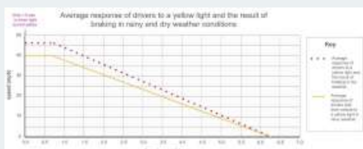
Lesson 5: Can we use mathematical models to explain differences in stopping in wet conditions?

Previous Lesson	*We used a speed versus time graph to predict how the initial speed, braking force, and mass of a moving vehicle affect stopping time. We collected data to test our predictions and graphed it in CODAP. We used curve fits to identify patterns indicating a mathematical relationship. To further test this relationship, we used a simulation to gather additional data.*
This Lesson Putting Pieces Together 1 day	 Data Source: Li, et al. (2012) We look back at our speed versus time graphs and use the slope to name acceleration. We rearrange our equations to show a = F / m and F = ma, and we add to our M-E-F triangle to show that unbalanced forces cause change in motion. We analyze graphs to determine what acceleration might look like when vehicles stop in rainy conditions, and we add possible design solutions to help drivers react sooner to our Engineering Progress Tracker. We complete an Electronic Exit Ticket to predict the stopping time for carts moving at various speeds with a specific friction force.
Next Lesson	*We will sensor data from a collision of a cart with a barrier and another between two carts. We will analyze fatality data from collisions between different-mass vehicles. We will develop an equation for the outcomes of two-vehicle collisions and test it with data from a simulation. We will develop and use alternate algebraic models to solve for the mass or velocity of an object before or after a collision.*

BUILDING TOWARD NGSS

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

What students will do

5.A Use a graph of speed as a function of time to explain differences in braking force due to road conditions, and consider how we can design systems to prevent drivers from running yellow or red lights. (SEP: 2.6; CCC: 2.3; DCI: PS2.A.1)

5.B Use graphs and an algebraic function representing Newton's second law to predict, describe, and solve for the motion of a cart and the magnitude of the friction forces acting on the cart as variables are changed along a track. (SEP: 5.2, 5.4; CCC: 3.5; DCI: PS2.A.1)

What students will figure out

- The slope in a speed over time graph shows how quickly an object changes speed over time and is the acceleration.
- For an object of a given mass, a force is always going to be associated with an acceleration, and we can rearrange our equations to solve for force, mass, and acceleration.
- Unbalanced forces cause change in motion.
- We can design solutions to increase stopping distance or time in wet and rainy conditions.
- We can use our science ideas to predict the motion of other real-world objects.

Lesson 5 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	5 min		**NAVIGATE: INTRODUCE ACCELERATION** Connect the Lesson 4 science ideas to the speed over time graphs. Use the slope of the line to introduce the term *acceleration*.	A-E	whiteboard, dry erase marker, whiteboard or chart paper with graph from slide C
2	9 min		**SOLVE FOR ACCELERATION AND UPDATE THE M-E-F TRIANGLE** Use algebra to solve for acceleration in partner pairs. Determine as a class that unbalanced forces cause change in motion and add this idea to the M-E-F triangle.	F-G	whiteboard, dry erase marker, M-E-F triangle poster, clear tape
3	7 min		**ANALYZE WET ROAD STOPPING TIMES** Read about a study of wet and rainy road reaction and stopping time. Analyze graphs to help explain the data.	H-I	*Wet Road Stopping*
4	6 min		**DISCUSS WET WEATHER BRAKING AND REACTION TIME** In a Scientists Circle, discuss what is causing the change in braking and reaction time and how this relates to forces versus change in speed.	J	*Wet Road Stopping*
5	4 min		**UPDATE THE ENGINEERING PROGRESS TRACKER** Add new proposed solutions to decrease red light running and yellow light stopping times in wet conditions to the *Engineering Progress Tracker*.	K	*Engineering Progress Tracker*
6	4 min		**REVISIT THE DRIVING QUESTION BOARD** Revisit the DQB to determine what questions we can now answer and to add any new questions.	L	permanent marker, 3x3 sticky notes, Driving Question Board (DQB)
7	10 min		**COMPLETE AN ELECTRONIC EXIT TICKET** Watch a video of a cart rolling along a track and complete an exit ticket.	M-N	device with access to the internet, https://youtu.be/wmlCn22dTwk, smart cart from Lesson 4

End of day 1

Lesson 5 • Materials List

	per student	per group	per class
Lesson materials	• whiteboard • dry erase marker • science notebook • *Wet Road Stopping* • *Engineering Progress Tracker* • permanent marker • 3x3 sticky notes • device with access to the internet		• whiteboard or chart paper with graph from slide C • dry erase marker • M-E-F triangle poster • clear tape • Driving Question Board (DQB) • https://youtu.be/wmlCn22dTwk • smart cart from Lesson 4

Materials preparation (15 minutes)

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

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

Make copies of the handout for this lesson:

- *Wet Road Stopping* (1 per student)

Be ready to project **slide C** on a whiteboard and draw on the projection using a dry erase marker or create a graph on chart paper that mirrors the graph on **slide C** to be drawn on alongside the slideshow.

