TEACHER WARNING

This lesson **addresses vehicle collisions and fatalities.**

This may evoke heightened emotional states due to related traumatic events that teachers, students, and/or their families may have experienced. Please see the unit front matter, the teacher reference associated with this lesson, and the callouts in the *Teacher Guide* for guidance around how to support social and emotional needs as you move through this unit. Never ask students to share their personal experiences unless they

Slide A

Student Content Advisory

In this lesson, we will examine the physics of vehicle collisions in detail as well as data on fatalities related to collisions.

If needed, you can use strategies from the *Student Mindfulness Resource* handout from Lesson 1.

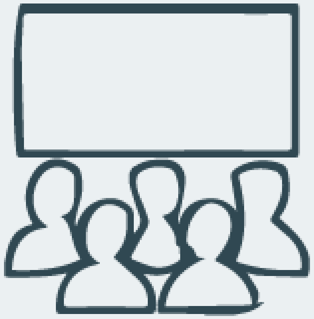
If at any point in this unit you find you need additional support, let your teacher or another trusted adult know how you are feeling.

Be aware that your teacher and/or classmates may have experienced trauma related to this topic. Approach conversations about car crashes and car safety with respect, guided by your class's Community Agreements.

Slide B

Navigate

We have looked at how to prevent a collision and at factors that affect the ability to do so. But sometimes a collision still occurs.

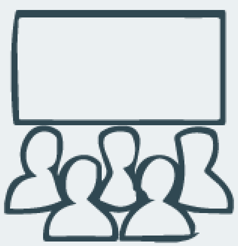


With your class

What factors did we identify in our initial consensus model that we said might affect the severity of the outcome of a collision?

Navigate

About 20% of crash fatalities are from a vehicle running into a fixed object like a tree, utility pole, or barrier.



With your class

Do we think the contact force (F) in these collisions has a similar relationship to the other 3 variables in our braking equations?

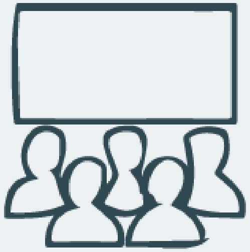
Our equations

$$\Delta t = \frac{m * \Delta speed}{F}$$

$$F = \frac{m * \Delta speed}{\Delta t}$$

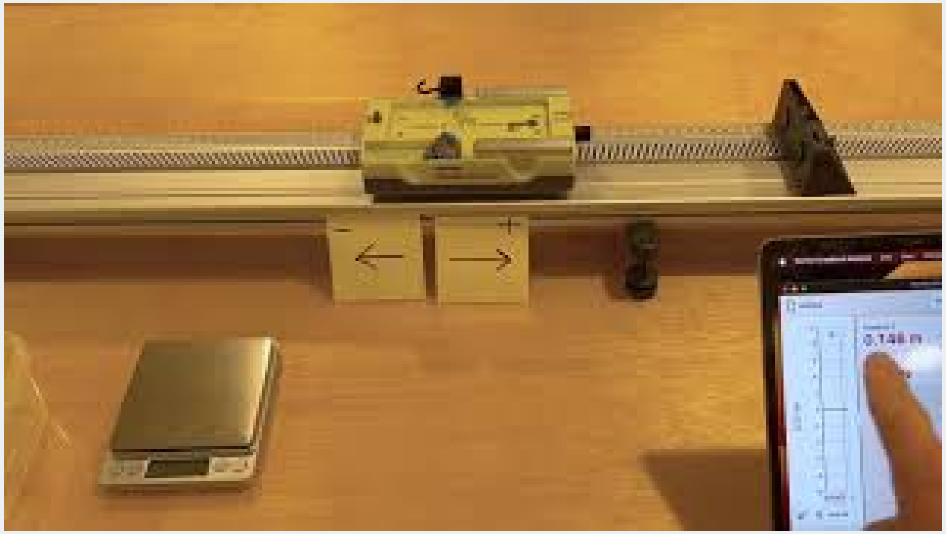
Slide D

Make Initial Observations



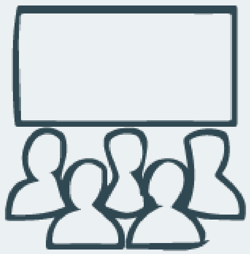
With your class

Orient to how data were collected from a 0.6 kg cart before, during, and after a collision with a barrier.



