PHYSICS

Collisions & Momentum

What can we do to make driving safer for everyone?

OpenSciEd

HIGH SCHOOL SCIENCE

TEACHER EDITION

What can we do to make driving safer for everyone?

Collisions & Momentum: Vehicle Collisions

OpenSciEd Unit P.3

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UNIT OVERVIEW

What can we do to make driving safer for everyone?

This unit is designed to introduce students to the concept of momentum and Newton's second law in an intuitive and grounded context. The learning is anchored by a puzzling set of patterns in traffic collision data over time: while overall, vehicle fatalities have been decreasing steadily for decades, the trend appears to have reversed, with both collisions and fatalities increasing. This phenomenon provides the context in which to investigate the physical relationships among mass, velocity, momentum, force, time, and acceleration, basic physical quantities that provide the foundation for the study of mechanics. Students will analyze statistics on vehicle collisions, analyze the motion of vehicles stopping short, and model vehicle collisions as part of an engineering task to reduce the chances of injury in a collision by testing and evaluating solutions that could change force interactions in the system.

The unit is organized into three lesson sets. **Lesson Set 1** (Lessons 1-7) focuses on answering the question: *What factors can make driving more risky?* In the first lesson set, students develop models to show how distracted driving and changes in vehicle design might contribute to trends in vehicle safety over time. This leads them to wonder about distracted driving. They analyze video of two drivers encountering a sudden obstacle, one who is not distracted and one who is distracted, and plot each to show how being distracted affects the motion of the vehicle over time. They use mathematical models to generate data about how speed affects reaction distance and identify design features that can decrease reaction distances to prevent collisions in the event of a sudden obstacle. They then conduct an investigation of braking time and use their own empirical data to develop a mathematical model for how mass, change in speed, and braking force affect braking time. This relationship is rearranged into various forms, including traditional representations of Newton's second law. Building off these mathematical models, students describe patterns between the masses and the changes in velocity of two colliding carts using videos, graphs, and simulations, co-developing a definition of *momentum* in the process. Finally, they put the pieces together in Lesson 7 and complete a transfer task that asks them to analyze and explain data about bus safety.

Lesson Set 2 (Lessons 8-12) focuses on answering the question: *How are vehicles designed to keep people safe?* In the second lesson set, students use an animation based on a vehicle collision simulator to create a collision timeline for the crash test dummy in a vehicle cabin. Students see that safety features extend the amount of time over which the crash test dummy changes velocity. They use the simulation to investigate how seat belts and airbags affect the forces on the crash test dummy. They investigate how characteristics of vehicle crumple zones affect the safety of the crash test dummy. While investigating the various safety features students also see that increasing speeds also decreases safety in collisions. In Lesson 12, they compare and evaluate arguments about speed limit design decisions and create a Gotta-Have-It Checklist for explaining how safety features can be designed to increase safety during vehicle collisions.

Lesson Set 3 (Lessons 13-15) focuses on answering the question: *How can we make design decisions that will make driving safer for everyone?* In the third lesson set, students consider how new design solutions might affect some people (or animals, plants) differently than others. Then they identify an issue that is relevant to the community and develop a plan for a Community Design Solution. Finally, they return to their DQBs in Lesson 15 and complete a transfer task that asks them to compare two vintage design solutions for catching pedestrians.

Building Toward NGSS Performance Expectations

HS-ETS1-3:
Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

HS-PS2-1:
Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.

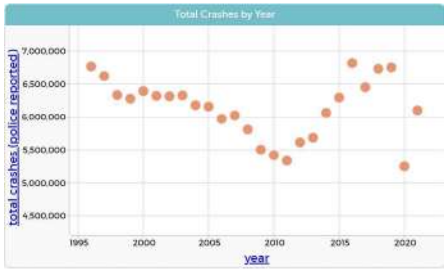
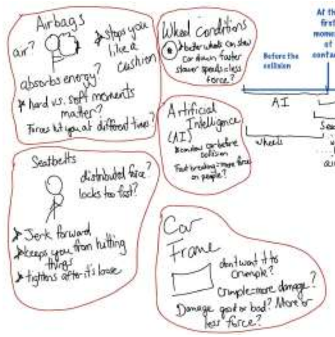
HS-PS2-2:
Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system.

HS-PS2-3:
Apply science and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.*

UNIT STORYLINE

Unit Question: What can we do to make driving safer for everyone?

Lesson Set 1: What factors can make driving more risky?

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 1 Lesson Set 1 4 days **Why is driving safer today than it was ten years ago, even though the number of vehicle collisions has gone up?** Anchoring Phenomenon	 *Overall we have seen a gradual decrease in crashes over time, but in recent years something has caused the number of crashes and fatalities to increase.*	We develop models to show how distracted driving and changes in vehicle design might contribute to trends in vehicle safety over time. We ask questions about the causes of these trends and develop ideas for investigation to help figure out the answers to our questions. We figure out: ● While overall trends in deaths have decreased, in recent years the number of collisions and injuries has increased. ● There are many potential causes for these trends, including changes in driver behavior (such as distracted driving), changes to vehicle design (such as airbags), changes to road conditions (such as more-visible stop signs), and changes to policy (such as speed limits).	

⇓ **Navigation to Next Lesson:** We think there are many factors that can contribute to the trends we see on our graphs. One of our ideas is that distracted driving may be a major cause of increased crashes and injuries. We want to figure out what impact distracted driving can have on a collision, among other things.

LESSON 2
Lesson Set 1

2 days

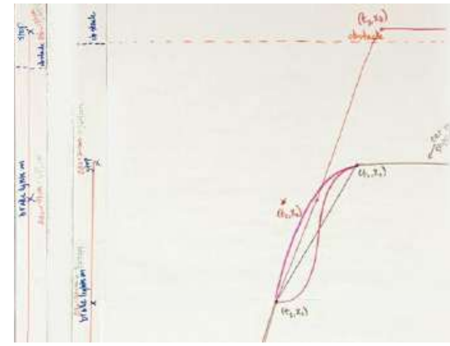
How does being distracted affect whether you will avoid a collision?

Investigation

Videos of an undistracted driver and a distracted driver encountering an obstacle provide speed and time data that are plotted on a graph.

We analyze videos of two drivers encountering a sudden obstacle: one who is undistracted and one who is distracted. We plot each to show how being distracted affects the motion of the vehicle over time. We figure out:

- We can plot the distance that a vehicle travels over time to learn more about how it is moving, including its speed.
- Distracted driving lengthens reaction time, which means that the driver has less distance over which to stop before the obstacle.



⇓ **Navigation to Next Lesson:** It seems like a shorter reaction time is key to preventing accidents. We want to investigate what else could increase a driver's reaction time other than whether the driver is distracted.

LESSON 3
Lesson Set 1

2 days

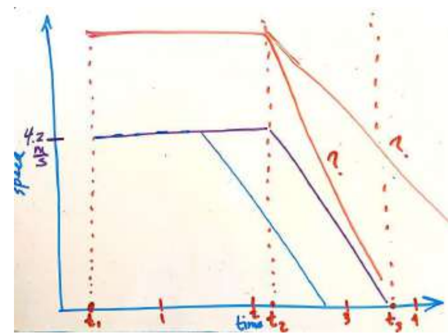
How does speed affect whether you will avoid a collision?

Investigation

A speed versus reaction distance graph is used to compare reaction times and distances traveled at higher speeds for both distracted and undistracted drivers.

We use mathematical models to generate data about how speed affects reaction distance. We identify design features that can decrease reaction distances to prevent collisions in the event of a sudden obstacle. We figure out:

- We can plot the speed at which a vehicle travels over time to learn more about how it is moving, including how its speed is changing.
- If you are going faster before the collision, your reaction time will not change but your reaction distance will, because distance = speed * time.
- Some engineering solutions that can affect reaction distance include speed limits, heads-up displays, and phones that turn off notifications while driving.



⇓ **Navigation to Next Lesson:** We figured out that driving is more dangerous when the car is moving faster because the car will travel farther during the time it takes the driver to react, making it harder to avoid an accident. We are wondering whether speed will also affect the time it takes to stop once the driver begins braking.

LESSON 4
Lesson Set 1

3 days

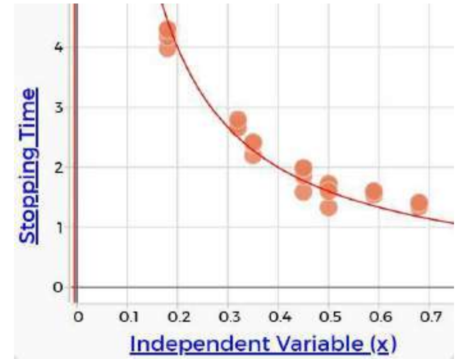
What affects the amount of time it takes a vehicle to stop after the driver presses the brakes?

Investigation

A controlled environment of a cart going down a ramp and then braking when it reaches the bottom provides a context to investigate the relationship between the speed at the bottom of the ramp, mass, braking force acting on the cart, and the length of time it takes to stop.

We use a speed versus time graph to predict how the initial speed, braking force, and mass of a moving vehicle affect its stopping time. We collect data to test our predictions and graph it in CODAP. We use curve fits to identify patterns indicating a mathematical relationship. To further test this relationship, we use a simulation to gather additional data. We figure out:

- The more braking force that is applied to a moving cart, the less time it takes to stop.
- The more mass and/or initial speed of a moving cart, the more time it takes to come to a stop.
- Mathematical models can help make very good, but not perfect, predictions of the changes in motion of a real-world object.
- It is not possible to eliminate measurement errors, but steps can be taken to reduce them.



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

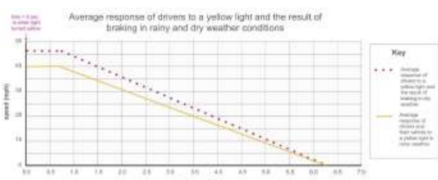
⇓ **Navigation to Next Lesson:** We are ready to put the pieces together to see what progress we have made in answering our questions about vehicle collisions.

LESSON 5
Lesson Set 1

1 day

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

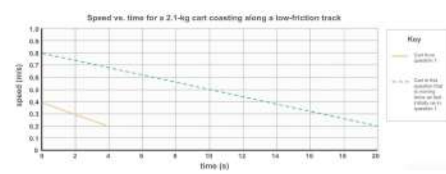
Putting Pieces Together



Though drivers are using more braking force in wet and rainy conditions, they are stopping later or running red lights.

We rearrange our equations to show a = F / m and F = ma and add to our M-E-F triangle to show that unbalanced forces cause change in motion. We analyze vehicle stopping times in wet and rainy conditions. We complete an Electronic Exit Ticket to predict the stopping time for carts going various speeds with friction. We figure out:

- The slope in a speed over time graph shows how quickly an object changes speed over time and is called *acceleration*.
- Unbalanced forces cause change in motion (*acceleration*).
- We can design solutions to increase stopping distance or time in wet and rainy conditions.



⇓ **Navigation to Next Lesson:** Though we have answered many questions about avoiding collisions, we identified the questions we had (and new questions) about objects that are unable to avoid collisions and are colliding.

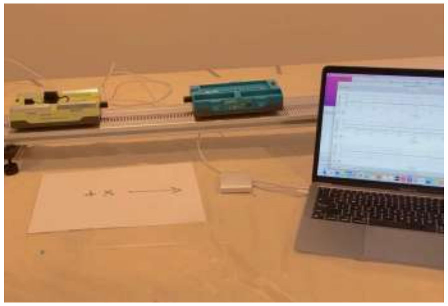
LESSON 6

Lesson Set 1

3 days

Do our motion relationships help predict any of the interactions or outcomes in a collision?

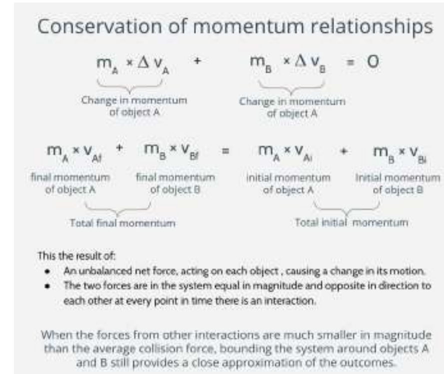
Investigation



Dynamic carts provide data about speed and contact forces in a collision. Data on fatalities show differences for different-mass vehicles. A simulation produces data on speed changes for different-mass for various collision conditions.

We analyze sensor data from a collision of a cart with a barrier and another between two carts. We analyze fatality data from collisions between different-mass vehicles. We develop an equation for the outcomes of two-vehicle collisions and test it with data from a simulation. We develop and use alternate algebraic models to solve for the mass or velocity of an object before or after a collision. We figure out:

- When two objects collide, the contact forces on each object are equal in magnitude and opposite in direction, acting over the same time period.
- In a collision between different-mass vehicles, the occupants of the larger-mass vehicle are at less risk of death and/or injury.
- The momentum of an object is the product of its mass and its velocity.
- During a collision, the total momentum of the colliding objects is conserved when there is no unbalanced external net force on the system.



⇓ **Navigation to Next Lesson:** Differences in the velocity change in a collision between vehicles of different-masses are correlated to differences in passenger safety. We are wondering how and why a difference in velocity would affect the passengers inside the vehicle.

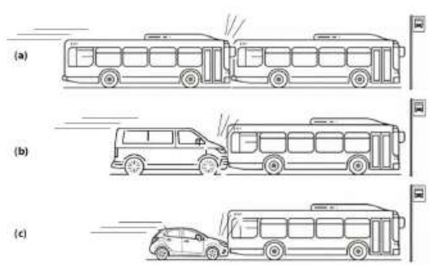
LESSON 7

Lesson Set 1

2 days

Can our models be used to predict the motion of real-world vehicles in a collision?

