Lesson 8: What interactions happen during a vehicle collision, and when do they happen?

Previous Lesson *We applied our ideas about momentum to an assessment and looked at new data on factors we think are important for explaining the trends we identified in Lesson 1. We discussed correlation versus causation. We explored a simulation of a vehicle collision to look for additional variables. We added new questions about safety features to the Driving Question Board.*

This Lesson

Problematizing, Investigation

1 day

We watch a video of people in a collision and determine it is too fast to analyze. We create collision timelines using an animation based on simulation data for the vehicle and crash test dummy with and without seat belt and airbag. We use velocity data from the simulation to add velocity data to our timelines.

Next Lesson *We will read about force interactions on drivers during collisions. We will make predictions and collect data from a simulation about how safety features affect force of contact versus time. We will try to optimize the characteristics of seat belts and airbags in a simulation. We will use simulation results to explain why survivability changes in different vehicle collisions.*

BUILDING TOWARD NGSS

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

What students will do

8.A Develop timeline models of vehicle collisions using animations and simulation data to illustrate and compare changes in motion for the systems of a vehicle and crash test dummies that are too fast to observe directly. (SEP: 2.3; CCC: 3.2; DCI: PS2.A.1)

What students will figure out

- The total change in velocity of the vehicle and the crash test dummy is always the same, regardless of safety features.
- In a collision, no matter the presence of seat belt and airbag, the vehicle will take the same amount of time to reach a velocity of 0.
- In a collision with safety features, a crash test dummy changes velocity over a longer period of time than in a collision without safety

features.

Lesson 8 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	15 min		**ANALYZE AN ACTUAL COLLISION** Watch video of a collision and try to identify the order of events.	A-D	https://youtu.be/VEHC2iJ3Ufg?feature=shared, dry erase markers (any two colors), Force and Motion Relationships poster from Lesson 6
2	10 min		**USE AN ANIMATION TO ESTABLISH TIMING OF COLLISION EVENTS** Use an animation based on simulation data to construct timelines for collisions both with and without safety features.	E-H	https://youtu.be/R7rlShd7aKk, https://youtu.be/rjICpd7SkIA, dry erase markers (any two colors)
3	10 min		**ADD VELOCITY CHANGES TO THE TIMELINES** Explore velocity data, using *Simulation Velocity Data*, for the collisions and connect it to the timelines. Compare the timelines for the crash test dummy with and without safety features.	I-M	*Simulation Velocity Data*, dry erase markers (any two colors)
4	5 min		**EXPERIENCE THE DIFFERENCE IN TIME PERIODS** Use stopwatches to gauge the time in which the crash test dummy goes from a velocity of 40 mph to 0 mph.	N	stopwatch, https://youtu.be/VEHC2iJ3Ufg?feature=shared
5	5 min		**DISCUSS THE ROLE OF SAFETY FEATURES IN A COLLISION** Discuss what safety features might be doing in the small window of collision time to potentially reduce injuries.	O-P	chart paper, chart paper markers

End of day 1

Lesson 8 • Materials List

	per student	per group	per class
Lesson materials	• science notebook • *Simulation Velocity Data* • stopwatch		• https://youtu.be/VEHC2iJ3Ufg?feature=shared • dry erase markers (any two colors) • Force and Motion Relationships poster from Lesson 6 • https://youtu.be/R7rlShd7aKk • https://youtu.be/rjICpd7SkIA • chart paper • 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 *Simulation Velocity Data* (1 per student).

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

Review *Timeline Development* for guidance on how to develop the timelines with your class and how to organize them on the whiteboard. After the lesson, you will create a poster of the timelines titled "Vehicle Collision Timelines" for reference in future lessons.

Test the following videos:

- https://youtu.be/VEHC2iJ3Ufg?feature=shared
- https://youtu.be/R7rlShd7aKk
- https://youtu.be/rjICpd7SkIA

Be sure that the Force and Motion Relationships poster from Lesson 6 is displayed in the classroom.

Lesson 8 • Where We Are Going and NOT Going

Where We Are Going

During this lesson, students create timelines of two collisions. One collision occurs with safety features (seat belt and airbag), and the other collision occurs without safety features. Students work to create timelines of these events for both the vehicle and the crash test dummy systems. Students also consider each system's velocities before and after a collision. By creating these timelines students start to reason out that velocity changes happen over a longer period of time for the crash test dummy in the collision with safety features. This does not apply to the vehicle, which experiences the same velocity changes over time in both collisions.