Slide E

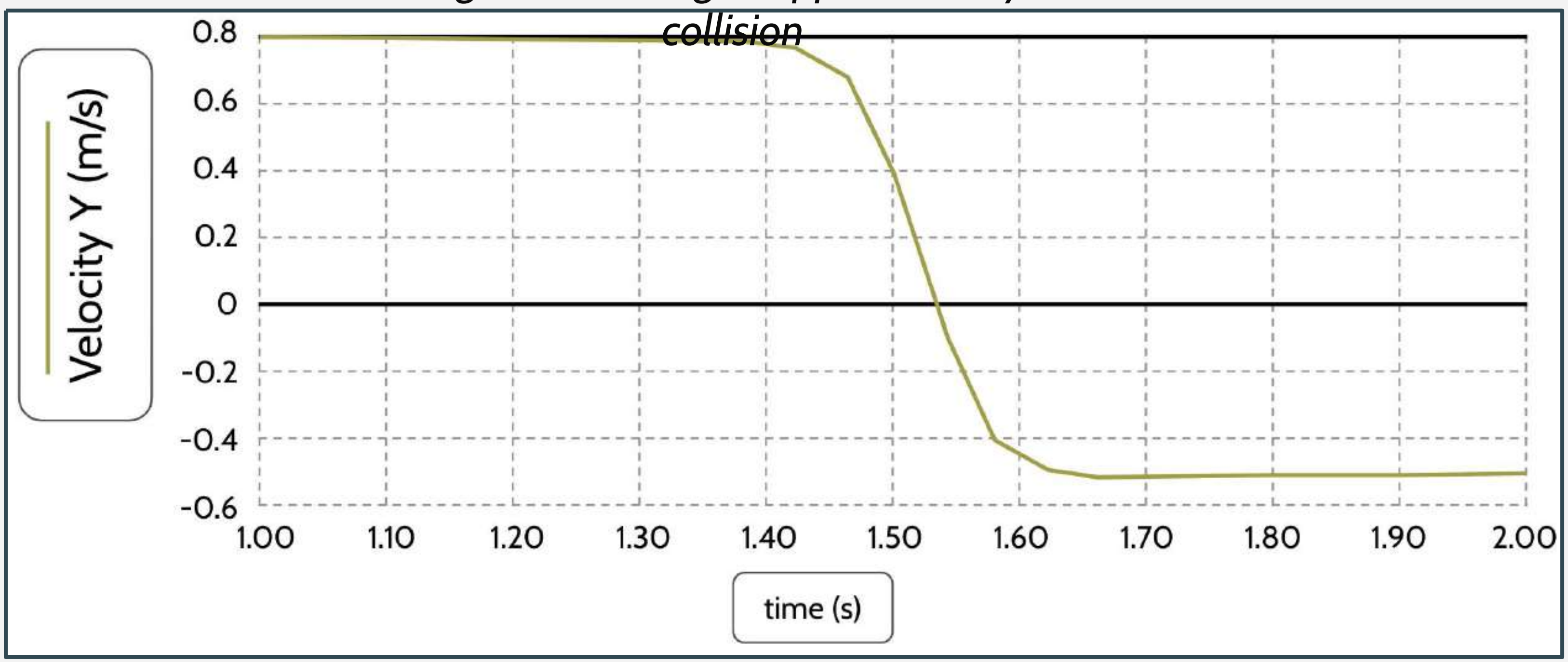
Analyze and Interpret Data



With your class

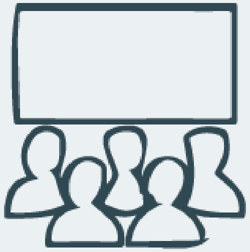
What part of the graph is before the collision and what part is after?

