **slide M**. Distribute 2 3" x 3" sticky notes and a permanent marker to each student. Distribute sets of *How Airbags Work* and *Biases in Modeling People* around the room and ask students to pick one of the readings for home learning.

Say, *Our explorations of safety features that have improved survival rates may have raised new questions for you. I have a couple of articles that may help answer some of those. Select* ***one*** *of the articles to read for home learning--either How Airbags Work or Biases in Modeling People.*

Emphasize the following for students:

- Record responses to the prompts at the end in the section “Consider the following questions.”
- Then record new questions that the reading raised for you, one per sticky note.
- Stick these to the bottom of the reading. We will share these at the start of our next class.

End of day 1

7 · NAVIGATE

5 min

MATERIALS: sticky note questions from the home learning, *How Airbags Work*, *Biases in Modeling People*

Optional: Share questions raised by the reading. If you assigned the optional reading, display **slide N**. Then do the following:

- Remind students that they each picked one of two readings to dig into as home learning. Give students a moment to find the question(s) they recorded on their sticky notes.
- Ask students to share some of their questions. For each question shared, ask students who had a very similar question to raise their hand. Celebrate that the more we figure out in this unit, the more questions it raises.
- Tell students to leave their sticky notes on their desks, and you will collect them in a moment to add to the Driving Question Board later, once students are carrying out their next investigation.

Optional: Share responses to the reading prompts. Ask students to share some of their ideas about the prompts included in the readings.

Brainstorm characteristics of airbags and seat belts. Display **slide O**. Give students a half minute to individually think about the question on the slide. Then share ideas as a class for 2-3 minutes and record a list of these ideas on the board. Here are some sample student responses:

- how quickly they are deployed and start working (e.g., the sensors in a car)
- material they are made of on the outside (e.g., polyester, nylon)
- material they are made of on the inside (e.g., air, foam, elastic)
- their size (or surface area)
- their shape
- what part of the body they make contact with (lap belt versus shoulder belt)

If students respond with only the variables from the simulation, ask how those variables might be changed when designing the safety feature. Emphasize that all these characteristics are variables that engineers can modify to try to design a better set of safety features, and this opens up millions of different possible combinations of characteristics to explore, and computer simulations can help engineers narrow in on the most promising combinations for particular vehicle conditions.

Suggest that we do something similar today by using the simulation to try to find some optimal combinations for a subset of these characteristics.

8 · PLAN AND CARRY OUT AN INVESTIGATION AND COMPARE RESULTS

13 min

MATERIALS: *Safety Optimization Investigation*, sticky note questions from the reading, computer with access to https://s3.amazonaws.com/p.3simulation/collisions/seatbelts-airbags.html, *Simulation Use Guide*, https://s3.amazonaws.com/p.3simulation/collisions/seatbelts-airbags.html

Orient to a control condition. Display **slide P**. Distribute a copy of *Safety Optimization Investigation* to each student. Orient students to the example for the default on the handout that models how students should use the simulation and record data.

<table>
<tr>
<td>Vehicle Collision Simulator: Seat Belts and Airbags</td>
<td>

Orient students to the controls of the Seat Belts and Airbags version of the Vehicle Collision Simulation (https://s3.amazonaws.com/p.3simulation/collisions/seatbelts-airbags.html).

Open the simulation and click “New Trial”.
Review the settings available in this version of the simulation and the default values.
Press “Run”.
Point to the list of outcomes and connect them to the table on the handout.
Click on the “View Graphs” tab to see the force versus time graph for the crash test dummy.
Connect the graph to the copy of it on the handout and explain how to identify the maximum (negative) net force and time values shown on the graph for the sketch. Use the example sketch on the handout.
Click the “Home” tab in the upper left.
Point to the Review Your Trials table and hover over the trial you just ran to show the outcomes.

To provide additional support to students in using the simulation, provide Simulation Use Guide from Lesson 7 as a guide.
</td>
</tr>
</table>

Go over the instructions for optimizing one variable and then recording data for three trials on *Safety Optimization Investigation*.

Explain that *stiffness* describes how much force a material applies when it is deformed a certain amount, which varies, like a spring. Explain that *rigidity* describes the constant force a material applies during deformation. ✱

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING STRUCTURE AND FUNCTION

This is a moment you can explicitly connect to this crosscutting concept:

- 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 the structure's function and/or to solve a problem.

To do this, ask students the following:

- *What properties of the system have you considered so far?*
- *What additional properties of other parts of the vehicle system would you want in a simulation as an engineer working on designing safer vehicles?*

Carry out the investigation. Display **slide Q**. Point students to the simulation link at the top of *Safety Optimization Investigation* (https://s3.amazonaws.com/p.3simulation/collisions/seatbelts-airbags.html). Give groups 8-9 minutes to carry out their investigations. Give students a two- or three-minute warning to make sure they record the data and graphs on their handout.

As they work, collect their sticky note questions from the home learning to add to the DQB.