Students start to reason out that safety features must be doing something to the forces on the body over time. This builds on their development of $F*\Delta t = m*\Delta v$, $F = m*a$, and $a = F/m$ in Lesson Set 1. Through the timeline creation and comparison process in this lesson, students are engaging in ideas and processes building towards the following disciplinary core idea:

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

Students encounter and/or co-construct ideas around a term and may decide to add the following term to their Personal Glossaries during this lesson: *crash test dummy* (or agreed upon alternative, see equity callout). Do not ask students to define or keep track of any words until after the class has developed a shared understanding of their meaning.

Where We Are NOT Going

While the analysis of motion and development of the timelines are essential for students to make sense of how forces and time are related and how Newton's second law predicted these changes, students will not be analyzing forces within this lesson. They begin to make connections to forces using Newton's second law from its use in other lessons, but they won't explicitly discuss forces on the crash test dummy until the next lesson.

LEARNING PLAN for LESSON 8

1 · ANALYZE AN ACTUAL COLLISION

15 min

MATERIALS: science notebook, https://youtu.be/VEHC2iJ3Ufg?feature=shared, dry erase markers (any two colors), Force and Motion Relationships poster from Lesson 6

Motivate the need to watch a real collision. Say, *Last class we added questions to our DQB. A lot of our new questions are about safety features that we noticed in the simulation.* Then say, *The simulation is a really useful tool. But before we use it again, let's actually look at a collision to try and determine what the safety features might be doing and when they might be acting to keep people safer.*

Discuss precautions taken in the video. Display **slide A**. Explain to students that they will watch a video of an intentional, slow-speed collision (https://youtu.be/VEHC2iJ3Ufg?feature=shared). Point out that the vehicle will be traveling at 40 mph and that the occupants have chosen to be in this collision. Tell students that safety gear like mouth guards are being worn for the collision, and we will also get to see the seat belt and airbag safety features deploy, and no one is injured in the video. Emphasize that these are professional stunt drivers and that even with the safety precautions put into place, they are putting themselves at risk of injury, and this should not be attempted under any circumstances.

ADDITIONAL GUIDANCE	**Social Emotional Learning (SEL):** Although this video was chosen specifically because of its lack of injuries and presence of clear safety procedures, this video may still be sensitive for some students. Make sure to inform the counselor or other trained student advocate at the school of the video and to provide an alternative plan for students who may need extra support or need to be excused from the video. Also make an effort to prepare all students for what they will see and remind them of the resources outlined in *Student Mindfulness Resource*. Preface this for students by saying something like, *Before we start the video, please be aware that this is a video with real people experiencing the elements of a crash from inside the vehicle. They are prepared for the collision as they have proper safety gear and are shown to be uninjured afterwards. Please take care of your needs. If this makes you uncomfortable, take a moment to settle and breathe or if necessary to focus on another visual element in the room.*

Ask students to get out their science notebook to record when the collision and safety feature events happen from the perspective of the camera, which is inside the cabin of the vehicle. Tell students that this video does not show the vehicle collision from start to stop, so we will do our best to establish when things happen qualitatively. Explain that after we watch the video we will try to create a rough timeline of these events together, similar to what we had done in Lessons 2-3, but without the ticker at the bottom of the screen.

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING SCALE, PROPORTION, AND QUANTITY

This is an important moment where students are not just acknowledging that a phenomenon cannot be observed directly but experiencing the struggle to do so. Highlight this thinking and support students in recognizing how the timescale is limiting direct observations. If students suggest using slow-motion video, you can slow down the play speed of the video and show that the timing is still too fast to determine when events happen.

✱ ATTENDING TO EQUITY

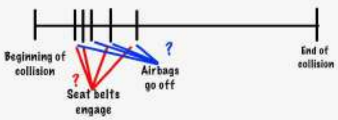
Universal Design for Learning: The colors chosen to *represent* the ideas for this timeline are color blind friendly, meaning that students who are color blind should still be able to distinguish between the different shades of colors. If you know you have color-blind students, using similar colors and/or using different shapes to *represent* the vehicle and the person/crash test dummy separately will be helpful so they can

Show the real-life collision video. Project **slide B**. Play https://youtu.be/VEHC2iJ3Ufg?feature=shared. After the completion of the first viewing, pause and allow students a moment to record on an initial timeline the order of each event in the collision. Students will likely be able to tell that the airbags go off and seat belts are in use but may be unsure of the timing and order of these events. Replay the video as many times as necessary for students to update their timeline and to feel comfortable moving on.