Collision A: *0.6-kg cart traveling at approximately 0.80 m/s before collision*



Slide F

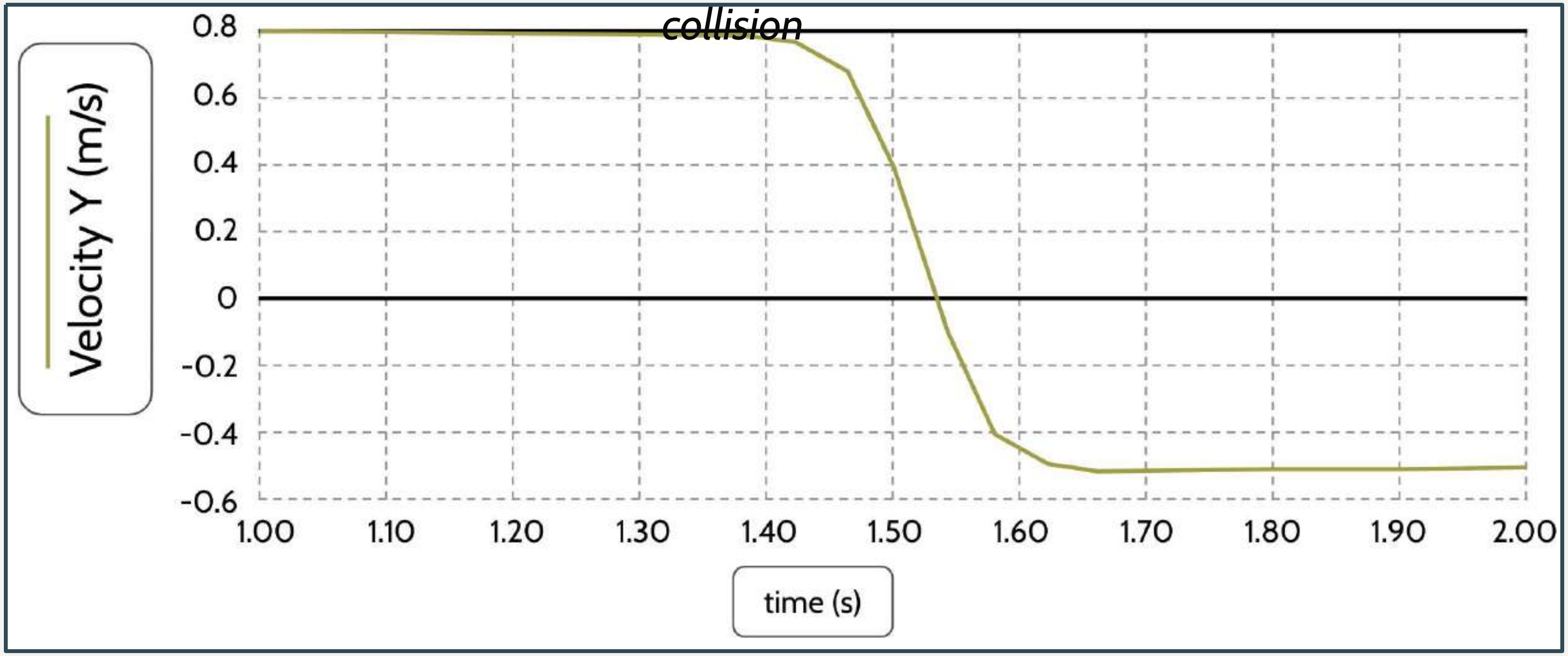
Analyze and Interpret Data



With your class

How is the cart moving during each part of the graph?

Collision A: *0.6-kg cart traveling at approximately 0.80 m/s before collision*



Slide G

Record Predictions

Predict what the graph will look like if ...

... we use the same mass cart (0.6 kg) but it is moving half as fast before it collides with the same barrier.

On your own

- Sketch the predicted shape of your line on the same graph as the prior collision.
- Label the value for the final velocity and the change in velocity (Δv) that you predict to see in this new collision.

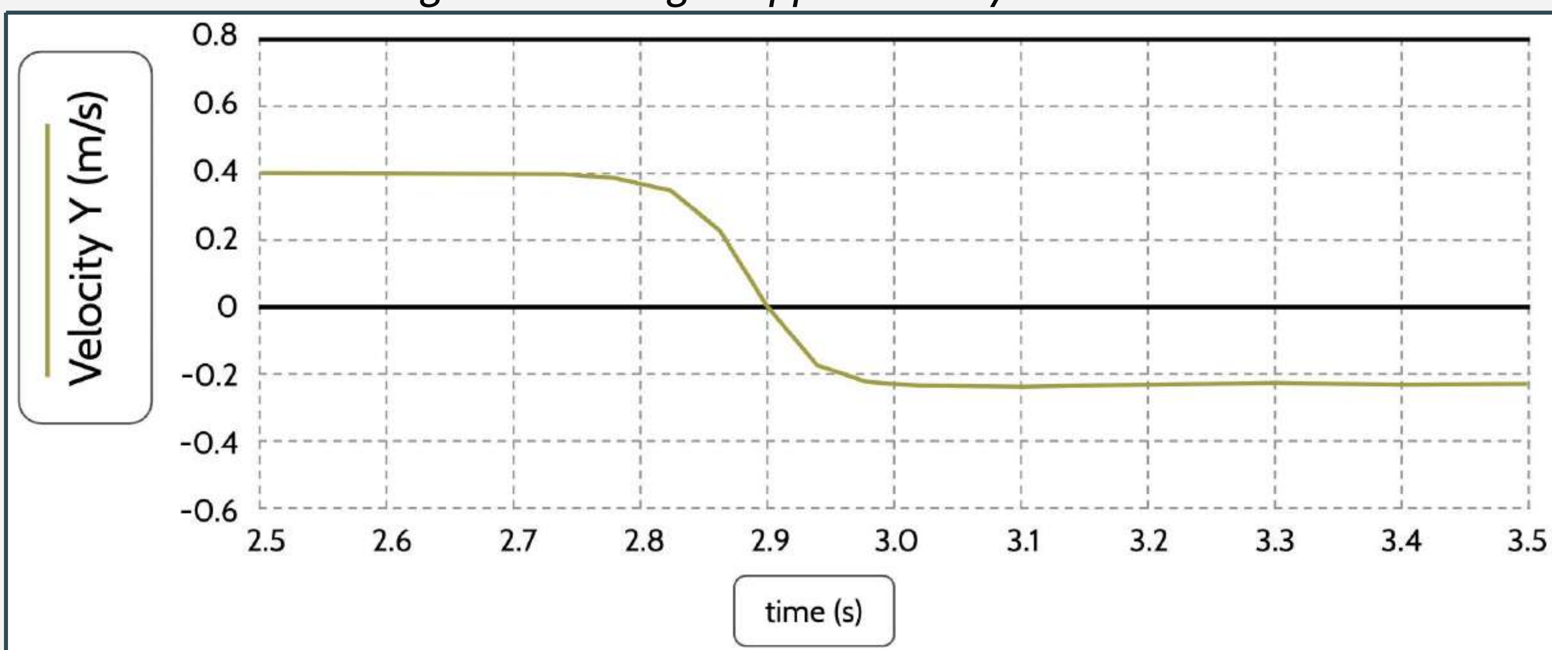
Slide H

Compare Predictions to Data

With a partner

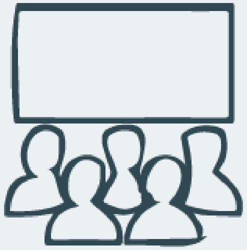
How do the final velocity and the change in velocity (Δv) compare to your predictions?

Collision B: *0.6-kg cart traveling at approximately 0.40 m/s before collision*



Slide I

Revise Our Models

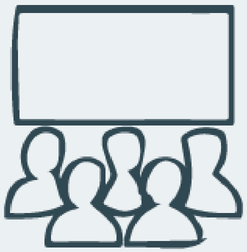


With your class

Revise our motion relationship equations to use Δvelocity (Δv) rather than Δspeed.

Slide J

Use a Model to Make Predictions



With your class

- What are the known values for 3 of our variables in each collision?
- Which equation should we use to determine the value of the 4th variable?

Collision A	
m (kg)	
Δt (s)	
Δv (m/s)	
F (N)	

Collision B	
m (kg)	
Δt (s)	
Δv (m/s)	
F (N)	

Slide K

Calculate the Predicted Force

On your own

What would the force be for your collision?

- Record the equation you used and the calculations you carried out.
- Add the predicted value to the table.