ALTERNATE ACTIVITY	This activity can be adjusted to differentiate. *Safety Optimization Investigation* asks students to optimize both variables independently. If students are struggling with navigating the simulation and optimization, you can have them optimize only one variable. Be sure that both variables are covered by the class as a whole. If students are very comfortable with the simulation and optimize the variables quickly, have them then combine the two and optimize while changing both seat belt stiffness and airbag rigidity. This can be added to the handout by copying the tables onto a blank piece of paper and attaching them to the rest of the handout.

Compare results. Display **slide R**. Take a poll with the question on the slide:

- *What was the highest likelihood of survival you achieved for your design of the seat belt and airbag for a vehicle colliding with a barrier at 25 mph?*

Take a poll of hands to see who got a likelihood of survival of higher than each of these: *Higher than 50%? 60%? 70%? 80%? 90%?*

ADDITIONAL GUIDANCE	**Social and Emotional Learning:** This is a good time to check in with students and give them a moment to notice their emotions. The very low likelihood of survival rates, even at a low speed, can be quite alarming. If questions arise about this, point out that the simulation is simulating a vehicle driving straight into an immovable barrier without braking. Assure them that this is an extreme case that is useful for experimenting but that most vehicle collisions in real life are less extreme.

This element will continue to be addressed and be assessed in the next lesson.

9 · ANALYZE DATA

5 min

MATERIALS: *Six Optimization Attempts*, Force and Motion Relationships poster from Lesson 6

Introduce additional data. Say, *Let's use our data from our simulation trials to further develop our understanding of how safety features help keep people safe in vehicle collisions. Since it's easier to compare data on graphs with the same scale, I have for you an additional data set with adjusted graphs.* Distribute *Six Optimization Attempts* to each student. Quickly review the two sets of graphs: the original simulation graphs and timescale-adjusted graphs.

ADDITIONAL GUIDANCE	This is a good time to remind students that they should be comparing the parts of the graphs from the beginning of the collision to when the crash test dummy first reaches 0 mph before beginning to move

backwards. This keeps the change in momentum of each crash test dummy equal. If students need support in understanding this, take a moment to look at the combination of velocity versus time and net force versus time in the simulation (https://s3.amazonaws.com/p.3simulation/collisions/seatbelts-airbags.html). Doing this, you can see that the point at which the airbag stops and the negative force begins to decrease is when the crash test dummy's velocity crosses 0 mph and becomes negative.

Analyze the data for patterns. Display **slide S**. Give students a couple minutes to consider the questions on the slide as they study their data and the data on the handout. Then discuss as a class.

Suggested prompt	Sample student response
What patterns do you see in these six attempts to optimize the safety features?	As the peak force on the person decreases, the length of time that forces are applied increases. The likelihood of survival goes up as the peak force goes down. The likelihood of survival goes up as the length of time the forces are applied increases. The shape of the force versus time graph is similar (if the same safety features are used), just stretched out in different directions. If the crash test dummy hits the steering wheel, the time gets cut super short and the peak force is very high.
What design decisions were made to optimize the likelihood of survival?	Lowering rigidity and stiffness. But not lowering too much and causing the crash test dummy to hit the steering wheel.
What equation(s) from our Force and Motion Relationships poster might help us understand these patterns?	Any of the equations that involve forces and time.

ADDITIONAL GUIDANCE	These are some of the big take-aways from this lesson that build on what students saw in Lesson 8 and will continue to build on when considering crumple zones in Lessons 10 and 11. If students are struggling with coming up with these patterns in the data, take some extra time to walk through these patterns with the data. Use a sentence stem like, *as ________ increases, __________ increases/decreases/stays the same* to help students understand the types of patterns they are looking for.

ASSESSMENT OPPORTUNITY	**What to look for/listen for in the moment**
	● Use characteristics of the graph to identify patterns, such as the following:
	    ● Shape change--the curve is wider.
	    ● The peak is either lower or higher than expected. (SEP: 4.6)
	● The design of the two safety features to be less rigid or stiff leads to increased survival rate by lowering the peak force and increasing the total time that the net force will act on the crash test dummy, as long as the crash test dummy doesn't hit the steering wheel. (CCC: 2.3; DCI: PS2.A.1)
	
	What to do: Point students back to the data and ask them to identify the magnitude of the peak force when the forces are first applied and when the forces stop. If students are struggling with these patterns, spend more time exploring them before moving on to the individual activity with speed, or complete the speed activity as a class instead.
	
	Building toward: 9.A.1 Develop an explanation for why designs of vehicle safety features improve survivability and why survivability changes in collisions at different speeds with the same safety features, using the relationships of Newton's second law and evidence derived from graphs produced by a collision simulation. (SEP: 6.1, 6.3, 4.6; CCC: 2.3; DCI: PS2.A.1)

10 · MAKE PREDICTIONS AND ANALYZE DATA

7 min

MATERIALS: *Comparing Three Speeds*, Force and Motion Relationships poster from Lesson 6

Make predictions. Display **slide T**. Review the thumb poll directions on the slide and then take a poll on the two questions.