Take a moment to discuss what events students are identifying or trying to track. At this point students should be trying to identify when the people interact with the seat belts and airbags and when the car hits something and when it stops moving. They won't be able to see these things clearly in the video but should be starting to think about when they might be happening.

ADDITIONAL GUIDANCE	The intention of the video is for the students to begin their timeline using a real-world collision. They will not, however, be able to judge timing well or create a detailed timeline because of the speed at which the events take place. This will be done using a simulation. Note that the minor amount of dialogue in the video is not important for this task.

Attempt a timeline and determine that the interaction is too quick to observe what happens when. Bring the class together and quickly draw on an easily editable space such as the whiteboard an order of events based on the video. Use different colors for the vehicle and the occupants. Begin by marking two points that the students can agree upon, the beginning and the end of the collision. Draw this timeline off to the side of the board and smaller so that you can reference it when building the more-detailed timelines with the animation later in the lesson. Ask students to share when they believe the events took place in the collision. There will be uncertainty due to the speed of the crash in the video. See *Timeline Development* for example step-by-step development of the timelines with larger images.



Remind students to record and/or modify in their science notebook our class thinking about this timeline as it is developed by the class. Some students are likely to believe that the features were deployed in different orders or that they deployed all at once. Stir up controversy with students around when each safety feature became engaged by asking questions like these:

- *_____ thought that the airbag deployed first. Are we sure about that? Does anybody disagree?*
- *How can we tell if that really was at the same time or if one was slightly before the other? You look like you might disagree with _______. What are you thinking?*

Ask students, *It seems like we don't have agreement on when each safety feature started and when it was active during the collision. Why is that?*

Guide students to determine that the interactions with this system happened too quickly to study in real time and that the collision needs to be slowed down in order to see what is happening in the system and when. ✱ Suggest that the simulation introduced in the previous lesson can be used to collect data at a faster

differentiate between them. There are many websites that have information about what colors are useful for different color blindness. Consider using a palette that uses orange, blue, black, or dark brown.

rate than the visual camera could provide and tell students that you also have an animation that aligns with two particular collision scenarios in the simulation that can show the collision in slow motion. Suggest using the simulation data and the animation based on simulation data to build a clearer timeline. Note that the animation and simulation include a crash test dummy as opposed to people.

Determine changes in velocity over the course of the collision. Project **slide C**. Tell students that we may not be able to slow down this interaction in real life, but, before we use the simulation, we can still complete more of our timeline using what we already know about the changes that occur when a vehicle comes to a stop. Have students turn and talk about the prompts on **slide C**:

- *What do we know about the velocity of the vehicle before and after the collision?*
- *What do we know about the velocity of the occupants before and after the collision?*

	Vehicle	Occupants
Initial velocity	40 mph	40 mph
Final velocity	0 mph	0 mph
Change in velocity	-40 mph	-40 mph

After 3 minutes, hold a whole class discussion on the changes to velocity for both the occupants and the vehicle during the collision time period. Use two different colors to record the information in a table about the occupants and the vehicle. ✱ Suggested prompts and anticipated responses are below.

Suggested prompts	Sample student responses	What to do
What do we know about the velocity of the vehicle before and after the collision time period?	The speed of the vehicle seemed constant. The video said the vehicle was going 40 mph. At the end of the collision time period, it had a velocity of 0 mph--the car had come to a stop.	
What about the velocity of the occupants?	The occupants were in the vehicle, so they were going the same velocity as the vehicle before the collision. Both the car and the occupants were going 0 mph after the collision. Their speed was at 0.	*Mark on the timeline in a space before the collision that both the occupants (or crash test dummy) and the vehicle were going 40 mph and mark that they were at 0 after the collision had ended.*
How do the changes in velocity for the vehicle and occupants compare?	They are the same.	*Note this on the timeline.*

Make a connection between the change in velocity and forces in the collision. Ask students to consider the potential problem of a large change in velocity over a short period of time using the relationship of force and the short duration of the collision. Display **slide D**. Give students a moment to turn and talk about the slide prompts. Then bring them together for a whole class discussion. If students are struggling to remember about the relationship between mass, velocity, force, and time, point them towards the Force and Motion Relationships poster from Lesson 6 and remind them how speed and velocity are related.