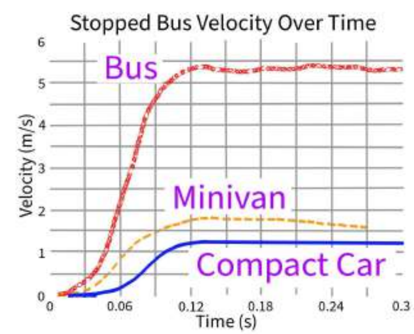
Putting Pieces Together, Problematizing



Data sets for factors that could potentially lead to increased injuries in collisions provide

We apply our ideas about momentum to an assessment about vehicles colliding with a stopped bus. We look at new data on factors to explore possible correlations with the trends we identified in Lesson 1. We discuss correlation versus causality. We explore a simulation of a vehicle collision to look for additional variables we want to explore. We add new questions to the Driving Question Board about safety features. We figure out:

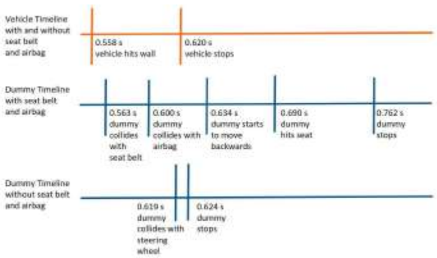
- Our mathematical model for momentum can be used to predict and explain changes in motion.



	information on how the trends have changed over time.	• Speed, mass, and new technology are probably all contributing to the trends we identified in Lesson 1. • New safety features may be weakening the strength of certain trends that we identified in Lesson 1.	*Data Source: Olivares, G. & Yadav, V. (2007)*

⇓ **Navigation to Next Lesson:** We have some ideas about how safety features might weaken some of the driving safety trends that we identified by improving collision outcomes over time. We want to investigate some of these features in more detail.

Lesson Set 2: How are vehicles designed to keep people safe?

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 8 Lesson Set 2 1 day **What interactions happen during a vehicle collision, and when do they happen?** Problematizing, Investigation	 *A video of a vehicle collision is fast. An animation and simulation data show the timing of events for collisions with and without safety features.*	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 the seat belt and airbag. We use velocity data from the simulation to add velocity data to our timelines. We 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.	

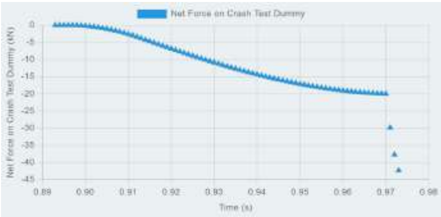
⇓ **Navigation to Next Lesson:** We know safety features increase the time it takes a person to change velocity in a collision. We used our mathematical models to identify that we should examine what safety features do to forces to see how much of a difference in time can really make in a collision.

LESSON 9
Lesson Set 2

2 days

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

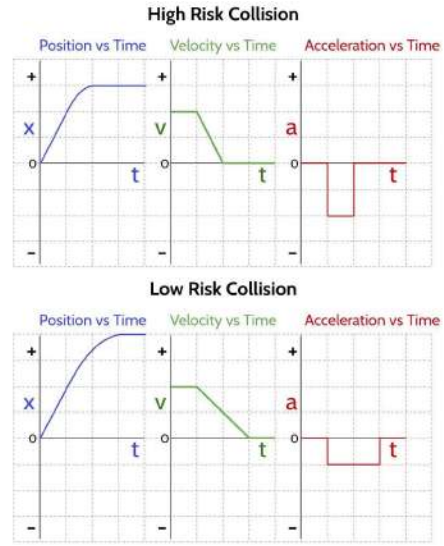
Investigation



The collision simulation provides force over time data for crash test dummies using various rigidities of seat belts and airbags in a collision.

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

- 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 $F\Delta t = m\Delta v$.



⇓ **Navigation to Next Lesson:** Having explained how seat belts and airbags are designed to make driving safer, we started considering some ways that the body of the vehicle could be redesigned to further reduce risk.

LESSON 10
Lesson Set 2

2 days

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

Investigation

Many modern-day vehicles have crumple zones designed into the the front and back of the car, but many vehicles before the 1990s and all vehicles before 1952 did not.

We make observations of a collision between two cars designed and built 50 years apart. We propose and compare solutions for the design of a vehicle's crumple zone to determine which of these designs provide better protection for the driver. We figure out:

- The rigidity and length of the crumple zone determine the magnitude of the force acting on the vehicle when it hits the wall.
- The longer the crumple zone, the longer the time lower forces act on the vehicle.

		RIGIDITY		
		Low	Medium	High
LENGTH	Short	A: 79%	B: 79%	C: 79%
	Medium	D: 88%	E: 80%	F: 79%
	Long	G: 100%	H: 80%	I: 79%

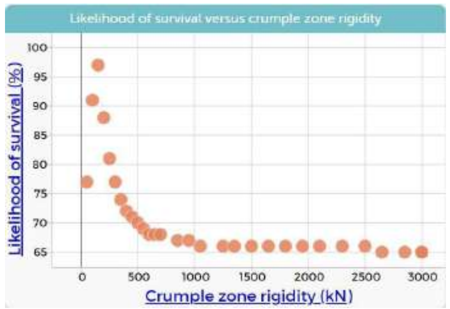
⇓ **Navigation to Next Lesson:** Though we know that the length and rigidity of the crumple zone affect the forces acting on the car and affect the safety of vehicle occupants, we haven't yet explained whether this is due to changes in the forces acting on the person.

LESSON 11
Lesson Set 2

2 days

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

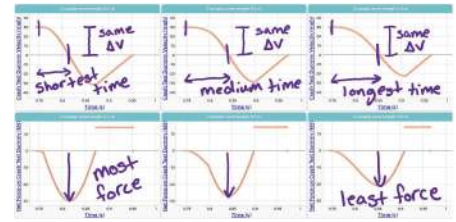
Investigation



Simulated car collision data provide evidence on how the length and rigidity of the crumple zone affect the motion and forces on a vehicle and crash test dummy.

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

- A less-rigid and longer crumple zone results in lower peak forces over longer periods of time acting on vehicle occupants during a collision.
- Energy transfers to the crumple zone as matter deforms.
- The amount of deformation is related to the amount of energy transferred.
- When the crumple zone is too short, the peak force is very high and the time to stop is very short.



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⇓ **Navigation to Next Lesson:** We have figured out that crumple zones can be designed to extend the time over which a crash test dummy comes to a stop in a collision. We are considering how velocity of vehicles affects safety.

LESSON 12
Lesson Set 2

3 days

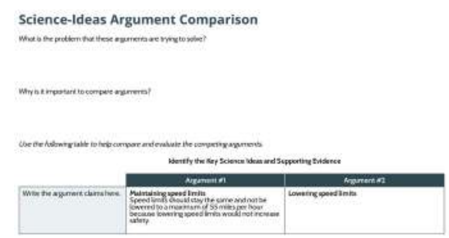
How can we use our models from across the unit to explain how vehicle systems can be designed to increase safety?

Putting Pieces Together, Problematizing

There are opposing arguments about whether speed limits should be decreased or allowed to continue to increase.

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

- There are many criteria that can be individually designed to collectively affect vehicle safety.
- Different arguments can be made on issues related to vehicle safety, and tradeoffs and societal impacts also need to be considered.


Science-Ideas Argument Comparison

What is the problem that these arguments are trying to solve?

Why is it important to compare arguments?

Use the following table to help compare and evaluate the competing arguments.

Identify the Key Science Ideas and Supporting Evidence

	Argument #1	Argument #2
Write the argument claims here.	Maintaining speed limits: Speed limits should stay the same and not be lowered to a maximum of 55 miles per hour because lowering speed limits would not increase safety	Lowering speed limits

<table>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="4">⇓ Navigation to Next Lesson: Now that we have a better understanding of the physics, we see that societal values also impact design decisions and we need to consider tradeoffs. We are wondering how we can apply this to our community.</td></tr>
</table>

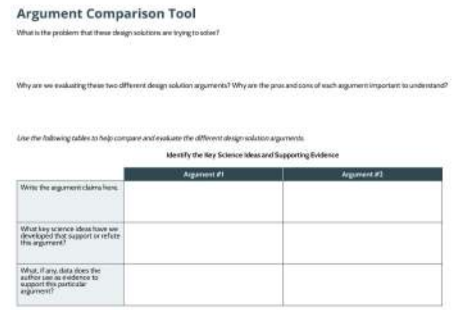
Lesson Set 3: How can we make design decisions that will make driving safer for everyone?

<table>
<tr><th>Lesson Question</th><th>Phenomena or Design Problem</th><th>What we do and figure out</th><th>How we represent it</th></tr>
<tr>
<td>LESSON 13
Lesson Set 3

1 day

How can we use our science ideas and societal wants and needs to evaluate arguments around design solutions?

Investigation</td>
<td>

There are many tradeoffs when considering the balance among science ideas, societal constraints, and ethical issues of a design solution.</td>
<td>We determine that risk is always involved in driving, but the risks are outweighed by benefits. We consider other issues in our community. We use the Argument Comparison Tool to compare arguments about a design solution relevant to our community and survey others to determine other issues related to transportation in our community. We figure out:
Science ideas alone cannot capture the whole picture related to tradeoffs, and societal impacts must be considered.
Tradeoffs are evaluated when making decisions about safety from a scientific perspective, and societal wants and needs are messy; there is not always one correct answer to design solution arguments.</td>
<td>
Argument Comparison Tool
What is the problem that these design solutions are trying to solve?
Why are we evaluating these two different design solution arguments? Why are the pros and cons of each argument important to understand?
Use the following tables to help compare and evaluate the different design solution arguments.
Identify the Key Science Ideas and Supporting Evidence<table><tr><th></th><th>Argument #1</th><th>Argument #2</th></tr><tr><td>Write the argument claims here.</td><td></td><td></td></tr><tr><td>What key science ideas have we developed that support or refute this argument?</td><td></td><td></td></tr><tr><td>What, if any, data does the author use as evidence to support this particular argument?</td><td></td><td></td></tr></table></td>
</tr>
<tr><td colspan="4">⇓ Navigation to Next Lesson: We have been talking about decision making related to transportation safety and are curious to see what our caregivers, friends, and family think.</td></tr>
</table>

LESSON 14
Lesson Set 3

3 days

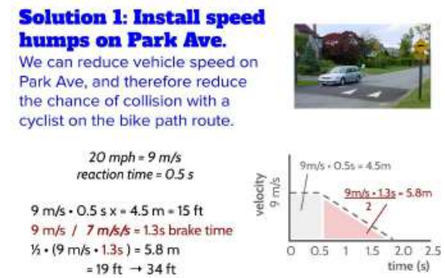
What can we do to make driving safer for everyone in our community?

Putting Pieces Together

Students notice a variety of real-world problems related to vehicle safety.

We develop solutions to driving-related problems we care about, using physics models to present our proposal in a format we choose. We figure out:

- We can impact change by offering evidence-based solutions.
- We should consider the scope of the effect they have on people or things we care about.
- Identifying cause-effect factors within a system can help us prioritize specific criteria to optimize solutions.
- We can use reasonable assumptions in our physics models to support a case for why a problem exists, or how a solution can make it safer.



⇓ **Navigation to Next Lesson:** We have come a long way in this unit. Next class, we will have the opportunity to demonstrate how much we have learned in an assessment.

LESSON 15
Lesson Set 3

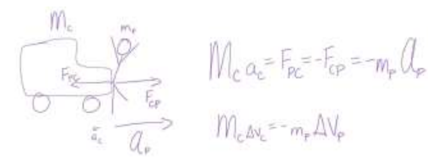
1 day

How can we use physics and engineering ideas to make decisions that will make driving safer for everyone?

Putting Pieces Together

We take an end-of-unit, transfer-task assessment. We revisit the DQB and determine what questions we can now answer. We reflect on and document the most important things learned in our unit. We figure out:

- We can use physics and engineering ideas to evaluate the merits of two design solutions and make recommendations for improvements.
- We can use our physics and engineering ideas to answer questions on our Driving Question Board.



	Design solutions from the 20th century intended to prevent pedestrian injury or death do not look like the design solutions we see on cars today.		
⇓ **Navigation to Next Lesson:** This is the last lesson in the unit.			

LESSONS 1-15

32 days total

TEACHER BACKGROUND KNOWLEDGE

Lab Safety Requirements for Science Investigations

It is important to adopt and follow appropriate safety practices when conducting hands-on science investigations and demonstrations, whether in an instructional space (traditional laboratory or classroom) or in the field. To this end, teachers must be aware of any school or district safety policies, legal safety standards, and better professional safety practices that are applicable to the activities being undertaken.

Science safety practices in instructional spaces require engineering controls and personal protective equipment (e.g., sanitized safety goggles or safety glasses with side shields as appropriate, nonlatex aprons and gloves, eyewash/shower station, fume hood, appropriate ventilation, and fire extinguishers). **Science investigations should always be directly supervised by qualified adults, who should review safety procedures annually, and also before initiating any hands-on activities or demonstrations.** Prior to each investigation, students should be reminded of the specific safety procedures they must follow. Each lesson within the OpenSciEd units includes teacher guidelines for applicable safety procedures for setting up and running an investigation as well as disassembling, disposing of, and storing materials.

Prior to the first investigation of the year, a safety acknowledgement form for students and parents/guardians should be provided and signed. You can access a model safety acknowledgement form for high school activities here: https://static.nsta.org/pdfs/SafetyAcknowledgmentForm-HighSchool.pdf

Disclaimer: The safety precautions provided for each activity are based in part on use of the specifically recommended materials and instructions as well as legal safety standards and better professional safety practices. Be aware that selecting alternative materials or procedures for these activities may affect the activity's level of safety and is therefore at the user's own risk.

Please follow these lab safety recommendations for any science investigation:

1. Wear sanitized safety goggles (specifically, indirectly vented chemical splash goggles) or safety glasses with side shields, as appropriate, a nonlatex apron, and nonlatex gloves during the setup, hands-on investigation, and take-down segments of the activity.
2. Safety goggles are required when working with liquid biological or chemical hazards (e.g., microbes, acids, bases). Safety glasses with side shields or safety goggles may be used when working with physical hazards (sharps, springs, glass, projectiles, etc.).
3. Immediately wipe up any spilled liquid (e.g., water) and/or granules on the floor, as this is a slip-and-fall hazard.
4. Follow your *Teacher Guide* for instructions on disassembling and storing materials and disposing of waste materials.
5. Secure loose clothing, remove loose jewelry, wear closed-toe shoes, and tie back long hair.
6. Wash your hands with soap and water immediately after completing the activity.
7. Never eat any food items used in a lab activity.
8. Never taste any substance or chemical in the lab.
9. Use only GFCI-protected circuits when using electrical equipment and keep away from water sources to prevent shock.
10. Use caution when working with glassware, which can shatter if dropped and cut skin.

11. Use caution when using sharp tools/materials, which can cut or puncture skin.
12. Never pour chemicals, either used or unused, back into their original container. Dispose of chemicals according to your teacher's instructions.
13. If you get a hazardous chemical on your clothing or have a clothing fire, use the emergency shower.
14. If you get a chemical in your eye, use an eyewash station immediately.
15. Point the test tubes, beakers, or other vessels away from yourself and other people when the vessels contain reactants or other substances.
16. When diluting acids or bases, the acid or base should be added to water and not water to the acid or base.
17. Projective trajectory zones must be well defined and free of any obstacles. No participant is to be in the zone during operation of the projectile..
18. Make sure the ventilation system meets the needs relative to removal of flammable vapors produced. Also make sure there are no active flames or sparks in the work zone.