Create a panel to add the M-E-F triangle that says, "Unbalanced forces cause change in motion." Have tape handy to attach this to the triangle.

Consider pulling a couple of examples of graphs from Lessons 2-4 for students to reference when discussing the slope in the first part of this lesson.

Before class, make a copy of the Electronic Exit Ticket at https://docs.google.com/forms/d/1fuFKiZlYVtxOOKnAneEOyUAaN1y_56hM9f-LTWKKj8A/copy. Share the link to the **copy** with students, **not** the link provided here; if you share the original link, that will create a new copy for each student, and you will not have access to their responses. See the reference *Electronic Exit Tickets*.

Lesson 5 • Where We Are Going and NOT Going

Where We Are Going

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)

In this lesson, students look back at the slopes from prior lessons. This slope will be named *acceleration*. They use this understanding to rearrange the equation developed in Lesson 4 and solve for both force and acceleration, and they also describe the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration as $a = F / m$ and $F = ma$. During the discussion of this rearrangement, students also determine that unbalanced forces cause change in motion and add this to the M-E-F triangle.

Because of this identification of the relationship among the variables and the use of these ideas related to Newton's second law of motion in the lesson, students are also making connections to the following elements of the Nature of Science:

- Laws are statements or descriptions of the relationships among observable phenomena.

Students use the ideas to identify the differences in braking time, reaction time, acceleration, and braking force in wet versus clear conditions. They consider why drivers brake harder but later in wet and rainy conditions, and they name some potential solutions, adding them to their *Engineering Progress Tracker*.

At the end of the lesson, students revisit the Driving Question Board (DQB) and add any new questions. After this, they complete an Electronic Exit Ticket in which they predict the motion of a cart on a track when the mass, force on the cart, and speed are manipulated, and they consider how the mathematical models could be helpful tools in explaining or predicting the motion of other objects in the world.

This lesson is designed to coherently build ideas related to the following crosscutting concept (CCC):

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

Students should be becoming more comfortable with this concept within the context of avoiding collisions from lessons 1 and 3. In this lesson, students will apply this concept to designing for collision avoidance in wet road conditions. In the second lesson set, students will build on these understandings to apply this concept to more specific safety feature systems within vehicle design. At the end of this unit, students will be assessed on this concept within the final transfer task.

Students encounter and/or co-construct ideas around several terms and may decide to add the following word to their Personal Glossary: *acceleration*. **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

Though this lesson does not discuss the colliding of two objects, please note that Lesson 6 will. Be sure to go over the "Student Content Advisory" slide with students before class ends, and seek support for both students and yourself if needed prior to Lesson 6.

LEARNING PLAN for LESSON 5

1 · NAVIGATE: INTRODUCE ACCELERATION

5 min

MATERIALS: whiteboard, dry erase marker, science notebook, whiteboard or chart paper with graph from slide C

Motivate putting the pieces together. Project **slide A**. Say, *We have figured out a lot, and we've been using a lot of new models to represent our ideas. Last time, we decided to take stock and see what kind of progress we've made on answering our questions about vehicle collisions.*

Look at graphs from past lessons to motivate attending to slope. Ask students to open their notebook and look across some of the graphs from the past several lessons. Give them a moment to turn and talk with a partner about the first two questions on the slide.

Bring the class back together and pose the slide's last question:

- *What clues have we been using from these graphs to make sense of the motion they are representing?*

Have students turn and talk for a moment, then elicit ideas. Look for ideas related to slopes, such as the shape, slope, steepness, if they are flat or a hill, if they are linear, a line, or curved, and so forth. Revoice the idea that slope has been a key clue we have used to interpret all these graphs.

Determine what the slope represents. Say, *The steepness of the line, or the slope, sounds like it has been particularly important. What does the slope of the line in a speed versus time graph like the ones we looked at in Lesson 3 actually mean?* Look for ideas about showing that the steeper the slope, the more quickly the car is changing its speed from one point to another.

ALTERNATE ACTIVITY	If students do not make connections between the steepness of the slope and the changing speed of the car right away, pause and give them a few minutes to puzzle over it with a manipulative, such as a toy car. Recreate the motion of one of the speed versus time graphs from Lesson 2 and ask students to observe the changes in motion of the car over time.

Decipher the slope of speed versus time. Ask, *What about the slope of a speed versus time graph, like the ones we used in Lessons 2 and 3?* Students should note that the slope shows how quickly the object slowed down over time. For the graphs in Lesson 3, this is related to the braking force, and the higher the speed, the more braking force is needed to stop in time.

Say, *It sounds like the slope of the speed versus time graph is telling us something important. Let's take a closer look.*

Take a closer look at the slope of a speed versus time graph. Project **slide B**. Ask students to consider two different slope cases: a steep slope and a flat slope. ✱ Give them a moment to think about these ideas silently, then lead a discussion to uncover the meaning of the steep slope and the flat slope.

✱ ATTENDING TO EQUITY

Supporting emergent multilinguals: Some students may not be familiar with the term *steep* to describe the angle of the slope in the graphs. If so, ask the class to recall where they have heard the term *steep* in everyday language. Students might mention a steep hill or steeping tea. Point out that these examples refer to an incline or to an item increasing in intensity. Consider comparing two graphs from Lesson 4 that have a more steep versus a less steep slope and asking students to identify the steeper slope before moving forward.

Begin with the first question, *What does a steep slope mean in a speed over time graph?* Allow students to articulate their ideas as a class. Students might suggest that a steep slope means that the car is slowing down very quickly and/or that there is more braking force.

Walk up to the projected image and hold your arm over the slope and at the same angle as the slope. Continue the discussion by moving your arm into a slope steeper than that of the graph. If needed, point to different corresponding positions on your arm and the graph, and ask students what speed the object would be going at that point in time on the graph and on your arm and compare the two speeds.

Ask students to compare the arm's slope to the slope shown on the graph on the slide and if the braking force would be more or less if the graph slope changed to the slope of your arm. Students should identify that this would be a greater braking force applied to the object and/or the speed has decreased more over a given time period.

From there, move your arm to a slope more gradual than the slope shown on the graph and repeat this process. Continue to illustrate slopes until students can articulate the relationship between slope, braking force, and a change in speed from one given position to the next over time.

After a connection has been made between the slope of the line and the speed of the object in a given point in time, transition to the slide's second question. Ask students to explain what a flat slope would mean in a speed over time graph, and move your sloped arm to a flat position, eliminating any angle. Guide them to determine that a flat slope means the vehicle is traveling at a consistent speed at a given point in time. It might also be helpful to gradually change the angle of your arm until it is flat and point to different positions the object might be in on the time axis to determine that the object would be at the same speed at any given point in time on a flat slope.
Connect the slope to acceleration. Display **slide C**. Suggest that this slope is an important idea since it has helped the class figure out so many things related to stopping our vehicles in time to avoid a collision. Tell students that scientists also find this slope important since it shows how much the speed of an object changes per unit of time. If needed, use the graph on the slide to point out how the slope shows the change within the specified time period of the slope. Explain to students that this slope is called the *acceleration*.

Say, *We have this new term,* acceleration*. But what is acceleration? If we look at this graph, how could we describe acceleration in terms of the graph? How would we say we could calculate this acceleration using graph terms, like, if we were just referring to this change in terms of the* x- *and* y-*axes?*

Relate the slope to rise/run. Allow students to respond, and remind them that in middle school they learned how to calculate this slope as rise over run.

Write "rise/run" on the board or chart paper next to the graph. Alternatively, students could suggest "change in *y*/change in *x*", which could also be written alongside or in place of "rise/run".

Ask students to explain how this might be drawn on the graph. They might suggest conventions, such as arrows. Use arrows or other conventions suggested by the class to point out the rise over run.

Turn rise/run into change in speed/change in time. Ask students what this rise over run or change in *y* over change in *x* corresponds to in graph terms. Students should note that this corresponds to the change in speed over change in time on our graph. Next to where you have written “rise/run” or “change in *y*/change in *x*”, write the following:
slope = change in speed/change in time

Consider the difference in the scientific versus everyday use of *acceleration*. Next, ask students to think about acceleration and what we know it to mean in everyday terms. Students might suggest that acceleration is when they press the gas pedal of a vehicle or when they speed up.

Project **slide D**. Say, *In everyday terms,* acceleration *means that something is speeding up. What would the slope look like if the car was speeding up? Does it look similar to or different from the slopes we have been studying to this point?*

Model a slope that shows an object speeding up. Prompt students to quickly draw a graph showing a car traveling at a constant speed then speeding up. Give partner pairs a moment to draw the slope that would correspond to this and consider the question on the slide. Quickly circulate through the classroom as students draw, and look for graphs to show a positive acceleration (toward positive, positive). If controversy arises about the direction of the slope, ask students to share their thinking with another partner pair before sharing their ideas with the class.

Bring the class back together and ask students to share their whiteboards, which should show a slope going up and toward the right.

Compare to slopes we have drawn thus far. Ask students whether this is similar to the slopes we have been studying thus far. They should note that the graphs we have studied are not speeding up but rather decreasing in speed over time.

Introduce positive and negative slope. Take this moment to point out the positive and negative nature of the two slopes and name that acceleration can be positive or negative.

Add *acceleration* to the Personal Glossary. Provide a moment for students to add the term *acceleration* to their glossary if they choose to do so. Suggest using both pictures and words to describe what *acceleration* means to them and to help them remember that later.

Connect acceleration back to avoiding a collision. Project **slide E**. Say, *OK, we've learned a new term, and we can now explain what the slope means. But why do we even care about this slope, and what else do we care about?* Students should respond that the slope is about applying braking force to stop in time, and the more braking force is applied for a given mass at a given speed, the faster we can slow down.

If they do not mention mass and speed in explaining why the slope is important, ask them to think back to Lesson 4 and name the other variables that also affect the time in which a vehicle can stop.

List the important variables for avoiding a collision. Write the variables on the board as they are shared. Your list may look something like this:

- mass of the vehicle
- speed of the vehicle over time
- braking force and/or change in time and/or braking force applied over time

2 · SOLVE FOR ACCELERATION AND UPDATE THE M-E-F TRIANGLE

9 min

MATERIALS: whiteboard, dry erase marker, M-E-F triangle poster, clear tape

Write equation from last lesson. Direct students to look at the variables we have just identified and that are now written on the board. Remind them that these were also part of the equation we developed in the last lesson. Write that equation on the board next to these variables:
Δt = (m * change in speed) / F

Circle the variables associated with acceleration. Once written, ask students to think back again to the acceleration, or the slope. Ask them to identify where this important idea would be represented in this equation. Help students determine that change in time and change in speed are the two important variables related to acceleration.

Circle the two variables: **change in time** and **change in speed**.

Say, *If we want to know how much force to apply to stop our vehicles at a specific time, we need to get the important variables that represent acceleration grouped together on the same side of the equation. How could we rearrange this equation to get change in speed over change in time?*

Move change in speed over Δt. Project **slide F**. Remind students that we can move things around in equations to get specific variables on one side of the equal sign or the other. Give students a moment with a partner to use algebra techniques on their whiteboards to move acceleration (change in speed / Δt) to the same side of the equation. At this point, they should have the following equation:

✱ SUPPORTING STUDENTS IN ENGAGING IN CONSTRUCTING EXPLANATIONS AND DESIGNING SOLUTIONS

Use this opportunity to broaden students' understanding of two elements of the nature of science: laws are statements or descriptions of the relationships among observable phenomena, and theories and laws provide explanations in science. At this moment, students have identified the relationship between force, mass, and acceleration and Newton's second law. Take this moment to call this out explicitly and name the second law of motion and that we

F = m * (change in speed / Δt)

Ask students to again articulate what in their equations represents acceleration. They should suggest that change in speed over Δt is the acceleration. Suggest that we replace this with the variable *a*, to represent acceleration.

Write the equation for force. Write the new equation on the board:
F = ma

Rearrange to solve for acceleration in partner pairs. Point out that we have solved for force but that we were wanting to solve for acceleration. Ask students to take a moment to solve for acceleration by manipulating their equation. Students should arrive at the following equation:
a = F / m

Say, *Wow, it looks like we've not only figured out how to solve for force but also for acceleration!*

Add equations to the Personal Glossary. Suggest that these equations feel important. Give students a moment to add both equations, if they choose, to their glossary.

Say, *We've done a great job of relating this idea of force, which we have used for several lessons, to this new term* acceleration*, which we've named as the slope on our graphs, or change in speed over change in time.* Point out that this means that for an object of a given mass, a force is always going to be associated with an acceleration.

Project **slide G**. Give students a moment to turn and talk about the prompts. Lead a quick discussion and allow students to share to determine that forces can change the motion of an object, as shown in the table below.

Suggested prompt	Sample student response
So, what does this mean about the relationship between force and a change in motion that we see happening when an object is accelerating, either positively and negatively?	Any amount of net force will change the motion of the object.
Then, what happens if we increase the magnitude of the net force on a mass?	The speed would change more over the same amount of time!
So, how are forces related to acceleration?	Forces can accelerate a mass.

have used this relationship to provide an explanation of the movement of objects.

Forces can accelerate it both positively and negatively.

Rephrase for students by saying, *So this means that the forces are changing the way something is moving.*

Review the M-E-F triangle for our new ideas. Point out that we have stumbled upon something that feels like a big idea and that we should visit our M-E-F triangle to dig into it.

Ask students to identify what forces do. Students should respond that forces transfer energy, as seen on our triangle. Point out that energy goes along with motion, and this idea is kind of already embedded in the M-E-F triangle.

Add a panel to the M-E-F triangle. Suggest to students that we explicitly add “Unbalanced forces cause change in motion” to the M-E-F triangle. Add a panel that states this to the M-E-F triangle between forces and energy. ✱

Say, *We've established this relationship among force, mass, and acceleration. It seems a bigger magnitude of the forces results in a larger change in the motion of the matter. We see this with braking force.*

Ask, *What do you think happens when you apply a greater braking force over a period of time?* Students should respond that the matter's motion would change to 0 over a shorter period of time.

Say, *But could we always expect the braking force to slow us down at the same rate over time? Or are there other factors not related to the car that might impact the ability of the braking force to slow the vehicle?* Allow students to share some external factors; they might mention things like rain or snow.

3 · ANALYZE WET ROAD STOPPING TIMES

7 min

MATERIALS: *Wet Road Stopping*

Used graphed data to consider the effect of wet roads. Display **slide H**. Ask, *If you were to look at a graph that showed the reaction and stopping times for drivers on wet pavement, what might you see happening with the braking force and reaction time?* Allow all students to respond, and accept all answers.

Then ask, *What do you think would change about the acceleration, or the slope, of the vehicles in rainy conditions versus clear conditions?* Allow all students to respond, and accept all answers.

Explain the task and allow work time. Display **slide I**. Explain that researchers have also considered these factors and in 2012 decided to investigate how these factors might be affected by wet and rainy road conditions. Distribute the *Wet Road Stopping* handout to each student. Have students work with a partner and pick out the one graph that best represents what the data are telling them about reaction and stopping times as well as braking force and acceleration. Ask them to also annotate their chosen graph on their own handout to show the features that helped them select it. Explain that after a few minutes we will come together to share and compare ideas.

ASSESSMENT OPPORTUNITY	**What to look for/listen for in the moment:** • comparing the graphs for the differences in initial speed, reaction time, acceleration, and stopping time (SEP: 2.6; DCI: PS2.A.1) • choosing the graph that has a delayed braking force being applied in the yellow light region of the graph, resulting in a graph that shows a negative slope at a later period of time for the wet and rainy conditions (DCI: PS2.A.1) • using the increased slope of the graph within the yellow light timing to explain that the driver's longer reaction time resulted in delayed braking (SEP: 2.6; DCI: PS2.A.1) • choosing a graph for the wet and rainy conditions in which drivers are initially traveling slightly over 45 mph • identifying the steeper slope with an earlier reaction time in the yellow light timing section and initial speed slightly over 45 mph as the clear day condition graph (DCI: PS2.A.1) • discussing the causes of the delayed reaction time and the reduced effects of the braking force, and generating potential solutions for drivers in the wet and rainy conditions to increase reaction time, the effects of braking force, or notice of the yellow light (SEP: 2.6; CCC: 2.3; DCI: PS2.A.1) **What to do:** Circulate as students work. Listen for any controversy as they select a graph. Because the class will discuss the data and graphs after this task, use questioning instead of direct intervention to have students consider the relationship between the data and what is illustrated on the graphs. Ask questions such as these: • *Why did you choose that graph for the wet and rainy conditions?* *What effect did the wet and rainy conditions have on the reaction time of the driver? How is that shown in the graph you chose?* • *What effect did the wet and rainy conditions have on the acceleration of the vehicle? How is that represented on the graph you chose?* • *What potential solutions can you come up with to help more drivers stop in wet and rainy conditions?*

	Building toward: 5.A.1 Use a graph with speed as a function of time to explain differences in braking force and related effects in stopping in wet versus clear conditions, and consider how we can design road and car systems to reduce yellow and/or red light running. (SEP: 2.6; CCC: 2.3; DCI: PS2.A.1)

ALTERNATE ACTIVITY	To extend students' sensemaking about braking and avoiding collisions, you can have students work with the collision avoidance restricted view version of the vehicle collision simulator (https://s3.amazonaws.com/p.3simulation/collisions/collision-avoidance.html). Consider having students try to recreate the scenarios they read about and adjust the parameters to test their design solutions.

4 · DISCUSS WET WEATHER BRAKING AND REACTION TIME

6 min

MATERIALS: *Wet Road Stopping*

Discuss the study results. Project **slide J**. Have students bring their *Wet Road Stopping* handout to a Scientists Circle. Use the questions on the slide to guide a discussion about the change in braking and reaction time.

To begin the discussion, ask students to summarize the purpose of the study and the testing done by researchers. They should identify the following:

- Researchers were studying how wet and rainy conditions affected the time it took for drivers to react and slow down or stop.
- Drivers drove a car in wet and rainy conditions, and half of the time the light they encountered turned yellow.

Then ask them to identify in words and/or gestures what the researchers found. They should state the following:

- Drivers in wet conditions took longer to react to the yellow light than drivers on a clear day.
- Drivers in wet conditions also applied more braking force but stopped closer to the line than drivers on a clear day.

Have students point out which graph they chose to represent the car stopping in wet and rainy conditions, and ask why they chose that graph. **They should identify the first graph that showed the wet conditions acceleration happening later than the other graphs. The speed was 46 mph.**

Help relate these findings with the equations and slope from earlier in the lesson, using prompts like those in the table below.

Suggested prompt	Sample student response

That's fascinating. You chose the wet conditions slope with braking occurring over a longer period of time than the others. How would that relate to the equations that we used today?	They saw the light later and they hit the brakes harder, but because friction was reduced it affected the stopping time. That means that they tried to make the acceleration period shorter, making the acceleration greater, but because of reduced friction, they could not make the slope, or acceleration, steeper. They couldn't create a greater change in speed over time.
But what was the problem researchers identified with the braking force? And how does that relate to the actual acceleration we saw in this study?	The braking force wasn't enough to make up for the lack of road friction. The drivers thought that they were going to accelerate, or slow down, a lot more because of the braking force they applied, but they didn't. So sometimes that probably made them stop late or run a red light. The braking force ended up being less than they thought it was going to be, making the acceleration less than they thought as well.
So, how was this acceleration different than on a clear day?	On dry days, people reacted sooner and had a more gradual change in speed over time. They braked sooner and could brake longer, if needed. The negative slope on a dry day has greater friction force, so the acceleration was more predictable to the drivers. They slowed down at a pace they anticipated.
As a driver, what variables in our equation would have been out of our control at that moment on the wet and rainy day?	The mass of the car. Their reaction time, kind of. Like, they saw the light but it took longer for them to process what they needed to do.

Shift to sharing solutions. Refer back to both equations, $F = ma$ and $a = F / m$, and the graph students chose. Point out the slope and help them think about potential solutions as shown in the table below.

Suggested prompts	Sample student responses	Follow-up questions
So it sounds like a problem has been identified, and we know what we can't change. But, if we look at our equation and this slope, what can we change with the car system to get drivers in wet and rainy conditions to stop in time?	We could maybe change the amount of braking force the driver uses, but that might be unsafe.	*How could you change the braking force? Would that make an impact on the stopping time of the driver, if friction force was also reduced?*
	We could change the acceleration.	*What could you do to make the time to accelerate greater?*
	We could change the time over which the car slows down.	
	We could also change the acceleration by changing the speed of the car; they were going slightly over the speed limit.	*What could you do to reduce the speed of the car? How could you control the driver's behavior?*
	We could maybe also let them know sooner that the light was going to change to yellow so they could prepare to stop.	*How could you adjust the reaction time? How would you prepare drivers to react sooner or faster?*
Did any partner pair come up with potential solutions to increase stopping distance, increase reaction time, or something else?	We could add a signal farther up the road that lets drivers know if the light is going to turn yellow on them.	*How would that help with reaction time?*
	We could add rumble strips that make them slow down before the light.	*What changes would that make to the slope, or how would that affect the variables in our equation?*
	We could increase friction on the road.	*How could we realistically implement this solution?*

Allow 2-3 students to share any ideas they have had, and then suggest that these ideas along with the other ideas in the classroom should be documented.

ASSESSMENT **What to look for/listen for in the moment**:

OPPORTUNITY	• Once drivers have applied braking force, we see negative acceleration. (DCI: PS2.A.1) • The shift in applying braking force occurs due to the change in conditions of the road (wet and rainy). (SEP: 2.6) • The graph of the dry conditions shows a shorter acceleration period (a steeper slope over a period of time). (DCI: PS2.A.1) • The graph of the wet conditions shows the acceleration occurring at a later time period than in the dry conditions and a longer acceleration period (a less steep slope over a period of time). (SEP: 2.6; DCI: PS2.A.1) • Both graphs explain that the driver is going slightly over 45 miles per hour before applying braking force, accelerating, and bringing the object to a stop. (SEP: 2.6; DCI: PS2.A.1) • Wet conditions increase the reaction time needed by drivers, making the yellow light time available for reacting shorter (DCI: PS2.A.1) • To compensate for this, drivers increase their braking force, but the braking force is not enough to overcome the reduced friction between the tires and the road, and the acceleration occurs over a longer period of time. (DCI: PS2.A.1) • To counteract this, drivers would need to either increase the reaction time or create a change in the system to reduce the rate of acceleration (reduce the steepness of the slope over a longer period of time) without running the light. (SEP: 2.6; CCC: 2.3; DCI: PS2.A.1) **What to do:** • At any point in the discussion, if students are uncertain or debating on the changes in acceleration or the reaction of the driver, project the graphs on the board. • Direct students to look back at the handout to find data to support their claims in the graphs. • Consider having students use their arms, as you did earlier in the lesson, to consider the effects of reduced friction and delayed braking on the slope of the line during acceleration. • Compare this to the graphs being displayed and talk through as a class what graph best represents students' ideas. **Building toward: 5.A.2** Use a graph with speed as a function of time to explain differences in braking force and related effects in stopping in wet versus clear conditions, and consider how we can design road and car systems to reduce yellow and/or red light running. (SEP: 2.6; CCC: 2.3; DCI: PS2.A.1)

5 · UPDATE THE ENGINEERING PROGRESS TRACKER

4 min

MATERIALS: science notebook, *Engineering Progress Tracker*

Add solutions to the *Engineering Progress Tracker*. Project **slide K**. Give students 4 minutes to add their ideas to their tracker. Remind them that this is a living document and that if they have thought of other solutions related to prior lessons, these can also be added at this time. ✱

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING CAUSE AND EFFECT

The progress tracker is a great opportunity to make consistent connections to CCC element 2.3, *Systems can be designed to cause a desired effect*, explicit to students. Consider taking time to have a discussion about this element and how it has been seen within the unit so far. Highlight the designs that students have added to their trackers and ask students to make connections between the systems and their specific desired effects.

6 · REVISIT THE DRIVING QUESTION BOARD

4 min

MATERIALS: permanent marker, 3x3 sticky notes, Driving Question Board (DQB)

Once students have updated their *Engineering Progress Tracker*, remind them that we have also been keeping track of the questions that we want answered.

Revisit the DQB and answer any questions. Project **slide L**. Ask students to gather around the DQB. Quickly review questions on the DQB, focusing on any clusters related to reaction time, stopping time, or other topics from Lessons 1-4. Ask whether any questions can be answered and move any questions that can now be answered to a separate part of the DQB.

Once the DQB has been checked, point out that the lessons thus far have been about avoiding collisions. Ask, *Do you have any new questions that we should add to our DQB about objects that are not able to avoid collisions and are colliding?*

Add new questions to the DQB. Give students a moment to write any new questions they have on sticky notes. Ask students to share their questions with the group and add them to the appropriate cluster. Once the DQB has been updated, prompt students to return to their seats.

7 · COMPLETE AN ELECTRONIC EXIT TICKET

10 min

MATERIALS: device with access to the internet, https://youtu.be/wmlCn22dTwk, smart cart from Lesson 4

Say, *Let's see if we can apply the ideas and practices we have developed to explain an aspect of the phenomenon we have taken for granted related to friction.*

Connect back to the cart system in Lesson 4. Hold up the smart cart from Lesson 4 and explain that it was designed to have relatively little friction force acting on it when it rolls along, but even on a relatively smooth track like the one we used, there was contact between the wheels and the ground and between the axles and the body of the car. Point out that there was even contact between the smart cart and the air, which produced a small amount of friction force.

Say, *Let's see if we can explain and predict the effects of those friction forces in this system in our individual exit ticket.*

Orient to the horizontal track for the exit ticket. Explain that for the exit ticket, the class will first get to orient to this phenomenon, which is simply 4 seconds of time over which this smart cart is rolling along a relatively low-friction horizontal track.

Before having students access the exit ticket, view https://youtu.be/wmlCn22dTwk as a class. Consider playing this video on repeat as students work on their exit ticket.

Conduct the exit ticket. Give students 8 minutes to complete the exit ticket, and ask them to press "submit" at the end of class.

ASSESSMENT OPPORTUNITY	**What to look for/listen for in the moment:** See the *L5 Electronic Exit Ticket Key*. **What to do:** • If students struggle determining the stopping time in question 1, reshow the video and consider using a whiteboard or a piece of chart paper to draw and predict the movement of the cart after it leaves the screen. • For question 1, if students selected 2 seconds, check to make sure that students are considering the time it takes to stop from the initial speed, not the speed at which the green line has ended on the

graph. This could result in an inaccurate answer but not an inaccurate science idea being conveyed.

- If students struggle with questions 2-4, conduct more practice examples as shown at the end of Lesson 4. Guide students in considering what happens if you double, halve, or triple any variable in the equations they have used thus far.
- If students cannot think of another application of the math for question 5, revisit this at the beginning of Lesson 6 and brainstorm some ideas as a class.
- Consider reviewing the entirety of the exit ticket with students at the beginning of Lesson 6.

Building toward: 5.B Use graphs and an algebraic function representing Newton's second law to predict, describe, and solve for the motion of a cart and the magnitude of the friction forces acting on the cart as variables are changed along a track. (SEP: 5.2, 5.4; CCC: 3.5; DCI: PS2.A.1)

Preview future lessons to provide space and systems for support. Before the end of the period, take a moment to go over **slide N**. Remind the class that although the topic may not be sensitive for some, it could be for others, and we should treat our space as a kind and compassionate environment for everyone. Suggest revisiting the Community Agreements, and provide space for students to share concerns with you privately or with another trusted person in their lives. **Remind students that as we learn more, we will always focus on solutions to make driving safer for everyone.**

ADDITIONAL GUIDANCE	In Lesson 6, students will begin to examine the physics of vehicle collisions in detail as well as data on fatalities related to collisions. Make sure to go over the last slide of this presentation with your students. If you or your students need additional social or emotional support to engage with this content, for any reason, see the guidance and materials in the *Student Mindfulness Resource* for suggestions. Consider using this also as a time to revisit the Community Agreements, and reframe it as a time to check in with the class to make sure the agreements provide the space for everyone to feel supported in any upcoming conversations.

Additional Lesson 5 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS	**Number and Quantity** **CCSS.MATH.CONTENT.HS.N-VM.3 Vector and Matrix Quantities:** Represent and model with vector quantities. Solve problems involving velocity and other quantities that can be represented by vectors.

IN MATH	In the Electronic Exit Ticket, students solve problems involving speed in a given direction and other quantities that can be represented by vectors. **Algebra** **CCSS.MATH.CONTENT.HSA-SSE.1b Seeing Structure in Expressions:** Interpret the structure of expressions. Interpret complicated expressions by viewing one or more of their parts as a single entity. Students acknowledge the parts of the equation Δt = (m * change in speed) / F and isolate the variables that represent acceleration. They view change in speed / Δt as a single entity and name it *acceleration*. They then interpret the equation to solve for forces and acceleration. **CCSS.MATH.CONTENT.HSA-CED.2 Creating Equations:** Create equations in two or more variables to represent relationships between quantities. Students rearrange Δt = (m * change in speed) / F to name and solve for acceleration. Students then analyze the relationship among forces, mass, and acceleration to determine that unbalanced forces transfer energy. **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. Students rearrange formulas to solve for force and acceleration.