- *What do we know about the relationship between mass, velocity, force, and time?*
- *Using our relationships, why might a large change in velocity like in this collision be problematic?*

Point to the velocity change that was recorded on the board, showing the vehicle and occupants going 40 mph and then within a very short time the speed of all objects in the system was reduced to 0. Guide students to use the mathematical relationships to determine that would mean very large forces are acting on the vehicle and occupants and that there might be a connection between the use of safety features and the forces in a collision. Example prompts and responses are below.

Suggested prompt	**Sample student response**
What do we know about the relationship between mass, velocity, force, and time?	We know that $F = (m * \Delta v)/\Delta t$ (or any other forms of the equation on the Force and Motion Relationships poster from Lesson 6).
We had a vehicle going 40 mph, and both the occupants and the vehicle went from 40 mph to 0 mph in an incredibly short period of time. So, thinking about this equation, what would this very small Δt mean for the forces on both objects?	There would be a very large force on the car, since the car is stopping so suddenly with such a large mass. The occupants would also experience a lot of force on their bodies because they are stopping so quickly.
So if it is such a short period of time and such high forces, what could have been protecting these people in the collision?	It was the seat belts and airbags.
So what do the seat belts and airbags change in this equation? Since the mass and initial velocity are already determined, what variable is left to change? Do they change the total collision time? The force?	The occupants would still be in the collision, and the velocity changes would be the same, but maybe the timing has something to do with it. If the airbags and seat belts weren't there, then the occupants would hit the dash. The dash is a lot harder than the airbags and seat belts. So maybe forces are different. It probably changes the force? Don't know why, it just feels right.

It's such a short period of time; in our video it was less than a second. How could seat belts and airbags really make that much of a difference?	It has something to do with the forces in a collision. The time is short, but the seat belts and airbags must be stopping the occupants or slowing them down at a different rate or preventing higher forces. Squishier things don't apply as much force as hard things, like the dashboard. Maybe it's because the airbag is squishy.

ADDITIONAL GUIDANCE

Note that this is a primer moment for considering the force and time relationship, not a moment for deep sensemaking. This relationship, and how it is related to safety feature design, will be built out across the next three lessons. If students aren't drawing out this relationship yet, that is OK.

ADDITIONAL GUIDANCE

Students may mention that regardless of safety features, there is the same change in velocity for each object in the same amount of time. While this is inaccurate, students may not have had the experiences to know that a person in a collision without safety features changes velocity at a faster rate once hitting the steering wheel or dashboard than a person in a collision encountering a seat belt and airbag. These changes in velocity will be uncovered later in the lesson.

Say, *OK. We have a large velocity change for both the vehicle and the occupants over a very short amount of time, and we think that the seat belts and airbags are helping the occupants during the collision by doing something to the forces and/or time in the collision. But our video was just too fast to see what was happening and when it was happening. Unfortunately, I don't have a slow-mo video of a collision, but I do have an animation based on simulation data that might be able to help us out.*

2 · USE AN ANIMATION TO ESTABLISH TIMING OF COLLISION EVENTS

10 min

MATERIALS: science notebook, https://youtu.be/R7rlShd7aKk, https://youtu.be/rjICpd7SkIA, dry erase markers (any two colors)

Say, *The simulation we saw in the last lesson calculates data for a collision of a vehicle with a barrier. It does this at very short time intervals for both the vehicle and a crash test dummy* ✱ *in the driver's seat. I have an animation that shows the events modeled in the simulation with parameters similar to the video we just watched.*

Explain the variables chosen in the simulation. Display **slide E**. Remind students that in the last lesson they saw that this simulation has many variables that can be manipulated. Tell them that for the purposes of our investigation we will try to recreate what we saw happen in

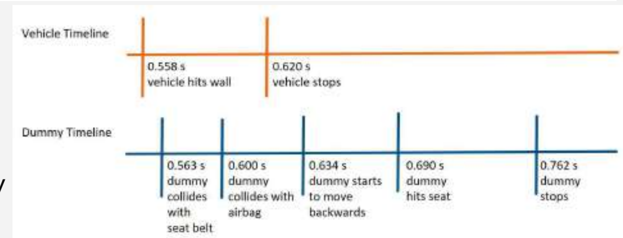
✱ ATTENDING TO EQUITY

In this unit, the use of the word *dummy* is as a "model or replica of a human being." However, when applied to a person, that our first video. Tell students that this simulation is set to 40 mph (18 m/s), the velocity that the vehicle was traveling in that video. The airbag and seat belt are turned on, and there is a crash test dummy that is comparable to the people in the video. The vehicle mass is set to 1,500 kg, which is approximately the mass of the vehicle in the video. Explain that you will play the collision animation and watch the collision. After that, the class will watch the slow-motion replay to determine when certain events are happening in this collision time period.

Determine basic events and interactions. Display https://youtu.be/R7rlShd7aKk. Play the animation and ask students to track each interaction between the vehicle and the wall and the crash test dummy and the components of the vehicle system. Remind students that we are looking at two different objects--the vehicle and the crash test dummy--that are changing velocity very rapidly. Explain that you will track these systems separately. Students will most likely need to see the slow-motion replay multiple times.

ADDITIONAL GUIDANCE	To play the animation in slow motion, click on the settings gear icon on the video, click “playback speed”, and then select the desired speed (less than 1).

Model the crash test dummy and the vehicle systems separately. Suggest using separate, stacked timelines to track the two systems. Draw out two new timelines, leaving space for a third underneath. Use student input to transfer the events from the video timeline onto the new, stacked timelines, using the animation to sequence the events more accurately using specific times. Have students record the timelines in their notebooks as they are co-constructed by the class. Play the animation again, pausing as necessary to confirm times. By this point, students should have timing for the events in the table below.



Event	Approximate time based on animation
Vehicle hits the barrier	0.558 s
Vehicle stops moving	0.620 s
Crash test dummy collides with seat belt	0.563 s
Crash test dummy collides with airbag	0.600 s
Crash test dummy starts to move backwards	0.634 s
Crash test dummy hits seat	0.690 s

word can be insulting and is considered particularly derogatory within the Deaf and disabled communities. Maintain zero tolerance for students who apply the word *dummy* to any person, in or out of the classroom, for any reason, and be sensitive to the needs of students who are deaf or have a disability. Consider agreeing on an alternative word with your students if any objection is raised, rather than attempting to defend the use of a potentially harmful word.

Crash test dummy stops moving	0.762 s

ADDITIONAL GUIDANCE

When playing the animation video, students may want to pause at a very specific moment. To advance the video to a frame, pause the video right before or after the moment you want to see. Press the "," key to go backward frame-by-frame or "." to go forward.

ALTERNATE ACTIVITY

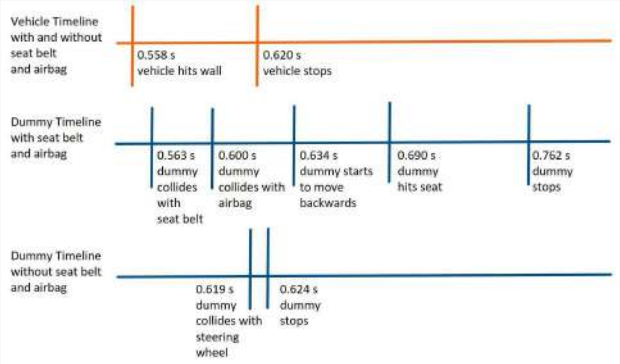
For students who need additional support, consider providing a timeline template with a list of the key events as a graphic organizer scaffold.

Make predictions about the timeline for the collision without safety features. Remind students that we thought something was happening with the safety features over the collision period and that we wondered how they could be affecting the crash test dummy. Introduce that you also have an animation based on simulation data where there is neither a seat belt nor an airbag.

Display **slide F**. Have students turn and talk about the prompt on the slide:

- *How do you predict the timeline without safety features will compare*
    - *for the vehicle?*
    - *for the crash test dummy?*

After a minute or so, have a few pairs share their predictions. Accept all answers and probe reasoning. Highlight ideas on how the vehicle timing might be the same or different. Then say, *Let's check our predictions using the animation.*



Compare the vehicle timelines for the collision with and without safety features. Display **slide G**, then https://youtu.be/rjlCpd7SkIA. Play the animation and ask students to start by tracking the timing of the vehicle. Look for students to notice that the timing for the vehicle is the same and propose that this means that we can use the same timeline for both vehicles. Note this on that timeline. Take a moment to connect back to student reasoning from the Turn and Talk to discuss why safety features wouldn't affect the timing of the vehicle.

Construct the crash test dummy timeline model for the collision without safety features. Play the animation without safety features again and ask students to track the timing of interactions for the crash test dummy. Then co-

construct a third timeline, stacked below the others, for the crash test dummy when safety features are not present. The times for the new timeline are listed in the table below.

Event	Approximate time based on animation
Crash test dummy (without safety features) collides with steering wheel	0.619 s
Crash test dummy (without safety features) stops moving	0.642 s

ALTERNATE ACTIVITY

If you have the time, consider having students work in groups with the animation to establish one or both timelines. If some students struggle with this task independently, work with them to identify a couple of the times before having them identify the rest.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment

- Students use data from the animation to develop timeline models for the vehicle and crash test dummy systems during the collision that they could not model through direct observation because it was too fast. (SEP: 2.3; CCC: 3.2; DCI: PS2.A.1)

What to do: See *Timeline Development* for guidance on how to scaffold the development of the timeline.

Building Toward 8.A.1 Develop timeline models of vehicle collisions using animations and simulation data to illustrate and compare changes in motion for the systems of a vehicle and crash test dummies that are too fast to observe directly. (SEP: 2.3; CCC: 3.2; DCI: PS2.A.1)

Compare the crash test dummy timelines. Display **slide H**. Pose the prompt on the slide:

- *Do our timelines confirm or refute your predictions on how they would compare?*

Accept all answers.

ADDITIONAL GUIDANCE	Note that to keep the changes in momentum of the crash test dummies equal, the time to compare on the timeline with safety features is the time from the crash test dummy first colliding with the seat belt to when it comes to a stop and begins to move backwards.

3 · ADD VELOCITY CHANGES TO THE TIMELINES

10 min

MATERIALS: science notebook, *Simulation Velocity Data*, dry erase markers (any two colors)

Select data to examine. Project **slide I**. Have students turn and talk about the prompt on the slide:

- *If we simulated these collisions using the Vehicle Collision Simulation, what data might help us make sense of the motion of the vehicle and the crash test dummy?*

Give students a minute or so to discuss and then have a few pairs share their ideas. Look for students to suggest motion variables they have previously examined in the unit such as position and velocity.

ADDITIONAL GUIDANCE	If students suggest forces as a variable, affirm this idea but suggest that we first analyze the motion variables to develop the timelines and then look at forces. If students don't suggest forces, that is OK. The simulation does not provide position data beyond the distance of the vehicle from the barrier because everything is moving in complex ways and tracking positions and relative positions gets messy very quickly. See *Collision Simulation Information* from Lesson 7 for more information on how the simulation functions.

Display **slide J** and pose the question on the slide:

- *What do you expect to see in the velocity data from the simulation for these two collisions?*

Look for students to expect to see sudden changes in the velocity and that the objects will come to a stop. Connect this back to the notes on the board from the original video about the initial and final velocity of the vehicle and occupants.

Examine velocity data. Say, *The simulation does calculate the velocity for both the vehicle and the crash test dummy.* Distribute *Simulation Velocity Data* to students and orient them to the data tables. Display **slide K** and pose the prompt on the slide to have students discuss with a partner:

- *What happens with the velocities at the moments on our timelines?*

Give students about 4 minutes to investigate the velocity data. Have students record their thoughts in their notebooks with their timelines.

ADDITIONAL GUIDANCE	While it may be tempting to give students access to the simulation or pull up the data here instead of using *Simulation Velocity Data*, doing so would give away force and acceleration data that we want students to dig

into at a later time. Providing force and acceleration data too early could take the focus away from what impacts the velocity data have in relation to the forces in the collision. By the end of this lesson, we want students to reason out what the force data would be in relation to the changes in velocity, helping to make a stronger conceptual connection to the relationship among these variables before moving forward.

Another constraint to providing access to the simulation for this activity is that the simulated likelihood of survival for this collision is quite low. This contrasts the video of the people in the car. The difference between the two is that the simulation simulates a vehicle hitting an immovable wall, while in the video, you can see that the car hits some object but then continues to move a significant distance while stopping. See *Collision Simulation Information* in Lesson 7 for more details on how the simulation models collisions.

Discuss observations about velocity data. Have students share what they observed in the velocity data. Consider posing the following probing questions:

- *When did a velocity stay the same? When did it change?*
- *What was different about how the velocity changed for the two crash test dummies?*
- *What similarities or differences did you see between the two crash test dummies' data?*
- *How do these data connect with what we saw in the animations or the video?*

Look for students to discuss the following ideas:

- Without safety features, the dummy velocity is almost constant until it hits the wheel.
- The dummy in the collision with the safety features has negative velocity for some period of time.
- The changes in the crash test dummy's velocity happen in less time when there aren't safety features.
- The overall changes in velocity of the vehicle and both crash test dummies are all the same.

Add velocity information to the timelines. Project **slide L**. Pose the prompt on the slide:

- *What velocity data should we add to our timelines?*

Come to a consensus on what data to add to the timelines and add it. Options include but are not limited to adding the change in velocity between each event time or selecting specific times to label the velocity. It is not necessary to conform to a specific annotation of velocity.

Compare crash test dummies' timelines. Project **slide M**. Have students turn and talk about the prompt on the slide.

- *What similarities and differences do you see between the two crash test dummies' timelines?*

Ask students to share with the class. Students should share that the timelines of the collisions for the vehicle are the same, along with its velocity changes over time. The crash test dummies, however, experience changes in velocity over very different time periods. Emphasize the large velocity changes of the crash test dummy over a very small period of time in the collision without safety features when compared to the collision with safety features. Add this to the timelines. Example prompts and responses are below.

Suggested prompt	Sample student response
Now that we have both timelines built out, let's compare them. What similarities do you see?	Well, both objects start at 40 mph and end at 0 mph in each timeline. The velocity changes are the same for the car over the same period of time on each timeline.
What about differences? What differences did we notice?	Well the first timeline had safety features, so the crash test dummy started to change velocity sooner than in the second collision. The crash test dummy went from a velocity of 40 mph to 0 mph for the first time in 0.071 seconds in the first timeline with safety features, and it only took 0.005 seconds for the same change in velocity in the second timeline.
Interesting. So the crash test dummy in the first timeline took 0.071 seconds to go from a velocity of 40 mph to a velocity of 0 mph, but the crash test dummy in the second timeline took 0.005 seconds for the same change?	Yes!

Record off to the right side of each timeline the amount of time it took in each collision for the crash test dummy to go from a velocity 40 mph to a velocity of 0 mph. Note that this time for the timeline with safety features should be the time from when the crash test dummy collides with the seat belt to when it first comes to a velocity of 0 mph before starting to move backwards. This keeps the change in momentum experienced by the crash test dummy equal.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment

- Students model and compare across systems to notice that the changes in velocity of the vehicle and both crash test dummies are the same but the time for that change is different for each system. (SEP: 2.3; DCI: PS2.A.1)

What to do: If students are struggling to make comparisons across the timelines, highlight the physical difference in the distance between times on the timelines. Consider calculating the change in velocity for the dummy between each interaction noted on the timeline. If students are still struggling to compare these, divide to calculate the acceleration to get single numbers to compare.

Building toward 8.A.2 Develop timeline models of vehicle collisions using animations and simulation data to illustrate and compare changes in motion for the systems of a vehicle and crash test dummies that are too fast to observe directly. (SEP: 2.3; CCC: 3.2; DCI: PS2.A.1)

ALTERNATE ACTIVITY

To extend the sensemaking about the changes in velocity over time, consider providing students with the velocity vs. time graphs for the vehicle and crash test dummies for each collision.

These graphs can be made using the simulation https://s3.amazonaws.com/p.3simulation/collisions/sandbox.html.
The settings for the collision with safety features are:

- Distance From Barrier 10 m
- Vehicle Speed 40 mph
- Vehicle Mass 1500 kg
- Driver Mass 77.5 kg
- Crumple Zone Length 1 m
- Crumple Zone Rigidity 450 kN
- Seat Belt Stiffness 60 kN/m
- Airbag Rigidity 15 kN
- No braking

The settings for the collision without safety features are:

- Distance From Barrier 10 m
- Vehicle Speed 40 mph
- Vehicle Mass 1500 kg
- Driver Mass 77.5 kg
- Crumple Zone Length 1 m
- Crumple Zone Rigidity 450 kN

- No Seat Belt
- No Airbag
- No braking

See *Collision Simulation Information* and *Simulation Use Guide* from Lesson 7 for more details about the simulation.

Say, *It seems like the time for the velocity change might be important, but it's only a difference of a few milliseconds. That feels like such a small period of time! Let's take a moment to really see how small that time period is.*

4 · EXPERIENCE THE DIFFERENCE IN TIME PERIODS

5 min

MATERIALS: stopwatch, https://youtu.be/VEHC2iJ3Ufg?feature=shared

Introduce the timing activity. Display **slide N**, which gives abbreviated instructions of what occurs in this activity. Tell students that we will use a stopwatch and try to start and stop it at these intervals to see how different these time periods are. Ensure that every student has a stopwatch of some kind or make a plan for taking turns before proceeding.

Guide the class in trying to start and stop their stopwatches with the interval of 0.07 seconds. Students may find this difficult to move their fingers fast enough to start and stop their stopwatch in this time period. Have students repeat this for the change in crash test dummy velocity interval for the second timeline. This task will be nearly impossible. Note that most stopwatches won't even have enough decimal places to try to time 0.005 seconds. ✱ Remind students that this is the time in which our crash test dummy was colliding and is comparable to what we saw happening in the first video. Show https://youtu.be/VEHC2iJ3Ufg?feature=shared to remind students of this short period, if needed.

Say, *This is a very short time period for each collision, both with and without the seat belt and airbag!*

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING SCALE, PROPORTION, AND QUANTITY

Vehicle collisions occur over a very short period of time (milliseconds), which can feel nebulous to students. This small adjustment in changes to velocity over time is significant, and changes in force over time that can lead to injury in a collision is important to grasp. Use this moment to allow students to experience how small this timing difference is and to also consider why safety features to increase the time over which the velocity shifts from 40 mph to 0 mph is important.

5 · DISCUSS THE ROLE OF SAFETY FEATURES IN A COLLISION

5 min

MATERIALS: chart paper, chart paper markers

Consider what safety features might be doing in a collision. Say, *We know that the window of time in which the crash test dummy's velocity changes is incredibly short. It was so short that we couldn't figure it out in the video at the start of the lesson and could hardly get times that small with our stopwatches for the longer of the times from the simulation.*

Display **slide O**. Ask students to turn and talk to a partner about the question on the slide:

- *What evidence have our timelines provided us that help us explain what safety features do to keep people safe?*

After 1 minute of partner talk, allow students to share their ideas with the class. Look for students to highlight that the safety features didn't change the change in velocity of the crash test dummy, but they did significantly increase the amount of time over which the change took place.

Consider what variable to investigate next. Display **slide P**. Pose the question on the slide:

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

Have students jot down their thoughts as an exit ticket. If there is time, ask a few students to share. Forecast that next time we will look more closely at how some of these variables related to safety features might affect the forces in a collision.

After the lesson, create a chart paper version of the timelines, titled "Vehicle Collision Timelines", for reference in future lessons. See *Timeline Development* for guidance.

ALTERNATE ACTIVITY	In the second and third lesson sets of the unit, there are several extension opportunities for students who are interested in the content to explore further. You may want to have students hold on to their extra questions and ideas for exploration during the design project in Lesson 14 (see *Design Challenge Organizer Key* in Lesson 14 for more details). Be sure to encourage students to record their questions on the DQB. You may also want to provide individual or small group extension readings to students with specific interests before the project. *Extension Opportunities* provides some examples of extension questions students may have and resources from the project resource database that you could provide.

Additional Lesson 8 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS	**CCSS.ELA-LITERACY.RI.11-12.7** Integrate and evaluate multiple sources of information presented in different media or formats (e.g., visually, quantitatively) as well as in words in order to address a question or solve a problem.

IN ELA	Students use a video and animations and read two data tables (information presented quantitatively) to construct a timeline of events. The sources of information provided in different formats have to be integrated in order to address the question of what features of the vehicle system interact with the crash test dummy at different times, specifically airbag deployment and collision with the crash test dummy, and how a collision with safety features is different from a collision without safety features.