Specific safety precautions are called out within the lesson using this icon and a call-out box.

Where does this unit fall within the OpenSciEd Scope and Sequence?

This unit is the third in the OpenSciEd High School Physics course sequence. It is designed to build on student ideas about forces and matter interactions from the second unit of the course. In the first unit of OpenSciEd HS Physics, students developed ideas around energy transfer and conservation in the context of charged particles (electrons) colliding with other electrons (electricity) to transfer energy across great distances. In the second unit of the course, the development of the concept of forces was needed in order to explain earth science phenomena that involve energy transfer across scales of time and space. In this unit, students develop a more-robust understanding of forces as vectors and use conservation of momentum and Newton's second law to make predictions about the outcomes of collisions.

In the unit that follows this one, students will build on what they figured out about contact forces in previous units (tectonic plates rubbing, vehicles colliding) to understand gravity, a force that acts at a distance, and use what they figure out to explain the dynamics of orbiting objects. The fifth unit uses energy transfer, electromagnetism, wave mechanics, and forces at a distance to explain how food heats up in a microwave and if and how this technology might be dangerous for humans. In the final unit of the course, students will explore cosmology and the Big Bang, applying ideas about forces and energy from all five previous units on the largest scales.

What is the anchoring phenomenon, and why was it chosen?

This unit is anchored by a puzzling set of patterns in traffic collision data over time: while overall, vehicle fatalities have been decreasing steadily for decades, the trend appears to have stalled, and collisions and fatalities have been increasing. This phenomenon provides the context in which to investigate the physical relationships among mass, velocity, momentum, force, time, and acceleration, basic physical quantities that provide the foundation for the study of mechanics. Students will analyze statistics on vehicle collisions, analyze the motion of vehicles stopping to avoid collisions, and model vehicle collisions to understand how vehicles are designed to reduce the chances of injury in a collision by testing and evaluating designs that could change force interactions in the system. Lastly, the students compare and evaluate arguments on how we can make driving safer for everyone and develop their own design solutions in an engineering design challenge.

The vehicle collisions anchoring phenomenon was chosen from a group of phenomena aligned with the target performance expectations based on the results of a survey administered to almost 1,000 students from across the country and in consultation with external advisory panels that include teachers, subject matter experts, and state science administrators. This phenomenon includes a strong engineering component with a complex global problem and includes humans and human activity in the systems under study. The full physics course is designed to purposefully highlight a variety of different types of phenomena. While we design to privilege the interests of students to whom we owe an educational debt, we must not essentialize minority groups by assuming that a trend in the data equates to homogenous interests and experiences. Providing a diverse suite of entry points into content and practices creates more opportunities for every student to connect with the content.

The collisions phenomenon was chosen for the following reasons:

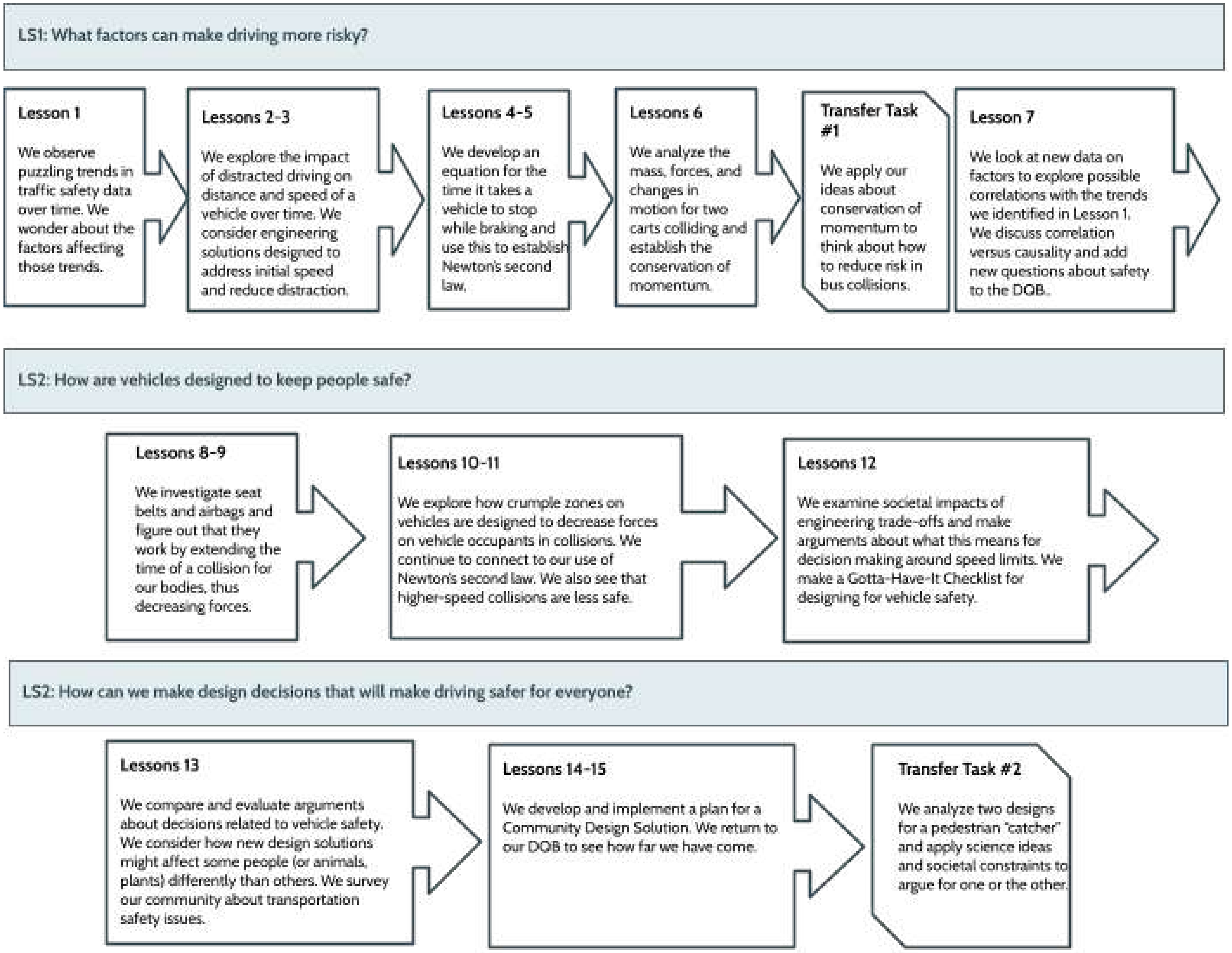
- Students showed high interest in explaining the puzzling data trends.
- To provide a diverse suite of entry points across the course, we were seeking an event that allowed students to consider a relevant societal problem.
- Teachers and administrators saw the phenomenon as interesting and on grade band.
- Explaining the mechanics of a collision using physics concepts grounds abstract ideas about momentum.
- Explaining the phenomenon addresses all the DCIs in the bundle at a high school level.
- Explaining the phenomenon requires the use of mathematical thinking at a high school level.
- In consultation with high school counselors, the team felt the phenomenon is relevant and important for high school students and could be approached from a trauma-informed perspective.

How is the unit structured?

The unit is organized into three lesson sets. **Lesson Set 1** (Lessons 1-7) focuses on answering the question: *What factors can make driving more risky?* In the first lesson set, students develop models to show how distracted driving and changes in vehicle design might contribute to trends in vehicle safety over time. This leads them to wonder about distracted driving. They analyze video of two drivers encountering a sudden obstacle, one who is not distracted and one who is distracted, and plot each to show how being distracted affects the motion of the vehicle over time. They use mathematical models to generate data about how speed affects reaction distance and identify design features that can decrease reaction distances to prevent collisions in the event of a sudden obstacle. Then they use a hands-on investigation to develop a mathematical model for the time it takes a vehicle to come to a stop while braking. They define *acceleration* and rearrange their mathematical model into Newton's second law. They then wonder what happens when avoiding a collision is not possible. They adapt their existing mathematical relationship to describe patterns between the masses and the changes in velocity of two colliding carts using videos, graphs, and simulations, co-developing a definition of *momentum* in the process. Finally, they put the pieces together in Lesson 7 and complete a transfer task that asks them to analyze and explain real data about bus safety.

Lesson Set 2 (Lessons 8-12) focuses on answering the question: *How are vehicles designed to keep people safe?* In the second lesson set, students analyze multiple design features of vehicles that are designed to keep people safe during collisions. They use simulation data to create a collision timeline for the crash test dummy in a vehicle cabin. They investigate how seat belts and airbags work together to stop a crash test dummy in a collision and make connections back to Newton's second law. They then use simulation data to analyze how the design of vehicle crumple zones can also reduce forces on a crash test dummy and notice that the speed of the vehicle greatly impacts the outcome of a collision. In Lesson 12, students put the pieces together by creating a Gotta-Have-It Checklist for designing vehicle safety features and consider how design solutions might affect some people (or animals, plants) differently than others.

Lesson Set 3 (Lessons 13-15) focuses on answering the question: *How can we make design decisions that will make driving safer for everyone?* Students compare and evaluate vehicle safety design solutions and survey community members about local issues with transportation safety. In Lesson 14, students research an issue that is relevant to the community and develop and implement a plan for a Community Design Solution. Finally, they return to their DQBs in Lesson 15 and complete a transfer task that asks them to compare two vintage design solutions for catching pedestrians.



What elements of the NGSS three dimensions are developed in this unit?

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This unit is designed to introduce students to the concept of momentum in an intuitive and grounded context. Analyzing and interpreting data **is intentionally developed across this unit**, beginning in Lesson Set 1 and building as students use a variety of data visualization and analysis tools in Lesson Set 2. The anchoring phenomenon is a set of complex data patterns that are not easy to explain and that we will return to across several lessons. Thus, patterns **is intentionally developed over the unit**. In addition, we will analyze and interpret data in almost every lesson, from video data to force sensor data to student-generated data using simulations and hands-on investigations to data on policy and driving behavior over time. Ideas about momentum and Newton's second law are derived from students' analysis of empirical evidence, and our approach to engineering design is grounded in analysis of data.

The use of mathematics and computational thinking **is intentionally developed in this unit**, motivated by students' questions about vehicle collisions. In **Lessons 2-3**, students build a foundation for thinking about motion through change over time graphs to establish the basic kinematics of a vehicle coming to a stop. In **Lessons 4-12**, students derive and apply equations for the conservation of momentum and Newton's second law because they need to in order to understand and explain the anchoring and investigative phenomena and weigh design solutions. While doing this, they collect data and use algebraic thinking to examine and predict the effect of changing one variable on another, thus scale, proportion, and quantity is **intentionally developed across this unit**.

Constructing explanations and designing solutions **is also intentionally developed in this unit**, as is argumentation in a design context. In the final lesson set, students begin to apply their understanding of momentum and force, along with the engineering design solutions they have considered, to address global and local challenges associated with driving vehicles. They use an argumentation scaffold (the Argument Comparison and Evaluation Tool) across **Lessons 12-15** to deliberate about complex socio-ecological explanations and proposed solutions. Over time, by applying empirical data to engineering thinking, students come to see that systems are designed to cause specific effects and that decisions that we make can cause changes in our own communities; thus, cause and effect **is intentionally developed over the unit**.

While not intentionally developed, developing and using models (diagrammatic and mathematical) is **key to the sensemaking** in this unit. **Key to the sensemaking** around engineering design is also asking questions and defining problems. Structure and function, systems and system models, and stability and change of systems are also key to the sensemaking in several lessons.

This unit builds toward these performance expectations:
HS-ETS1-3 Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, ~~including cost,~~ safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts. **HS-PS2-2** Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system. **HS-PS2-3** Apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision. **HS-PS2-1** Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.

Science and Engineering Practices	Disciplinary Core Ideas*	Crosscutting Concepts

Analyzing and Interpreting Data: This unit **intentionally develops** students' engagement in this practice by providing the opportunity for students to analyze and interpret complex, real-world data using a variety of tools, technologies, and models, including simulations, video, algebra, force sensors, graphs, and data about policy and human behavior that can only be explained using science ideas. ● Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. ● Evaluate the impact of new data on a working explanation and/or model of a proposed process or system. ● Analyze data to identify design features or characteristics of the components of a proposed process or system to optimize it relative to criteria for success. **Using mathematics and computational thinking:** This unit **intentionally develops** students' engagement in this practice. Throughout, students use algebraic thinking and graphical representations to interpret data patterns and derive mathematical models, including equations for the conservation of momentum and Newton's second law to understand and explain the anchoring and investigative phenomena and weigh design solutions. ● Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations. ● Apply techniques of algebra and functions to represent and solve scientific and engineering problems.	**PS2.A: Forces and Motion** ● Momentum is defined for a particular frame of reference; it is the mass times the velocity of the object. (HS-PS2-2) ● Newton's second law accurately predicts changes in the motion of macroscopic objects. (HS-PS2-1) ● If a system interacts with objects outside itself, the total momentum of the system can change; however, any such change is balanced by changes in the momentum of objects outside the system. (HS-PS2-2),(HS-PS2-3) **ETS1.A: Defining and Delimiting Engineering Problems** ● Humanity faces major global challenges today, ~~such as the need for supplies of clean water and food or for energy sources that minimize pollution,~~ which can be addressed through engineering. These global challenges also may have manifestations in local communities. (HS-ETS1-1) ● Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account~~, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them.~~ (HS-ETS1-1, secondary to HS-PS2-3) **ETS1.B: Developing Possible Solutions** ● When evaluating solutions, it is important to take into account a range of constraints, including ~~cost~~, safety, ~~reliability,~~ and aesthetics, and to consider social, cultural, and environmental impacts. (HS-ETS1-3) ● Both physical models and computers can be used in various ways to aid in the engineering design process. Computers are useful for a variety of purposes, such as running simulations to test different ways of solving a problem or to see which one is most	**Cause and Effect:** This unit **intentionally develops** this crosscutting concept. Students reason about how vehicle designs affect safety. They see that systems are designed to cause specific effects and that decisions that we make can cause changes in our own communities. ● Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. ● Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller-scale mechanisms within the system. ● Systems can be designed to cause a desired effect. ● Changes in systems may have various causes that may not have equal effects. **Scale, Proportion, and Quantity:** This unit **intentionally develops** this crosscutting concept. Students use algebraic thinking to establish relationships between variables. ● The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. ● Some systems can only be studied indirectly as they are too small, too large, too fast, or too slow to observe directly. ● Algebraic thinking is used to examine scientific data and predict the effect of a change in one variable on another (e.g., linear growth vs. exponential growth). **Patterns:** This unit **intentionally develops** this crosscutting concept. The anchoring phenomenon is a set of complex data patterns that are not easy to explain and that we will

- Use simple limit cases to test mathematical expressions, computer programs, algorithms, or simulations of a process or system to see if a model "makes sense" by comparing the outcomes with what is known about the real world.