- *What impact would an increase in vehicle speed before the collision with a stationary barrier have on*
    - *the peak net force (maximum) acting on the person during the collision?*

- *likelihood of survival?*

ALTERNATE ACTIVITY	Some students may have found a scenario that had a very high or 100% likelihood of survival. If so, test those designs at the higher speed as a class. This will provide an opportunity to talk about how optimization for one condition might not be optimal for all conditions.

Explain the results. Display **slide U** and distribute *Comparing Three Speeds* to each student. Remind them that the Force and Motion Relationships poster from Lesson 6 is available for reference. Give them the remaining time to develop an explanation by answering the questions on the handout.

Collect *Comparing Three Speeds* as a formative assessment.

ASSESSMENT OPPORTUNITY	**What to look for/listen for in the moment:** See the *Comparing Speeds Key*. **What to do:** See the *Comparing Speeds Key*. **Building toward: 9.A.2** Develop an explanation for why designs of vehicle safety features improve survivability and why survivability changes in collisions at different speeds with the same safety features, using the relationships of Newton's second law and evidence derived from graphs produced by a collision simulation. (SEP: 6.1, 6.3, 4.6; CCC: 2.3; DCI: PS2.A.1)

11 · DEVELOP AND USE A MODEL TO EXPLAIN THE DATA

7 min

MATERIALS: *Six Optimization Attempts*, Force and Motion Relationships poster from Lesson 6, index card, chart paper markers, transparent tape

Introduce the idea of trade-offs to motivate mathematical modeling. Say, *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. But as we saw, the optimal design for one condition might not work in another. There are trade-offs that need to be made. We can, however, use mathematical relationships to understand these design trade-offs.*

Rearrange the equation to isolate variables that were changing. Display **slide V**.

Point to the two equations on the Force and Motion Relationships poster that have F = and Δt = on the left side of them, as shown to the right. Rewrite these equations on the whiteboard.

$$\Delta t = \frac{m \times \Delta v}{F}$$

$$F = \frac{m \times \Delta v}{\Delta t}$$

Ask what operation we would need to do to bring the two variables that were changing, F and Δt, to the same side of the equation in order to isolate the two variables that were not changing--mass of the person (m) and their Δv--as they came to a stop. Listen for students to suggest we would need to move the variable in the denominator in either equation (F or Δt) by multiplying both sides of the equation by that term.

Rearrange either (or both) of the equations using this step and show the cancellation of the variable on the right side of the equations.

$$\Delta t = \frac{m \times \Delta v}{F}$$

$$F * \Delta t = \frac{m * \Delta v}{\cancel{F}} * \cancel{F}$$

Add a box around the new equation. If this is your last period class, use an index card to add this equation to the bottom of the Force and Motion Relationships poster.

$$\Delta t = \frac{m \times \Delta v}{F}$$

$$F * \Delta t = \frac{m * \Delta v}{\cancel{F}} * \cancel{F}$$

$$\boxed{F * \Delta t = m * \Delta v}$$

Compare the equation to the patterns we identified. Display **slide W**. Say, *Let's remind ourselves that if the force is changing over time, this F refers to the average force over the whole collision, which is something we saw in a previous lesson. We can roughly estimate the average forces on our graphs to see that increasing the peak force in our examples also increases the average force.*

ADDITIONAL GUIDANCE	Take a moment to make sure that students understand how peak force and average force are related. If necessary, talk about the different graphs and where the approximate average force is. Be sure that students understand that increasing the peak force typically also raises the average force.

Discuss the question on the slide as a class. Have students use *Six Optimization Attempts* during this discussion. Follow up as shown in the table below.

Suggested prompt	Sample student response
How does this version of the equation help explain the patterns we see in these graphs?	As the average force goes up, the length of time it is applied for goes down. As the time goes down, the average force increases.
If we used the simulation to keep testing different characteristics for the airbag and seat belt and we came upon one that ends up doubling the amount of time the force is applied to the person, how much would the magnitude of the average force on the crash test dummy change?	The average force would be half as much.
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 the time over which the force is applied change?	The time would be four times as long.
To have less injury during a collision, what types of forces and times should we design for?	Lower forces. Longer times.

12 · ADD TO THE ENGINEERING PROGRESS TRACKER AND BRAINSTORM VEHICLE BODY REDESIGNS

7 min

MATERIALS: science notebook, *Engineering Progress Tracker*
Add to the *Engineering Progress Tracker*. Display **slide X**. Give students 4 minutes to add to their tracker. Collect *Six Optimization Attempts* to reuse for your next class of students. **Brainstorm vehicle body redesigns.** Forecast that we will shift to investigating some other safety features next time. Display **slide Y**. Read the text at the top and then give students 1 minute to stop and jot their ideas related to the question: • *What are some ways in which the body of the vehicle could be redesigned to make a collision safer?*

Additional Lesson 9 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN MATH	**The Number System** **CCSS.MATH.CONTENT.HS.N-VM.1 Represent and model with vector quantities:** Recognize vector quantities as having both magnitude and direction. **Algebra** **CCSS.MATH.CONTENT.HS.A-CED.4 Creating equations:** Create equations that describe numbers or relationships. Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations.