## LESSON 1
Lesson Set 1

**Lesson Question:** 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.

### What we do and 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).

### How we represent it:

![Graph showing total crashes by year from 1995 to 2020.](image)

- 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:

- 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:

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.

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## LESSON 2
Lesson Set 1

**Lesson Question:** 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 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.
**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.](image)

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.](image)

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.

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.

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**

<table>
<thead>
<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>
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<tr>
<td><strong>LESSON 5</strong></td>
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<td><strong>Can we use mathematical models to explain differences in stopping in wet conditions?</strong></td>
<td><strong>Putting Pieces Together</strong></td>
<td><strong>We rearrange our equations to show ( a = \frac{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:</strong></td>
<td><strong>Through drivers are using more braking force in wet and rainy conditions, they are stopping later or running red lights.</strong></td>
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**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**

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<td>3 days</td>
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<tr>
<td><strong>Do our motion relationships help predict any of the interactions or outcomes in a collision?</strong></td>
<td><strong>Investigation</strong></td>
<td><strong>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:</strong></td>
<td><strong>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.</strong></td>
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**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 Set 1: What we do and figure out

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

![Diagram of a bus and a car colliding]

Data sets for factors that could potentially lead to increased injuries in collisions provide information on how the trends have changed over time.

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.
- 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.


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 8
Lesson Set 2
1 day

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

Problematizing, Investigation

![Video of a vehicle collision]

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**

**Lesson Question**

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

**Investigation**

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 $\Delta v$ is higher, peak force on the person is higher and likelihood of survivability goes down.
- Newton’s second law can be rearranged to show that $F \Delta t = m \Delta v$.

### LESSON 10
**Lesson Set 2**

**Lesson Question**

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

**Investigation**

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.

### Table: RIGIDITY and LENGTH of CRUMPLE ZONE

<table>
<thead>
<tr>
<th>RIGIDITY</th>
<th>LENGTH</th>
<th>Sample</th>
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<tbody>
<tr>
<td>Low</td>
<td>Short</td>
<td>A: 79%</td>
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<tr>
<td></td>
<td>Medium</td>
<td>B: 79%</td>
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<tr>
<td></td>
<td>Long</td>
<td>C: 79%</td>
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<tr>
<td>Medium</td>
<td>Short</td>
<td>D: 88%</td>
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<tr>
<td></td>
<td>Medium</td>
<td>E: 80%</td>
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<tr>
<td></td>
<td>Long</td>
<td>F: 79%</td>
</tr>
<tr>
<td>High</td>
<td>Short</td>
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<tr>
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<td>Long</td>
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</table>
**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  

**Phenomena or Design Problem**  
How do the rigidity and length of the crumple zone affect the safety of the occupants during a collision?  

**What we do and figure out**  
- 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.

**How we represent it**  
Images generated using CODAP (https://codap.concord.org/), developed at the Concord Consortium

**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.

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**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

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

**What we do and figure out**  
- 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.

**How we represent it**  

**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.

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

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<td><strong>LESSON 13</strong></td>
<td><strong>Lesson Set 3</strong></td>
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<tr>
<td><strong>How can we use our science ideas and societal wants and needs to evaluate arguments around design solutions?</strong></td>
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<td><strong>Investigation</strong></td>
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<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:</td>
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<td>• Science ideas alone cannot capture the whole picture related to tradeoffs, and societal impacts must be considered.</td>
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<td>• 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>
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**Argument Comparison Tool**

What is the problem these design solutions are trying to solve? We can use the Argument Comparison Tool to evaluate 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.

**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.

| **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. | |

**Solution 1: Install speed humps on Park Ave.**

We can reduce vehicle speed on Park Ave, and therefore reduce the chance of collision with a cyclist on the bike path route.

- 20 mph • 9 m/s reaction time • 0.5 s
- 9 m/s • 0.5 s • 4.5 m = 15 ft
- 9 m/s / 7 m/s = 1.3 s brake time
- 1.3 s • (9 m/s • 1.3 s) = 5.8 m
- 19 ft • 34 ft

**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.
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<td><strong>LESSON 15</strong></td>
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<td>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:</td>
<td><img src="image" alt="Equation" /></td>
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<tr>
<td>Lesson Set 3</td>
<td></td>
<td>- We can use physics and engineering ideas to evaluate the merits of two design solutions and make recommendations for improvements.</td>
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<tr>
<td>1 day</td>
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<td>- We can use our physics and engineering ideas to answer questions on our Driving Question Board.</td>
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<td>Putting Pieces Together</td>
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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