Constructing Explanations and Designing Solutions: This unit **intentionally develops** students' engagement in this practice. The unit includes several opportunities for students to construct explanations supported by multiple sources of evidence consistent with scientific ideas, principles, and theories. Throughout, students are also thinking about design solutions. They keep track of their explanations and design ideas in an Engineering Progress Tracker, and their culminating task is a Community Design Solution.

- Make a quantitative and/or qualitative claim regarding the relationship between dependent and independent variables.
- Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects.
- Design, evaluate, and/or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.

Engaging in Argument from Evidence: This unit **intentionally develops** students' engagement in this practice. Students use an argumentation scaffold across Lessons 12-15 to deliberate about complex socio-ecological explanations and proposed solutions.

- Compare and evaluate competing arguments or design solutions in light of currently accepted

efficient or economical, and in making a persuasive presentation to a client about how a given design will meet his or her needs. (HS-ETS1-4)

ETS1.C: Optimizing the Design Solution

- Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. (HS-ETS1-2, secondary to HS-PS2-3)

ETS2.B: Influence of Engineering, Technology, and Science on Society and the Natural World

- New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology.

return to across several lessons. Students continually use graphical representations of data to identify patterns in data.

- Patterns of performance of designed systems can be analyzed and interpreted to reengineer and improve the system.
- Mathematical representations are needed to identify some patterns.
- Empirical evidence is needed to identify patterns.

The following crosscutting concepts are also **key to the sensemaking** in this unit:

- Stability and Change of Systems
- Systems and System Models
- Structure and Function

explanations, new evidence, limitations (e.g., trade-offs), constraints, and ethical issues. The following practices are also **key to the sensemaking** in this unit: • Developing and Using Models • Asking Questions and Defining Problems		

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Connections to the Nature of Science (NOS) and/or Engineering, Technology, and the Application of Science (ETS)

Connections to the Nature of Science (NOS)	
Which elements of NOS are developed in the unit?	How are they developed?
Scientific Investigations Use a Variety of Methods. Scientific investigations use diverse methods and do not always use the same set of procedures to obtain data.	In the investigation in Lesson 4, students discuss issues of accuracy and consider strategies that could be used to obtain more-precise data. They also discuss the advantages and disadvantages of collecting data using the physical setup and the simulation.
Science Is a Human Endeavor. Science and engineering are influenced by society, and society is influenced by science and engineering.	In Lessons 12-14 students engage with multiple problems that connect both to science ideas and society.
Science Addresses Questions about the Natural and Material World. Not all questions can be answered by science.	In Lesson 14 students look at problems in their communities related to vehicle safety and identify that some cannot be addressed by using the science ideas from the unit.
Science Addresses Questions about the Natural and Material World. Science and technology may raise ethical issues for which science, by itself, does not provide answers and solutions.	In Lessons 12-14 students look at multiple examples of when ethical considerations impact decisions.

Science Addresses Questions about the Natural and Material World. Scientific knowledge indicates what can happen in natural systems--not what should happen. The latter involves ethics, values, and human decisions about the use of knowledge.	In Lessons 12-14 students grapple with societal impacts of design decisions, including ethics and values.
Science Addresses Questions about the Natural and Material World. Many decisions are not made using science alone, but rely on social and cultural contexts to resolve issues.	In Lessons 12-14 students engage in argumentation and design around real-world problems and see that the answer the science ideas give is not always the best answer.
Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena. Laws are statements or descriptions of the relationships among observable phenomena.	In Lessons 4-6, students develop Newton's second law as a description of the relationships they observe in the motion of a braking cart.

How does the unit build three-dimensional progressions across the course and the program?

This unit uses and builds upon **disciplinary core ideas (DCIs)** and other science ideas that students should have previously developed in this course and in middle school:

- **Forces and motion** (8.1 Contact Forces, P.2 Afar). This unit reinforces and builds from the following DCI elements from the OpenSciEd Middle School sequence: Forces cause matter changes and energy transfer. In the P.2 Afar unit, students use and apply the idea that forces are pushes and pulls, a review from middle school. They learn that unbalanced forces transfer energy within and across systems, and they begin to apply the idea that a force is a vector, meaning it has a magnitude and a direction. They also figure out that when a force is applied to matter, it will behave elastically up until a point when it will deform permanently and/or break, an idea they reinforce in P.2 Afar. In P.2 Afar students started thinking about force as a vector, and they extend that idea in this unit to recognize they can have negative direction and that velocity is also a vector quantity. In this unit, they uncover mathematical relationships among forces and time, acceleration, and momentum (mass and velocity) that help them make predictions about peak force on vehicle occupants during a collision.
- **Defining and delimiting engineering problems; Developing possible solutions** (P.1 Electricity). In the first unit of this course, students also considered a major global challenge with local implications and developed a design solution plan to advocate for in their community. In this unit, students build on the work they did in P.1 by applying an argumentation scaffold (the Argument Comparison and Evaluation Tool) to think critically about what will be the best design solution and then actually bringing an iteration of that solution to life through a culminating project.

This unit uses and builds upon **science and engineering practices (SEPs)** that students should have previously developed in this course and in middle school:

- **Analyzing and interpreting data** (P.1 Electricity). In the first unit of the course, students spent time looking at complex graphs of real data and using them to make inferences. In this unit, students apply this practice in a new context, teasing apart overlapping patterns over the course of the unit and developing their own change over time graphs for distance, velocity, and force.
- **Using mathematics and computational thinking** (P.1 Electricity, P.2 Afar). In the first two units of the course, students used algebraic thinking to reason and apply mathematical models. In this unit, students apply this practice in a new context, deriving mathematical relationships from empirical evidence, expressing them as equations, and manipulating them to derive new models as well as solving for unknown values.

- **Constructing explanations and designing solutions** (P.1 Electricity, P.2 Afar). In the first unit of the course, students constructed explanations about how energy moves through systems and designed a community solution. In the second unit, students constructed explanations about what will happen to the future of the Afar region of Ethiopia. In this unit, students think deeply about the design solutions at multiple grain sizes, both within a vehicle (i.e., airbags) and at a societal level (i.e., policy requiring airbags in vehicles). In addition, students think deeply about the implications of design trade-offs in new ways, including how the constraints associated with certain design solutions might have implications for some groups of people more than for others.
- **Engaging in argument from evidence** (P.1 Electricity, P.2 Afar). In the first two units of the course, students justified claims with evidence and in the first unit (P.1 Electricity) even argued from evidence for a design solution for their community. In this unit, students apply this practice using the Argument Comparison and Evaluation Tool, a scaffold that helps students keep track of evidence and consider complex trade-offs and societal constraints.

This unit uses and builds upon **crosscutting concepts (CCCs)** that students should have previously developed in this course and in middle school:

- **Cause and effect** (8.3 Speakers, P.2 Afar). In the third unit of the eighth grade sequence, students used a series of sentence starters to scaffold engagement in practices through the lens of cause and effect. The structure of those sentence starters was echoed again in the second unit of this physics course (P. 2 Afar), when students collaboratively built a cause-effect model for understanding how interactions on a nuclear scale can cause patterns on a global scale. In this unit, the scaffold of these sentence starters has moved further into the background, and students are expected to begin applying cause-effect thinking to design solutions.
- **Scale, Proportion and Quantity** (P.2 Afar). In the second unit of the course, students focus on systems at multiple scales and use a scale chart with axes across spatial and temporal dimensions. While students do not use the scale chart in this unit, they will use their ideas about phenomena at multiple scales to make sense of what they observe using mathematical thinking.
- **Patterns** (P.1 Electricity, P.2 Afar). In the first two units of the course, students identified patterns in data. Typically, one or two causes can be attributed to these patterns. In this unit, students analyze complex data with many overlapping patterns that must be teased apart, each with multiple causes.

This unit uses and builds upon high school-level **science and engineering practices (SEPs)** and **crosscutting concepts (CCCs)** that students should have previously developed in **OpenSciEd High School Biology and Chemistry** and will continue to build in future units. The progressions of these practices and concepts across the program are as follows:

	Questions	Models	Investigations	Data	Math	Explanation	Argument	Obtaining
Biology	*Cancer Unit*	*Serengeti Unit, Fires Unit*	*Fires Unit, Natural Selection Unit*	*Natural Selection Unit, Cancer Unit*	*Serengeti Unit*	*Fires Unit, Cancer Unit, Natural Selection Unit*	*Speciation Unit*	*Cancer Unit, Speciation Unit*
Chemistry	*Polar Ice Unit, Oysters Unit*	*Electrostatics Unit, Space Survival Unit*	*Polar Ice Unit*	*Fuels Unit*	*Polar Ice Unit, Oysters Unit*	*Fuels Unit*	*Fuels Unit*	*Electrostatics Unit, Space Survival Unit*
Physics	*Electricity Unit, Cosmology Unit*	*Electricity Unit, Microwave Unit*	*Microwave Unit*	*Electricity Unit, Earth's Interior Unit, Vehicle Collisions Unit, Meteors Unit*	*Vehicle Collisions Unit, Meteors Unit*	*Electricity Unit, Earth's Interior Unit, Vehicle Collisions Unit*	*Vehicle Collisions Unit*	*Cosmology Unit, Microwave Unit*

	Patterns	Cause/Effect	Scale	Systems/Models	Energy/Matter	Structure/Function	Stability/Change
Biology	*Natural Selection Unit, Speciation Unit*	*Cancer Unit, Natural Selection Unit, Speciation Unit, Serengeti Unit*	*Serengeti Unit*	*Fires Unit, Cancer Unit, Serengeti Unit*	*Fires Unit, Serengeti Unit*	*Cancer Unit*	*Speciation Unit, Serengeti Unit*
Chemistry	*Electrostatics Unit, Space Survival Unit*	*Oysters Unit, Fuels Unit*	*Electrostatics Unit, Oysters Unit*	*Polar Ice Unit*	*Polar Ice Unit, Fuels Unit*	*Space Survival Unit*	*Oysters Unit*
Physics	*Cosmology Unit, Vehicle Collisions Unit, Earth's Interior Unit*	*Vehicle Collisions Unit, Earth's Interior Unit*	*Meteors Unit, Earth's Interior Unit*	*Electricity Unit, Vehicle Collisions Unit, Microwave Unit*	*Electricity Unit, Earth's Interior Unit*	*Earth's Interior Unit, Vehicle Collisions Unit*	*Electricity Unit, Cosmology Unit*

What are some common ideas that students might have?

Students will come into the unit with many ideas about forces derived from previous classroom experiences, intuitive understandings of the way the world works, everyday experiences with movement, and the conversations they have had with parents, friends, and family members.

Some relevant ideas that students may come into the unit with include the following:

1. A continuous force is needed for continuous motion.
2. Forces get things moving but can't stop them.
3. Direction of motion implies direction of force.
4. Rest is the natural state of objects.
5. Equal and opposite refers only to forces that are in balance and ceases to be true when unbalanced forces cause motion.

It is valuable to think of ideas like these not as misconceptions that need to be erased but as productive ideas that we can use to build understanding. Not only does this help some students feel more comfortable talking about science and build a scientific identity, it improves science learning across the board.

How will I need to modify the unit if taught out of sequence?

This is the third unit of the High School Physics Course in the OpenSciEd Scope and Sequence. Given this placement, several modifications would need to be made if teaching this unit earlier in the Physics course. These include the following adjustments:

- If taught earlier in the school year, supplemental teaching around the nature of energy transfer through systems and how to represent it may be required.
- If taught earlier in the school year, supplemental teaching around the basics of forces may be required.
- If taught as part of an AP Physics course, be prepared to provide students with additional support around equations that are not treated in depth.

How do I shorten or condense the unit if needed? How can I extend the unit if needed?

The following are example options to shorten or condense parts of the unit without eliminating important sensemaking:

- Lesson 4: Instead of conducting the Braking Lab, you could provide students with demonstrations and the sample data to do the analysis.
- Lesson 11: The Scientists Circle about M-E-F perspectives wraps up the crumple zone discussion but could be excluded or integrated into the Lesson 12 Gotta-Have-It Checklist discussion.

To extend or enhance the unit, consider the following:

- Lesson 3: Consider having students use the collision avoidance view of the Vehicle Collision Simulator to experiment with the relationships established.
- Lesson 6: If you have multiple smart carts, consider collecting the data shown in the videos in your classroom together. Be sure to test it out ahead of time, as it is easy for the measurements to be off because of error.
- Lesson 11: Have students collect the data using the simulation instead of providing them with the graph handouts.
- Lesson 14: Spend more time having students research and develop their community design solutions.
- All lessons: Remove scaffolds provided with science and engineering practices (SEPs) as a way to give students more independent work with the elements of these practices.

What mathematics concepts will students engage with in the unit?

This unit requires knowledge of how to solve algebraic equations and is more math intensive than units P.1 and P.2. Note that mathematical modeling is best interpreted not as a collection of isolated topics but in relation to other standards. Making mathematical models is a Standard for Mathematical Practice, and specific modeling standards appear throughout the high school standards.

This unit does not assume students are fluent with the mathematical practices listed below; rather, students develop these practices as part of the sensemaking. Thus, these standards are not so much prerequisites as co-requisites. If students are simultaneously developing the skills and vocabulary in math class, you can help by making explicit connections to the mathematical standards below. Co-requisite concepts from students' math classes include the following:

Category	Code	Domain and heading	Standard	Relevant lessons
Number and Quantity	CCSS.MATH.CONTENT.HS.N-VM.1	**Vector and Matrix Quantities:** Represent and model with vector quantities.	Recognize vector quantities as having both magnitude and direction.	6, 9, 10
	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.	5, 6
Algebra	CCSS.MATH.CONTENT.HS.A-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. For example,	4, 5, 6

			interpret P(1+r)n as the product of P and a factor not depending on P.	
	CCSS.MATH.CONTENT.HS.A-SSE.2	**Seeing Structure in Expressions:** Interpret the structure of expressions.	Use the structure of an expression to identify ways to rewrite it.	6
	CCSS.MATH.CONTENT.HS.A-CED.2	**Creating Equations:** Create equations that describe numbers or relationships.	Create equations in two or more variables to represent relationships between quantities; graph equations on coordinate axes with labels and scales.	2, 3, 4, 5, 6
	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.	4, 5, 6, 9, 10
Functions	CCSS.MATH.CONTENT.HS.F-IF.4	**Interpreting Functions:** Interpret functions that arise in applications in terms of the context.	For a function that models a relationship between two quantities, interpret key features of graphs and tables in terms of the quantities, and sketch graphs showing key features given a verbal description of the relationship.	4, 11
	CCSS.MATH.CONTENT.HS.F-LE.1a	**Linear, Quadratic, and Exponential Models:** Construct and compare linear, quadratic, and exponential models and solve problems.	Distinguish between situations that can be modeled with linear functions and with exponential functions.	4

What strategies are available to support equitable science learning in this unit?

OpenSciEd units are designed to promote equitable access to high quality science learning experiences for all students. Each unit includes strategies that are integrated throughout the OpenSciEd routines and are intended to increase relevance and provide access to science learning for all students. These equity goals are supported through several specific strategies, such as (1) integrating Universal Design for Learning (UDL) Principles during the unit design process to reduce potential barriers and increase accessibility for students to engage in learning experiences; (2) developing and supporting classroom agreements that encourage a safe learning culture; (3) supporting classroom discourse to promote students in developing, sharing, and revising their ideas; and (4) offering specific strategies for supporting emerging multilingual students in science classrooms.

Many of these strategies are highlighted in the *Teacher Guide* in sidebar callout boxes with these headings:

- Attending to Equity
- Supporting Emerging Multilingual Learners
- Supporting Universal Design for Learning
- Additional Guidance

- Alternate Activity
- Key Ideas
- Discussion

What are recommended adult-level learning resources for the science concepts in this unit?

The OpenSciEd instructional model focuses on the teacher being a member of the classroom community, supporting students to figure out scientific ideas motivated by their questions about phenomena. Students iteratively build their understanding of phenomena as the unit unfolds. To match the incremental build of a full scientific explanation across the unit, the science content background necessary for you to teach individual lessons incrementally builds too. Throughout the unit, we provide just-in-time science content background for you that is specific to the disciplinary core ideas (DCIs) that will be figured out in a lesson. Places to look for this guidance include the "Where we are going" and "Where we are not going" sections for each lesson. Also, the expected student responses, keys, and rubrics illustrate important science ideas that should be developed in each lesson. The K-12 Science Framework is another great resource to learn more about the DCIs in this unit (**ETS1.A: Defining and Delimiting Engineering Problems, ETS1.B: Developing Possible Solutions, ETS1.C: Optimizing the Design Solution, PS2.A: Forces and Motion**), including what students have learned previously and where they are headed in high school. In addition to the science content background information embedded in the lesson resources, below we provide recommended resources that can help build your understanding of phenomena and a performance expectations bundle for this unit:

- To learn more about the physics of vehicle collisions
    - https://driving.ca/features/feature-story/motor-mouth-the-physics-of-car-crashes-prove-bigger-is-better
    - https://www.epermittest.com/drivers-education/physics-collisions
    - https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4288294/
    - Also see the articles in the Key Words Database in Lesson 14 (https://docs.google.com/spreadsheets/d/1EqONf6yEYqLFZZn4LUcmzFQeJNATscIE9rWCmN-xNyO/copy).
- To learn more about distracted driving and safe driving habits
    - https://www.nhtsa.gov/risky-driving
    - https://www.nhtsa.gov/road-safety

How do I support students' emotional needs?

Often in science classrooms, we are focused on evidence and data. When addressing a phenomenon or design solution that straddles the nature-cultural divide, like the one in this unit, strong emotions can become entangled with scientific reasoning. For this reason, supporting students in using an empathy or socio-emotional lens will also be important. Make space for students to process and validate their feelings and reactions. To help foster a safe environment during this unit, consider revisiting the Community Agreements as necessary to help guide respectful engagement around emotionally sensitive topics.

The culminating project task in Lesson 14 was designed to give students and educators the chance to engage in meaningful problem solving in their local community. Rather than provide students with a fictional scenario, the task is designed to support students in taking agency and provide them with the tools to speak up in their local and global community in hopes of a better future for everyone.

In this unit, students will analyze data on vehicle collisions and vehicle fatalities. We recognize that vehicle collisions can be traumatic and recalling past experiences or learning about others' experiences can be triggering, so this unit was designed to support students and teachers using a trauma-informed approach. According to the CDC, "Adopting a trauma-informed approach is not accomplished through any single particular technique or checklist. It requires constant attention, caring awareness, [and] sensitivity" (CDC, 2022). Particularly, when engaging with a trauma-related topic such as vehicle collisions, it is important not to ask students to share their personal experiences unless they volunteer to do so. While it is generally pedagogically productive to encourage students to connect their personal experiences to the content in science class, in this case it is more important to protect students who may have experienced a traumatic vehicle collision or lost a loved one to a car accident. This topic is very strongly relevant to most students' lives, and you do not need to proactively draw out their prior experiences to help them see that relevance. See [material:PM.L1.TREF] for more information on engaging in a trauma-informed approach.

Be aware that students who are struggling may demonstrate a variety of behaviors, including but not limited to fidgeting, withdrawal, disruption or distraction, rapid breathing, holding their breath, and change in body language or tonation. If you notice a student might be struggling, check in with the student. This may look like sharing what you are observing and/or asking if the student needs support. It is also important to be aware of your own past experiences and responses to this unit. Be mindful of your own emotions and reactions and take a break or reach out to others for support, if needed. As needed, you can also utilize calming techniques (e.g., deep breathing) with your students as a whole group and/or individually to support yourself and/or have emotionally impacted students utilize these techniques at their desk.

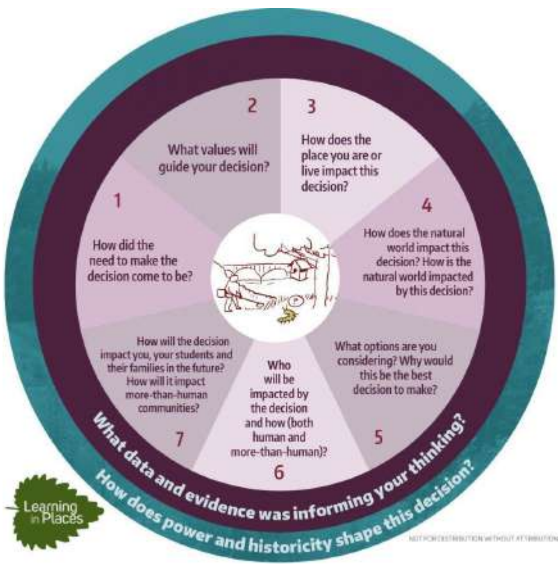
Before beginning this unit, make sure to reach out to a counselor, social worker, or mental health professional at your school for student-specific support and strategies that might be needed regarding the students in your classroom and consider asking them to join you on the first day of instruction. Also consider planning follow-up check-ins with the counselor (or other mental health professional) concerning any students who may need additional emotional support. If your school site has limited mental health support, please consider reaching out to your school leadership team.

Reach out to students' support system at home before the unit using the *Pre-Unit Letter Home*. This letter is a way to communicate with trusted adults and make them aware of the content of the unit. The letter also provides an opportunity for trusted adults to share important context with you about students' experiences and background that might be relevant. If your school has other home-contact resources such as automated phone calls, consider using multiple means of communication. This topic can be sensitive for those who have experienced injury, trauma, or loss due to collisions. Please be mindful of this and provide safety and support by sharing awareness. If there is time, consider beginning the class with a brief mindfulness activity (see *Student Mindfulness Resource* for strategies).

For more trauma-informed strategies to support your students' emotional needs, please visit https://transformingeducation.org/.

What is the Learning in Places socio-ecological deliberation and decision-making framework?

This unit is informed by the Learning in Places socio-ecological deliberation and decision-making framework. This framework involves sensemaking across seven dimensions. These dimensions include making sense of both human and other-than-human values, needs, and behaviors across multiple temporal and spatial scales. The framework guides learners towards designing actions or making decisions for "making change in adaptive and resilient ways". (Learning in Places Collaborative, 2022)



Socio-ecological decisions are those made by individuals, communities, organizations, and institutions that are informed by and impact the natural world. These decisions are affected by relationships between humans and the natural world, what is called "nature-culture relations". Nature-culture relations often vary by culture, context, and society and affect which socio-ecological decisions are made and enacted. Understanding the connections between humans and the natural world is imperative for creating and sustaining socially and environmentally just decisions.

In this unit, students are faced with many decisions around designing and legislating vehicle safety. In thinking about these decisions, students are asked to consider the needs of humans, but also more-than-humans (animals, the environment), starting in Lesson 1. They consider human driving behavior (seat belts, distracted driving) as a factor in engineering design thinking and across time in Lessons 1-3, Lesson 7, and again in Lesson 13. They wonder about whose safety is being prioritized and consider the ethical implications of various trade-offs in Lessons 11-14 as they wrestle with the science and societal influences on "should" questions and design solutions. Built into their Engineering Progress Trackers throughout the unit are questions about how design solutions might affect some people (or other-than-humans) differently than others, leading them to consider issues of power and historicity more closely in Lesson 13.

For more about socio-ecological deliberation and decision making, please visit http://learninginplaces.org/.

Text and image courtesy of Learning in Places Collaborative. (2021). "Ethical Deliberation and Decision-Making in Socio-Ecological Systems Framework." Learning in Places website. http://learninginplaces.org/frameworks/ethical-deliberation-and-decision-making-in-socio-ecological-systems-framework/.

Guidance for Developing Your Personal Glossaries

This unit refers to two categories of academic language (i.e., vocabulary). Most often in this unit, students will have experiences with and discussions about science ideas before they know the specific vocabulary word that names that idea. After students have developed a deep understanding of a science idea through these experiences, and sometimes because they are looking for a more efficient way to express that idea, they have co-developed that definition and can add the specific term to a personal glossary at the back of their notebook. These "definitions we co-develop" should be recorded using the students' own words whenever possible. On the other hand, "definitions we encounter" are "given" to students in the course of a reading, video, or other activity, often with a definition clearly stated in the text. Sometimes, definitions we encounter are helpful just in that lesson and need not be recorded in students' personal glossaries. However, if a word we encounter will be frequently referred to throughout the unit, it should be added.

It is best for students if you create consensus definitions in the moment, using phrases and pictorial representations that the class develops together as they discuss their experiences in the lesson. When they co-create the meaning of the word, students "own" the word--it honors their use of language and connects their specific experiences to the vocabulary of science beyond their classroom. It is especially important for emergent multilingual students to have a reference for this important vocabulary, which includes an accessible definition and visual support. Sometimes defining a word is a challenge. The *OpenSciEd Teacher Handbook: High School Science* provides a suggested definition for each term to support you in helping your class develop a student-friendly definition that is also scientifically accurate.

The definitions we co-develop and encounter in this unit are listed in this document and in each lesson to help prepare and to avoid introducing a word before students have earned it. They are not intended as a vocabulary list for students to study before a lesson, as that would undermine the authentic and lasting connection students can make with these words when they are allowed to experience them first as ideas they're trying to figure out.

Lesson	Words and equations with meanings we co-construct	Words and equations with meanings we encounter
L1		
L2	reaction time, braking distance, reaction distance	*distance = speed * time,* delta (Δ)
L3	constraints	collision avoidance system, following distance
L4	$\Delta t = (m * \Delta\ speed)/F$	braking force
L5	acceleration, $a = F/m$, $F = m*a$	
L6	velocity, $m_A*\Delta v_A + m_B*\Delta v_B = 0$, momentum	inelastic collision, elastic collision, magnitude
L7		
L8		
L9	$F*\Delta t = m*\Delta v$	peak force, crash test dummy, accelerometer
L10		rigidity, crumple zone
L11		
L12		trade-off, limitations
L13		
L14		
L15		

ASSESSMENT SYSTEM OVERVIEW

Each OpenSciEd unit includes an assessment system that offers many opportunities for different types of assessments throughout the lessons, including pre-assessment, formative assessment, summative assessment, and student self assessment. Formative assessments are embedded and called out directly in the lesson plans. Please look for the “Assessment Icon” in the teacher support boxes to identify places for assessments. In addition, the table below outlines where each type of assessment can be found in the unit.

Overall Unit Assessment

When	Assessment and Scoring Guidance	Purpose of Assessment
Lesson 1	Initial models Driving Question Board	**Pre-Assessment** The student work in Lesson 1 available for assessment should be considered a pre-assessment. It is an opportunity to learn more about the ideas your students bring to this unit. Revealing these ideas early on can help you be more strategic in how to build from and leverage student ideas across the unit. The initial model developed on day 1 of Lesson 1 is a good opportunity to pre-assess student understanding of forces and collision mechanics. The Driving Question Board is another opportunity for pre-assessment. Reinforce for students to generate open-ended questions, such as” how” and “why” questions, and to post to the board. However, any questions students share, even if they are close-ended questions, can be valuable. Make note of any close-ended questions and use navigation time throughout the unit to have your students practice turning these questions into open-ended questions when they relate to the investigations underway.
Lesson 4	*Braking Variables Predictions* *Braking Variables Predictions Key*	**Formative** At the beginning of Lesson 4, students use what they know so far in conjunction with their prior knowledge about forces to make predictions about how changing variables will affect braking time. They use speed versus time graphs to do this. This builds off of the work they have done with graphs in Lessons 2 and 3 and leads towards continued use in Lessons 6, 7, 10, and 11. This is a good moment to see where students are struggling with representing their claims in graphs and to provide additional support if needed before they engage in supporting claims with graphs on the *Braking Exit Ticket* in Lesson 4 and in later lessons.

Lesson 5	L5 Electronic Exit Ticket *L5 Electronic Exit Ticket Key*	**Summative** This Electronic Exit Ticket addresses 3-D elements associated with the lesson-level performance expectations (LLPEs) for Lesson 5, which is a putting-the-pieces-together routine for the first part of the first lesson set, on avoiding collisions. This assessment is designed to make it easy for you to gather information about where students are still struggling to put the pieces together before moving on to analyzing collisions.
Lesson 6	*Different Momentum Cases* *Momentum Self-Assessment Key*	**Student Self-Assessment** At the end of Lesson 6, students get the chance to practice using the math models associated with momentum conservation to explain and predict a series of collisions. This assessment and the self-assessment key that students use to score themselves at the start of Lesson 7 can be used to get a sense of how comfortable students feel with the math in the unit and identify areas where they might need more support before the first transfer task in Lesson 7.
Lesson 7	*Bus Collision Assessment* *Bus Collision Key*	**Summative Mid-Unit Transfer Task** Students complete a transfer task at the start of Lesson 7. In this assessment, students get a chance to use what they have figured out about momentum conservation to analyze and explain data about bus collisions. A key is provided to support the scoring of this task. The ideas, crosscutting concepts, and practices students engage with as part of completing this assessment can be found at the top of the scoring guidance (key). The scoring on this assessment represents our recommendation for how to weigh questions. Please use scoring that works for your class and your requirements. We strongly recommend that you encourage students to use their notebook as a resource for completing all assessments. The performance expectation being assessed in this task is: **HS-PS2-2** Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system.
Lesson 9	*Comparing Three Speeds* *Comparing Speeds Key*	**Formative** In this lesson students develop an explanation for why designing vehicles with two safety features together improves survivability and why survivability changes in collisions at different speeds with the same safety features. This assessment gauges students' ability to chain together evidence from graphs (the results from a simulation) and relationships predicted by Newton's second law and the resulting chain of cause and effect among peak forces experienced by the body, deformation, and likelihood of injury. Use it to gauge students' application of both scientific ideas and evidence in their construction of scientific explanations.
Lesson 10	*Design Solution Comparison*	**Formative**

	Design Solution Comparison Key	In this lesson, students design and test crumple zones. This assessment is used to gauge how well they grasp the key ideas after this activity. Use it to see if students are recognizing that less-rigid and longer crumple zone designs are safer. Knowing this will help inform your approach to Lesson 11 when they will develop support for these claims using simulation data.
Lesson 11	*Survivability versus Length* *Survivability versus Length Key*	**Summative** This lesson wraps up the arcs of students engaging in analyzing and interpreting data and using mathematical and computational thinking, specifically with graphs. In this assessment opportunity, students analyze multiple graphs and use their analyses to develop and support a claim about how crumple zone length can be designed to increase safety during a vehicle collision. The specific ideas, crosscutting concepts, and practices students engage with as part of completing this assessment can be found in the scoring guidance (key) along with leveled example student responses.
Lesson 12	Lesson 12 Electronic Exit Ticket *L12 Electronic Exit Ticket Key*	**Summative** This Electronic Exit Ticket addresses 3-D elements associated with the lesson-level performance expectations (LLPEs) for Lesson 12, which is a problematize and putting-the-pieces-together routine for the second lesson set on how vehicles are designed to keep people safe. This assessment is designed to make it easy for you to gather information about where students are still struggling to put the pieces together before moving on to further analyzing and comparing arguments in the third lesson set.
Lessons 12-14	Argumentation Tool See these documents: *Science-Ideas Argument Comparison* *Societal-Impacts Argument Comparison* *Argument Comparison Keys* *Argument Comparison Tool* *Lift Kit Argument* *Weight Limit Argument* *Public Transportation Argument* *Scaffolded Argument Tool*	**Formative** Students use a scaffold that can be assessed using individual keys provided in each lesson. This scaffold allows students to compare across explanations or design solutions and make an argument for one based on evidence and/or trade-offs and constraints. In Lesson 12 students are introduced to the tool as a whole class. In Lesson 13 they use it in groups. In Lesson 14 they apply it more abstractly to design solutions in their projects. For the projects in Lesson 14, an optional scaffold is provided for students who still need more-concrete support. This tool is also embedded in the Lesson 15 transfer task described below.

Lesson 14	Community Design Solution Project see: *Design Challenge Organizer* *Design Challenge Organizer Key*	**Summative Culminating Engineering Task** In Lesson 14, students get a chance to research an issue relevant to their community and plan and implement a Community Design Solution. Some examples of Design Solutions might be the following: • Producing an information pamphlet for students who drive, explaining the physics of why driving distracted can endanger the lives of others • Writing a letter to the city council advocating for a lower speed limit on a main road in the community • Writing a letter to a local politician encouraging them to introduce a bill that subsidizes low-income families who drive a car without airbags to purchase a vehicle with airbags • Making posters to hang in the community, encouraging everyone to purchase smaller vehicles to reduce the impact of large vehicles on passenger safety • Mapping the public transit options for students to get to school and demonstrating the physics of why taking the bus can be safer than driving While the example culminating tasks are all in the format of presentations, students' products will look very different depending on the solution your students choose. Support your students with verbal and written feedback encouraging them to make connections to science ideas from the unit to explain the problem or why their design solution improves safety. To help students make these connections, you can point them to these resources: the Engineering Progress Tracker; the three "case studies": *Case Study #1: Electric Cars*, *Case Study #2: Our Crumple Zone Designs*, or *Case Study #3: Self-Driving Car Ethics*; the more-scaffolded *Scaffolded Argument Tool*.
Lesson 15	*Pedestrian Solutions* *Pedestrian Solutions KEY*	**Summative End-of-Unit Transfer Task** At the end of this final lesson, students will have the opportunity to demonstrate their competence with a transfer task, where they will compare two engineering design solutions. This task is robust and will take 30-45 minutes. The ideas, crosscutting concepts, and practices students engage with as part of completing this assessment can be found at the top of the scoring guidance (key). The scoring on this assessment represents our recommendation for how to weigh questions. Please use scoring that works for your class and your requirements. We strongly recommend that you encourage students to use their notebook as a resource for completing all assessments. The performance expectation being assessed in this task is: **HS-PS2-3** Apply scientific and engineering ideas to ~~design,~~ evaluate, and refine a device that minimizes the force on a macroscopic object during a collision. (SEP: 6.3; CCC: 2.3; DCI: PS2.A.3, ETS1.C.1, ETS1.A.1)

<table>
<tr><td>Embedded in each lesson</td><td>Lesson-by-Lesson Assessment Opportunities (below)</td><td>Formative Assessment
Use this document to see which parts of lessons can be used as embedded formative assessments.</td></tr>
<tr><td>Occurs in several lessons</td><td>Engineering Progress Tracker</td><td>Formative and Student Self-Assessment
Students begin keeping track of their ideas in an Engineering Progress Tracker in Lesson 3. An example entry is below:
<table>
<tr><th>Lesson #</th><th>What is the design solution?</th><th>How do science ideas explain why this solution could keep people safe?</th><th>Who does this solution protect? Who does it fail to protect, and why?</th></tr>
<tr><td>3</td><td>Speed limits</td><td>Driving faster means that your reaction distance will be longer. Speed limits prevent people from driving too fast.</td><td>This solution protects everyone by making car crashes less likely. But sometimes people don't follow the speed limit, so even if you set it people might not follow it. It is much easier for wealthier people to pay speeding tickets, so a speed limit might not matter as much for them. Also some people might live in places with different speed limits.</td></tr>
</table>
The Progress Trackers embedded in OpenSciEd units are thinking tools designed to help students keep track of important discoveries that the class makes while investigating phenomena and figure out how to prioritize and use those discoveries to develop a model to explain phenomena. It is important that what the students write in the Progress Trackers reflects their own thinking at that particular moment in time. In this way, the Progress Trackers can be used to formatively assess individual student progress or for students to assess their own understanding throughout the unit. Because the Progress Trackers are meant to be a thinking tool for students, we strongly suggest it is not collected for a summative "grade" other than for completion.

In this unit, students add to their Engineering Progress Tracker in Lessons 3, 5, 9, and 11 and use it as a reference in Lessons 7, 12, and 14. Examples of models and ideas that students may include in this tracker are embedded in these lessons and occasionally in the accompanying keys.</td></tr>
<tr><td>Anytime after a discussion</td><td>Student Self-Assessment Discussion Rubric</td><td>Student Self-Assessment
This resource is available in the OpenSciEd Teacher Handbook: High School Science. The student self-assessment discussion rubric can be used anytime after a discussion to help students reflect on their participation in the class that day. Choose to use this at least once a week or once every other week. Initially, you might give students ideas for what they can try to improve for the next</td></tr>
</table>

		time, such as sentence starters for discussions. As they gain practice and proficiency with discussions, ask for their ideas about how the whole-class and small-group discussions can be more productive.
After students complete substantial meaningful work	Peer Feedback Facilitation: A Guide	**Additional Guidance for Interpreting and Being Responsive to Assessments** This resource is available in the *OpenSciEd Teacher Handbook: High School Science*. Use this to help make decisions about how to be responsive to the performance of your class as a whole on an assessment task. **Peer Feedback** This resource is available in the *OpenSciEd Teacher Handbook: High School Science*.. There will be times in your classroom when facilitating students to give each other feedback will be very valuable for their three-dimensional learning and for learning to give and receive feedback. We suggest that peer review happen at least two times per unit. This document is designed to give you options for how to support this in your classroom. It also includes student-facing materials to support giving and receiving feedback, along with self-assessment rubrics in which students can reflect on their experience with the process. Peer feedback is most useful when there are complex and diverse ideas visible in student work and not all work is the same. Student models or explanations are good opportunities to use a peer feedback protocol. They do not need to be final pieces of student work; rather, peer feedback will be more valuable to students if they have time to revise after receiving it. This should be a formative rather than summative type of assessment. It is also necessary for students to have experience with past investigations, observations, and activities in which they can use these experiences as evidence for the feedback they give.

For more information about the OpenSciEd approach to assessment and general program rubrics, visit the OpenSciEd Teacher Handbook.

Lesson-by-Lesson Assessment Opportunities

Every OpenSciEd lesson includes one or more lesson-level performance expectations (LLPEs). The structure of every LLPE is designed to be a three-dimensional learning, combining elements of science and engineering practices, disciplinary core ideas and cross cutting concepts. The font used in the LLPE indicates the source/alignment of each piece of the text used in the statement as it relates to the NGSS dimensions: alignment to Science and Engineering Practice(s), alignment to Cross-Cutting Concept(s), and alignment to the Disciplinary Core Ideas.

The table below summarizes opportunities in each lesson for assessing every lesson-level performance expectation (LLPE). Examples of these opportunities include student handouts, home learning assignments, progress trackers, or student discussions. Most LLPEs are recommended as potential formative assessments. Assessing every LLPE listed can be logistically difficult. Strategically picking which LLPEs to assess and how to provide timely and informative feedback to students on their progress toward meeting these is left to the teacher's discretion.

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance

Lesson 1	1.A Ask questions about patterns in vehicle safety over time that we have identified using empirical data and about factors that might have affected them (such as driver distraction, safety features, vehicle mass, and vehicle velocity). (SEP: 1.1; CCC: 1.5; DCI: PS2.A, ETS1.A.2) 1.B Develop a model of a vehicle-driver system that includes safety components designed to alter the physics of a collision in order to predict the impact of these components on traffic safety statistics. (SEP: 2.6; CCC: 2.3; DCI: PS2.A, ETS1.A.2)	**1.A When to check for understanding:** When students develop the Driving Question Board. **What to look for/listen for in the moment:** Look for students to do the following: ● Develop questions about how factors such as distracted driving, road safety, or vehicle design solutions (like seat belts, airbags, or automation) might affect collision outcomes. (SEP: 1.1, DCI: ETS1.A.2) ● Connect questions to specific patterns revealed in the empirical data. (CCC: 1.5) ● Ask questions about how changes in mass and velocity, among other variables, affect the outcomes of a collision (note that students will likely **not** use the appropriate scientific terminology at this point, and that is fine). (DCI: PS2.A.1) **1.B When to check for understanding:** When students model to explain how or why a factor might affect the outcome of a vehicle collision and how this could be connected to the patterns we identified. **What to look for/listen for in the moment:** Look for students to do the following: ● Identify and model safety features designed to change the physics of a vehicle collision (do not expect students to be able to explain **how** these features affect the collision yet). (CCC: 2.3) ● Use ideas about motion, size, speed, or forces to make connections between how the design solutions and other factors they model might affect specific trends they see in the graphs (making a prediction). (SEP: 2.6; DCI: PS2.A.1, ETS1.A.2)
Lesson 2	**2.A** Analyze videos of two drivers encountering a sudden obstacle by graphing change in distance over time in order to describe and predict how being distracted can affect the risk of a potential vehicle collision. (SEP: 4.1; CCC: 1.4, 7.2; DCI: ETS1.A.2)	**2.A.1 When to check for understanding:** On day 2, when students consider the meaning of the slope of their graphs. **What to look for/listen for in the moment:** ● (prompt A) When the slope is steeper, the object is moving faster. (CCC: 1.4, 7.2) ● (prompt B) When the slope is zero, the object isn't moving. (CCC: 1.4, 7.2) ● (prompt C) When the slope is negative, the object is moving backward. (CCC: 1.4, 7.2) **2.A.2 When to check for understanding:** On day 2, when students debrief after analyzing the second video (distracted driver) on their own. **What to look for/listen for in the moment:** Look for students to correctly analyze the distracted driver video by graphing position versus time for clip #2 as shown in the example. (SEP: 4.1; CCC: 1.4, 7.2) Then in the debrief, listen for them to explain that: ● The graphs reveal a pattern for the distracted driver that looks different than the pattern in the undistracted driver

		data. (CCC: 1.4) • The graphs show that the distracted driver moved farther during the time between the appearance of the obstacle and the brake lights. (CCC: 7.2) • This suggests that being distracted increases the time it takes to react to something (reaction time). (DCI: ETS1.A.2) • A longer reaction time means that the car travels farther before braking (reaction distance) and is more likely to hit the obstacle. (SEP: 4.1)
Lesson 3	**3.A** Use a mathematical model (distance = speed * time) to generate data about how speed affects reaction distance based on average reaction times for distracted versus undistracted drivers. (SEP: 5.2; CCC: 3.5; DCI: ETS1.A.2) **3.B** Use student-generated evidence from video data and mathematical modeling to make a claim about the problem of distracted driving. Identify design solutions that could have the effect of decreasing reaction distances to prevent a collision in the event of a sudden obstacle, and identify a range of constraints associated with each solution. (SEP: 6.5; CCC: 2.3; DCI: ETS1.A.2, ETS1.B.1)	**3.A When to check for understanding:** Move around the classroom while students work on the handout. Collect the handout at the end of class in order to formatively assess and provide individual feedback. **What to look for/listen for in the moment:** • Look for students to have correctly applied the equation most of the time, and flag solutions that don't make sense. (SEP: 5.2) • Look for somewhat straight lines in the graphs as in the example in the *Teacher Guide*. (SEP: 5.2) • Look for students to describe how in both scenarios reaction distance goes up with speed and thus increases the probability of a collision in the event of an obstacle. (CCC: 3.5; DCI: ETS1.A.2) • Look for students to describe how in the distracted driver scenario the reaction distance goes up faster with speed, making it even more likely that there will be a collision in the event of an obstacle. (CCC: 3.5; DCI: ETS1.A.2) **3.B When to check for understanding:** Collect the *Engineering Progress Tracker* at the start of the next class. An example of what this might look like is in the *Teacher Guide*. **What to look for/listen for in the moment:** Look for students to do the following: • Complete at least one additional design solution row addressing the problem of distracted driving. Ideally students will identify two or three. (DCI: ETS1.A.2) • Connect each new design solution to a claim (or claims) that we made during the lesson based on evidence about change over time, such as speed, reaction time, and reaction distance. (SEP: 6.5; CCC: 2.3) • Highlight at least one reasonable constraint for each new design solution. (DCI: ETS1.B.1) • Respectfully consider how the constraint might affect some people, animals, and environments differently than others.
Lesson 4	**4.A** Use mathematical representations of the relationship between mass, initial	**4.A.1 When to check for understanding:** On day 1, when students complete the *Braking Variables Predictions* handout.

	speed, force, and stopping time and algebraic thinking to make a quantitative claim that predicts how much changing the braking force will affect the time it takes a vehicle to stop. (SEP: 5.2, 6.1; CCC: 3.5; DCI: PS2.A.1) **4.B** Use simple limit cases and algebraic thinking to determine whether curve fits of data on the relationship between force, mass, initial speed, and stopping time make sense compared to what is known about the real world (SEP: 5.4; CCC: 3.5; DCI: PS2.A.1)	**What to look for/listen for in the moment:** Students should use the speed-time graph to predict how increasing the braking force or decreasing the mass and initial velocity of the vehicle will result in a steeper negative slope (faster decrease in speed), whereas increasing the mass and initial speed or decreasing the braking force will lead to a less steep slope (slower decrease in speed). (SEP: 5.2, 6.1; CCC: 3.5; DCI: PS2.A.1) See the *Braking Variables Predictions Key* for sample responses. **4.A.2 When to check for understanding:** At the end of day 3, when students complete the *Braking Exit Ticket*. **What to look for/listen for in the moment:** Students should use the speed-time graph to claim that tripling the braking force will reduce the stopping time to one third the original stopping time, and they explain this using the equation relating force, mass, initial speed, and stopping time. (SEP: 5.2, 6.1; CCC: 3.5; DCI: PS2.A.1) **4.B When to check for understanding:** On day 2, when students complete the Discussion Questions section of *Braking Investigation*. **What to look for/listen for in the moment:** Students' answers should include: ● When the force is too large, the stopping time will be very small. (SEP: 5.4; CCC: 3.5; DCI: PS2.A.1) ● When the force is too small, the stopping time will be very long. (SEP: 5.4; CCC: 3.5; DCI: PS2.A.1) **or** ● When the mass/initial speed is too large, the stopping time will be very long. (SEP: 5.4; CCC: 3.5; DCI: PS2.A.1) ● When the mass/initial speed is too small, the stopping time will be very long. (SEP: 5.4; CCC: 3.5; DCI: PS2.A.1) **and** ● reasoning connecting their answers to experiences of the real world (SEP: 5.4; CCC: 3.5) ● reasoning connecting their predictions to the curve fit they selected for their data
Lesson 5	**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.A.1 When to check for understanding:** As students work in pairs to complete the *Wet Road Stopping* handout (**slide I**). **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 with a delayed braking force being applied in the yellow light region, resulting in 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

	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)	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 an 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 their notice of the yellow light (SEP: 2.6; CCC: 2.3; DCI: PS2.A.1) **5.A.2 When to check for understanding:** As students discuss *Wet Road Stopping* (**slide J**). **What to look for/listen for in the moment**: ● 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 the road conditions (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 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) **5.B When to check for understanding:** During the Electronic Exit Ticket, administered at the end of class (**slide M**). **What to look for/listen for in the moment:** See the *L5 Electronic Exit Ticket Key*.

Lesson 6	**6.A** Analyze data collected from speed and force sensors and use multiple mathematical representations to describe and make claims about the patterns that show the relationship between different variables in a collision (force applied to a vehicle, mass, and change in velocity of a vehicle). (SEP: 5.2; CCC: 1.4; DCI: PS2.A.1) **6.B** Apply techniques of algebra to solve for an unknown initial condition or outcome of a collision in a two-object system using a version of Newton's second law, arranged to describe conservation of momentum. (SEP: 5.3; CCC: 4.2; DCI: PS2.A.2)	**6.A.1 When to check for understanding:** On day 1, when students individually annotate their graph on the *Collision A and B Predictions* handout (**slide G**). **What to look for/listen for in the moment:** ● Students draw a predicted graph of velocity versus time for a collision that includes two flat regions, one in the left part of the graph (velocity close to 0.4 m/s) and another in the right part (velocity close to -0.25 m/s); and a region between these that is close to 0.25 seconds in duration. (SEP: 5.2) ● Students identify Δv on their graph with a downward arrow extending from the *y*-value of the left flat region to the *y*-value of the right flat region and a predicted value close to -0.65 m/s. (CCC: 1.4) **6.A.2 When to check for understanding:** On day 1, as the class discusses patterns noticed in the graphs on the *Collisions D-F Forces* handout (**slide R**). **What to look for/listen for in the moment:** Students use features of the graphs to make claims (SEP: 5.2) such as: ● The forces on each cart are opposite in value (direction) and equal in magnitude at every point in time. (CCC: 1.4; DCI: PS2.A.1) ● The forces reach a higher magnitude in collision D, which has more total mass in the system than the others. (CCC: 1.4; DCI: PS2.A.1) ● The forces reach a comparable magnitude in collisions E and F, which have the same total mass in the system. (CCC: 1.4; DCI: PS2.A.1) **6.A.3 When to check for understanding:** On day 2, as students analyze and annotate *Collisions D-F Velocities* (**slide W**) and discuss the related patterns as a class (**slide X**). **What to look for/listen for in the moment:** Students use features of the graphs to make claims (SEP: 5.2) such as: ● When masses are equal in collision D, velocity changes are very nearly equal in magnitude but opposite in direction. (CCC: 1.4; DCI: PS2.A.1) ● When one mass is twice as big as the other (in collisions E and F), the magnitude of the velocity change of the smaller-mass cart is approximately twice as large as that of the other cart. (CCC: 1.4; DCI: PS2.A.1) **6.B.1** When to check for understanding: On day 2, as student pairs document and share their whiteboard work related to their experimental results (**slide FF**), and then use it to argue that our equation predicts outcomes across all collisions tested (**slide GG**).

		What to look for/listen for in the moment:
		● writing a symbolic equation ($m_1 * \Delta v_1 + m_2 * \Delta v_2 = 0$) in a system of two objects (CCC: 4.2; DCI: PS2.A.2)
		● substituting known values into all the variables in the equation (SEP: 5.3)
		● one or more steps to keep track of products and/or sums of the resulting values on each side of the equation (SEP: 5.3)
		● both sides of the equation equaling zero (SEP: 5.3)
		● interpreting this equality as showing the applicability of our equation to predicting the outcome of this collision (CCC: 4.2)
		
		6.B.2 When to check for understanding: On day 3, as students work on one scenario on *Collision A and B Predictions* in class (**slide NN**) and the remaining scenarios for home learning and the related *Motion: Collision B* (**slide PP**).
		
		What to look for/listen for in the moment: For specific responses to individual answers, see *Momentum Self-Assessment Key*. Look for the following across student responses:
		● Questions 1-4:
		    a. defining the parts of the system that are changing motion using a diagram (CCC: 4.2)
		● Questions 1-3:
		    a. writing a symbolic equation for momentum conservation in a system of two objects (SEP: 5.3; CCC: 4.2; DCI: PS2.A.2)
		    b. substitution of known values into all the variables in the equation (SEP: 5.3)
		    c. one or more steps to keep track of products and/or sums of the resulting values on each side of the equation (SEP: 5.3)
		    d. a correct predicted value (DCI: PS2.A.2)
		● Question 4:
		    a. describing how changes in velocity for the larger vehicle in all four graphs (4b, 4c, 4d, 4e) correspond to the outcome described for that vehicle
		    b. describing how velocity changes predicted for the smaller vehicle are correctly represented in graphs 4b and 4d but not in graphs 4a and 4c (DCI: PS2.A.2)

Lesson 7	**7.A** Evaluate a series of explanations for what might be causing driving to get more dangerous over time, including the impact of new technology, by looking for	**7.A When to check for understanding:** On day 2, while students compare data to the trend lines chart from Lesson 1. **What to look for/listen for in the moment:** ● Students are evaluating the explanations they proposed in Lesson 1 for what might have caused changes in vehicle

	correlations in new data, recognizing that this does not prove causality. (SEP: 4.5; CCC: 2.1; DCI: ETS2.B.3) **Transfer Task PE: HS-PS2-2** Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system. (SEP: 5.2; CCC: 4.2; DCI: PS2.A.2, PS2.A.3)	safety trends in light of additional data. (SEP: 4.5, CCC: 2.1) ● Students are looking for correlations, but when challenged they can articulate why they should not make causal claims. (CCC: 2.1) ● Students are noting the impact of rapid adoption of smartphones after 2010 on these trends. (DCI: ETS2.B.3) **Transfer Task:** On day 1 administer the *Bus Collision Assessment*. This assessment is not building toward a lesson-level performance expectation (LLPE). It is designed to assess a performance expectation from the NGSS (HS-PS2-2). See the accompanying *Bus Collision Key* for details.
Lesson 8	**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)	**8.A.1 When to check for understanding:** During the whole-class construction of the timelines using the animations **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) **8.A.2 When to check for understanding:** When students compare across the multiple timelines on **slide M** **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)

Lesson 9	**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)	**9.A.1 When to check for understanding:** On day 2, when students are analyzing data from their simulation investigation and *Six Optimization Attempts*
		
		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)
		
		9.A.2 When to check for understanding: On day 2, in students' response to the four prompts on *Comparing Three Speeds*

		What to look for/listen for in the moment: See the *Comparing Speeds Key*.
Lesson 10	10.A Design and evaluate a solution to reduce the peak force (function/effect) in a collision through the choice and modification of type of material and the structure (causes) used in building, testing, and comparing physical models of alternate front-end crumple-zones. (SEP: 6.5; DCI: ETS1.B.2, ETS1.A.1; CCC: 2.3, 6.2) 10.B Analyze force and motion graphs of cart collisions with differing front-end crumple zone designs as well as driver survivability data in order to identify patterns in peak forces, time of impact, and design characteristics of the crumple zone (amount of deformation, thickness of material, and structure/length). (SEP: 4.6, 5.2; DCI: ETS1.A.1, PS2.A.1; CCC: 2.3, 6.2)	**10.A.1 When to check for understanding:** On day 1, when the class discusses the goal for the design activity (**slide I**). **What to look for/listen for in the moment:** ● Students identify the problem relating the structure of crumple zones and how/why they affect passenger safety. (DCI: ETS1.A.1; CCC: 2.3, 6.2) ● Students identify the criteria we will use to evaluate alternative solutions (cause) that include one or more of the following effects: peak force reduction and/or increase in length of time forces are applied. (DCI: ETS1.A.1; CCC: 2.3) ● Students evaluate the results from all of our physical models to help us better understand how and/or why crumple zones work and are designed to reduce the peak force. (SEP: 6.5; DCI: ETS1.B.2, ETS1.A.1; CCC: 2.3, 6.2) See the *Design Solution Comparison Key* for sample responses. **10.A.2 When to check for understanding:** On day 1, when you collect student responses to Part B on the *Design Solution Comparison* (**slide L**). **What to look for/listen for in the moment:** ● Students design physical crumple zone models that are made to collapse in order to reduce the peak force. (SEP: 6.5; DCI: ETS1.B.2, ETS1.A.1; CCC: 2.3, 6.2) ● Students evaluate their designs using the data from the graphs as well as the observational data for whether (or how much) the peak force is reduced (function/effect) in each of their physical models. (SEP: 6.5; DCI: ETS1.B.2, ETS1.A.1; CCC: 6.2) See the *Design Solution Comparison Key* for sample responses. **10.B.1 When to check for understanding:** On day 2, in student responses to Part C on the *Design Solution Comparison* (**slide N**). **What to look for/listen for in the moment:** Look for students to do the following: ● Students analyze force and motion graphs of cart collisions with differing front-end crumple zone designs in order to identify the designs with the lowest peak force (function/effect). (SEP: 4.6, 5.2; DCI: PS2.A.1; CCC: 2.3, 6.2)

		• Students analyze force and motion graphs of cart collisions with differing front-end crumple zone designs in order to relate lower peak forces (function/effect) to longer time of collision (cause). (SEP: 5.2; DCI: ETS1.A.1, PS2.A.1; CCC: 2.3) • Students identify patterns in design characteristics of the crumple zone (amount of deformation, thickness of material, and structure/length) that led to the lowest peak force. (SEP: 4.6; DCI: ETS1.A.1, PS2.A.1; CCC: 2.3, 6.2) **10.B.2 When to check for understanding:** On day 2, when students identify the length and rigidity combinations they predict would be safer for the driver (**slide R**). **What to look for/listen for in the moment:** Listen for students to connect the design characteristics of the crumple zone in the simulation (thickness of material and structure/length) (cause) with driver survivability data (effect). (SEP: 4.6; DCI: ETS1.A.1; CCC: 2.3, 6.2)

Lesson 11	**11.A** Analyze patterns in graphical data from simulated collisions to make and support scientific claims about how the rigidity and the length characteristics of the crumple zone of a vehicle can be designed to optimize safety during a collision. (SEP: 4.6, 5.2; CCC: 1.3, 2.3; DCI: PS2.A.1)	**11.A.1 When to check for understanding:** On day 1, when students complete part 1 on *Investigating Rigidity*, they will draft an initial claim about how the force acting on the dummy during a collision changes as the crumple zone rigidity increases.
		
		What to look for/listen for in the moment: Look for students to start to do the following:
		• Support the claim by describing the relationship between crumple zone rigidity and the forces acting on the dummy. (SEP: 5.2; DCI: PS2.A.1)
		    • One example is: As the crumple zone rigidity increases, the peak force on the dummy increases and the time the force is acting on the dummy decreases.
		
		11.A.2 When to check for understanding: On day 1, when students complete parts 2 and 3 on *Investigating Rigidity* to analyze the graphs and explain how increasing the rigidity of the crumple zone affects survivability in a collision
		
		What to look for/listen for in the moment
		• Use the graphs to connect the increased time for the vehicle to stop to the increased time for the crash test dummy to stop. (SEP: 4.6; DCI: PS2.A.1)
		• Use the patterns on the graphs to identify that differences in time and force are relevant to the impact of rigidity on the changes in velocity. (SEP: 4.6; CCC: 1.3; DCI: PS2.A.1)
		• Make a claim that connects the design characteristic of rigidity for crumple zones and safety in a collision. (SEP: 4.6; CCC: 2.3; DCI: PS2.A.1)
		    • One example is: The design with the lowest rigidity will be the safest.
		• Support the claim by describing the relationship between crumple zone rigidity, the changes in velocity of the

		vehicle and dummy, and the forces acting on the vehicle and dummy. (SEP: 5.2; DCI: PS2.A.1)
		    ● One example is: As the crumple zone rigidity decreases, the peak force on the car and the dummy decreases and the time the force is acting on the car and dummy increases. As the crumple zone rigidity decreases, the velocity of the vehicle and the crash test dummy changes over a longer time period. These changes in force and velocity increase the likelihood of survival.
		● Use patterns in the graphs to support their claim about improving safety. (SEP: 4.6, 5.2; CCC: 1.3, 2.3)
		    ● One example is: When the rigidity was lower, the shape of the force vs. time graph of the car and the dummy were more spread out on the time axis and less tall on the force axis.
		
		11.A.3 When to check for understanding: On day 2, when students complete their claim on *Survivability versus Length* to explain why the crumple zone length can help in the design of vehicles that makes driving safer for everyone.
		
		What to look for/listen for in the moment
		● Use the graphs to connect the increased time for the vehicle to stop to the increased time for the crash test dummy to stop. (SEP: 4.6; DCI: PS2.A.1)
		● Use the patterns in the graphs to identify that differences in time and force are relevant to the impact of length of crumple zone on the changes in velocity. (SEP: 4.6; CCC: 1.3; DCI: PS2.A.1)
		● Make a claim that connects the design characteristic of the crumple zone length and safety in a collision. (SEP: 4.6; CCC: 2.3; DCI: PS2.A.1)
		● Support the claim by describing the relationship between crumple zone length, the changes in velocity of the vehicle and dummy, and the forces acting on the vehicle and dummy. (SEP: 5.2; DCI: PS2.A.1)
		● Use patterns in the graphs to support their claim about improving safety. (SEP: 4.6, 5.2; CCC: 1.3, 2.3)
		
		See *Survivability versus Length Key* for leveled example student responses and suggested supports.

Lesson 12	**12.A** Evaluate and compare competing arguments related to policy decisions to change speed limits within driving systems based on scientific knowledge and principles, prioritized criteria, unequal effects, limitations (e.g., tradeoffs), constraints, and societal and ethical impacts. (SEP: 7.1; CCC: 2.4; DCI: ETS1.B.1)	**12.A.1 When to check for understanding:** After day 1, review student responses to the final questions on *Science-Ideas Argument Comparison*. **What to look for/listen for in the moment:** Look for students to do the following: ● Cite key science ideas and data presented from written arguments and their investigation data which support the claims of the authors about the effects of a speed limit change. (SEP: 7.1; CCC: 2.4) ● Compare two arguments and judge which one has the strongest evidence from a science perspective while considering criteria and constraints related to unequal effects of speed limits. (SEP: 7.1; CCC: 2.4; DCI: ETS1.B.1) See *Argument Comparison Keys* for example student responses.

	12.B Identify multiple simple criteria in the complex vehicle-driver system that combine to determine the vehicle safety in collisions and organize the scientific ideas that explain how these criteria can be used to design safer vehicle-driver systems. Then apply ideas about forces and changes in motion to explain how prioritizing certain criteria could create a safer design. (SEP: 6.3; CCC: 2.3; DCI: PS2.A.1, ETS1.C.1)	**12.A.2 When to check for understanding:** After day 3, review student responses to the final questions on *Societal-Impacts Argument Comparison*.
		
		What to look for/listen for in the moment: Look for students to do the following:
		● Compare and evaluate written arguments (SEP: 7.1) based on tradeoffs, criteria, and constraints that the author has made about speed limits. (DCI: ETS1.B.1)
		● Identify possibly unequal effects of accepting the arguments on themselves and others in their community. (CCC: 2.4)
		● Identify how these factors influence their thinking about the merits of competing arguments.
		
		12.B.1 When to check for understanding: On day 2, when students are constructing the Gotta-Have-It Checklist.
		
		What to look for/listen for in the moment: Look for students to do the following:
		● Identify multiple criteria and design solutions within vehicle systems that can be designed to affect safety. (CCC: 2.3; DCI: ETS1.C.1) For example:
		    ● distraction (L2-3)
		    ● speed or velocity (many lessons)
		    ● mass of vehicle (L4, L6, L11)
		    ● braking force (L4)
		    ● seat belts (L9)
		    ● airbags (L9)
		    ● crumple zone rigidity (L10-11)
		    ● crumple zone length (L10-11)
		● Connect the relationships between force and changes in motion to how these criteria and design solutions can be designed to increase safety. (SEP: 6.3; CCC: 2.3; DCI: PS2.A.1)
		
		12.B.2 When to check for understanding: On day 2, when students are constructing explanations.
		
		What to look for/listen for in the moment: Look for students to do the following:
		● Apply the relationships between force and changes in motion and the relationships between different parts of the vehicle system to construct an explanation about how one criterion or design solution can specifically be designed to increase safety. (SEP: 6.3; CCC: 2.3; DCI: PS2.A.1)

		• Identify possible unanticipated effects and/or tradeoffs of changing one or more of these criteria and how this may impact how criteria should or shouldn't be prioritized. (SEP: 6.3; DCI: ETS1.C.1)
Lesson 13	**13.A** Evaluate and compare competing arguments for a design solution based on scientific knowledge and principles, prioritized criteria, limitations (e.g., tradeoffs), constraints, and societal and ethical impacts. (SEP: 7.1; DCI: ETS1.B.1; Connections to Engineering, Technology, and Applications of Science: Influence of Science, Engineering, and Technology on Society and the Natural World)	**13.A When to check for understanding:** during the Consensus Discussion around the *Argument Comparison Tool* **What to look for/listen for in the moment:** Use the detailed guidance given in the teacher references (*Lift Kit Argument*, *Weight Limit Argument*, or *Public Transportation Argument*) to assess students' argumentation related to societal and ethical impacts for the topic you have selected for your class. (SEP: 7.1; DCI: ETS1.B.1; Connections to Engineering, Technology, and Applications of Science: Influence of Science, Engineering, and Technology on Society and the Natural World)
Lesson 14	**14.A** Define a design problem within a vehicle-related system by analyzing how transportation technologies impact society to a level that requires attention or mitigation, considering the scale, proportion, and quantity at which the problem is significant. (SEP 1.8; CCC 3.1; ETS2.B.3) **14.B** Design and/or refine a solution to a problem related to vehicle safety, considering cause-effect relationships suggested or predicted by smaller-scale mechanisms within the system and prioritizing certain criteria over others to optimize the focus. (SEP 6.5; CCC 2.2; ETS1.C.1) **14.C** Use reasonable assumptions or approximations to develop a mathematical model to generate data to predict behavior	**14.A.1 When to check for understanding:** On day 1, while students are working to complete questions 1-3 on *Design Challenge Organizer* and while looking through examples of student work on question 3 after day 1. **What to look/listen for in the moment:** Look for student work in question 3 of the *Design Challenge Organizer* to • select a transportation-related design problem that includes social, technical, and/or environmental considerations and is relevant at a scale, proportion, and quantity that matters to people or things students care about. (SEP 1.8; CCC 3.1; ETS2.B.3) **14.A.2 When to check for understanding:** On day 2, while students are working to complete question 4b. **What to look/listen for in the moment:** Look for student work in question 4b of the *Design Challenge Organizer* to • describe criteria and trade-offs related to a system with interacting components--the relevant transportation-related social, technical, and/or environmental problem they chose on day 1. (SEP 1.8; CCC 3.1; ETS2.B.3) **14.B When to check for understanding:** On day 2, while students are working to complete the *Design Challenge Organizer*, specifically, students' answers for questions 4-5 **What to look/listen for in the moment:** Look for student work in the *Design Challenge Organizer* questions 4-5 to • suggest and predict cause-effect mechanisms and potential solutions relevant to the criteria of the problems they've identified and to prioritize what to focus on, since some causes will be more realistic to affect than others.

	of a design solution, analyze a system or support an explanation, and meet prioritized criteria. (SEP 2.6; CCC 4.4; ETS1.C.1)	(CCC 2.2, ETS1.C.1) ● prioritize specific criteria in their solutions, so look for them to recognize that their solution will only address some specific parts of the problem they identified. (SEP 6.5, ETS1.C.1) **14.C.1 When to check for understanding:** After day 2 while looking through students' preliminary work on question 6 on the *Design Challenge Organizer* **What to look/listen for in the moment:** At this point, students may only have a very rough idea of what sort of modeling will be helpful to them in their project. That's OK, as they will spend much more time on this next class. In the time between day 2 and day 3, look at one copy of each group's *Design Challenge Organizer* for evidence in their answer to question 6 that this group will be able to ● identify a useful category of physics models we have developed together in this unit as well as reasonable assumptions that will need to be made in approaching their design problem. (SEP 2.6; CCC 4.4) ● target their modeling on these prioritized criteria or relevant details about the solution. (ETS1.C.1) Refer to *Design Challenge Organizer Key* for detailed guidance on how to give targeted feedback. **14.C.2 When to check for understanding:** On day 3, when students are working to complete question 6 on the *Design Challenge Organizer* and finish their Final Product **What to look/listen for in the moment:** Look for students to ● use the models we have developed throughout the unit through specific, quantitative criteria within their problem or their solution. (SEP 2.6; ETS1.C.1) ● acknowledge that there are limitations to the calculations they can make in their model because of assumptions and approximations they make for the criteria focused on within their design solution. If necessary, students can make up reasonable approximations or research-related values that help support the case for their solution. (CCC 4.4; ETS1.C.1) ● focus their attention on factors related to the prioritized criteria and focus both their modeling and their solutions around these criteria. (SEP 2.6; ETS1.C.1)
Lesson 15	**15.A** Apply scientific ideas, principles, and evidence that we developed over the course of the unit related to changes in the motion of macroscopic objects to answer questions on our DQB about how the	**15.A When to check for understanding:** On day 2, when students revisit the DQB **What to look/listen for in the moment** ● Look for students to apply science ideas from the unit related to momentum, forces, and Newton's second law. (SEP: 6.3; DCI: PS2.A.1, PS2.A.2)

	safety features we had questions about may have been designed to mitigate risk. (SEP: 6.3; CCC: 2.3; DCI: PS2.A.1, PS2.A.2) **Transfer Task PE:** HS-PS2-3 Apply scientific and engineering ideas to ~~design,~~ evaluate, and refine a device that minimizes the force on a macroscopic object during a collision. (SEP: 6.3; CCC: 2.3; DCI: PS2.A.3, ETS1.C.1, ETS1.A.1)	• Look for students to explain the purpose of design features such as seat belts and airbags using those science ideas. (SEP: 6.3; CCC: 2.3) **Transfer Task:** In this lesson, you will administer *Pedestrian Solutions*. This assessment is not building toward a lesson-level performance expectation. It is designed to assess a performance expectation from the NGSS (HS-PS2-3). See the accompanying key for details.

HOME COMMUNICATION

Dear Parents, Guardians, and Caregivers,

Your child's high school physics class is starting a unit called *What can we do to make driving safer for everyone?* as part of the OpenSciEd high school science curriculum. Students will analyze data on vehicle collisions and vehicle fatalities. This unit focuses on how modern safety features and policy changes have reduced the risk of traffic fatalities, even as the number of vehicle collisions have increased due to distracted driving and risky behavior. Students will analyze statistics on vehicle collisions, analyze the motion of vehicles stopping short, and model vehicle design within collisions as part of an engineering task to reduce the chances of injury in a collision. They will also evaluate and engineer design solutions for how we can make driving safer for everyone.

We recognize that vehicle collisions can be traumatic and recalling past experiences or learning about others' experiences can be triggering. If your child or someone close to your child has sustained an injury or lost a loved one in a vehicle collision, please contact me at ____________________, if you are comfortable doing so. You can also contact a school counselor, social worker, or other mental health professional at _________________. By knowing about these experiences in advance we can be sensitive to students' needs and provide support for students if they experience any strong emotions during this unit. This support may include providing breathing exercises for students to ground themselves and/or connecting students to a mental health professional, such as a school counselor.

After a traumatic experience, adolescents will sometimes develop or intensify difficult behaviors. It is important for trusted adults to understand that these behaviors and emotions are common when children experience trauma. Students may exhibit more aggressive behaviors or become withdrawn while also experiencing periods of sadness, anger, or emotional numbness. Some students may have exacerbating conditions that also link to these behaviors. Contact a counselor if you see any of the following behaviors in your child:

- problems sleeping and/or nightmares
- changes in school performance
- truancy
- risk-taking behavior
- conflicts with peers
- new or increasing psychosomatic complaints, including stomachaches and headaches
- depression or suicidal thoughts

Being able to talk to someone who is removed from the situation is often helpful to both adults and children after a traumatic event. We recommend you engage in open, active, and caring listening to support your child. This can be done by letting your child come to you, providing a safe space for when they are ready to talk, and respecting their need to take breaks when conversing about this traumatic event and related feelings.

Mental health resources outside school include the following:

- Suicide and Crisis Lifeline: Call, text, or online chat 988 (English, Spanish, ASL)
- Substance Abuse and Mental Health Services Administration's (SAMHSA) National Helpline: 1-800-662-HELP (4357) (English and Spanish)
- National Alliance for Mental Illness Teen & Young Adult Helpline: Text "Friend" to 62640
- Local resources include: ____________________

Reach out to your child's school counselor, social worker, or mental health professional if you are concerned about trauma your child may have experienced related to a vehicle collision.

If you have any questions about the content of this unit or would like to discuss anything further, I encourage you to reach out to me at __________________.

Best,