Variables	
m (kg)	
Δt (s)	
Δv (m/s)	
F (N)	

Equation and Calculations:

Slide L

Analyze and Interpret Data

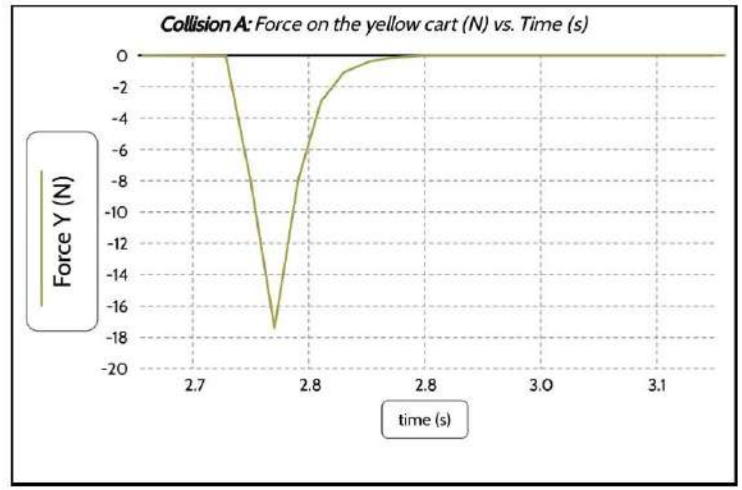
With a partner

Compare the contact forces in each collision.

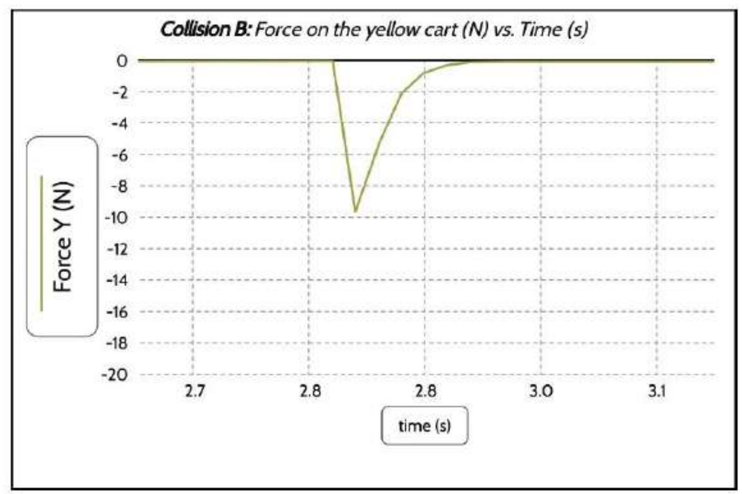
- What was surprising?
- What was not?

→ Be ready to share your ideas with the class.

Time (s)	Velocity (m/s)	Force Y (N)
1.34	0.89	-0.01
1.36		-0.01
1.38	0.80	-0.01
1.40		0.00
1.42	0.78	-0.02
1.44		-8.19
1.46	0.69	-17.48
1.48		-6.14
1.50	0.39	-3.13
1.52		-1.15
1.54	-0.00	-0.42
1.56		-0.17
1.58	-0.40	-0.07
1.60		-0.03
1.62	-0.49	-0.03
1.64		-0.01
1.66	-0.52	-0.01
1.68		-0.01
1.70	-0.52	-0.02
1.72		-0.01
1.74	-0.52	-0.01
1.76		-0.02
1.78	-0.52	-0.01
1.80		-0.01
1.82	-0.51	-0.01
1.84		-0.01
1.86	-0.51	-0.01

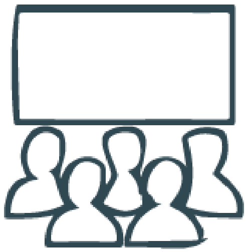


Time (s)	Velocity (m/s)	Force Y (N)
2.64		-0.01
2.66	0.40	-0.01
2.68		-0.01
2.70	0.39	-0.01
2.72		-0.01
2.74	0.39	-0.01
2.76		-0.02
2.78	0.39	-0.02
2.80		-0.02
2.82	0.35	-0.05
2.84		-9.61
2.86	0.23	-5.30
2.88		-2.14
2.90	0.01	-0.80
2.92		-0.30
2.94	-0.17	-0.12
2.96		-0.05
2.98	-0.22	-0.02
3.00		-0.02
3.02	-0.23	-0.01
3.04		-0.01
3.06	-0.24	-0.01
3.08		-0.01
3.10	-0.24	-0.01
3.12		-0.01
3.14	-0.24	-0.01
3.16		-0.01



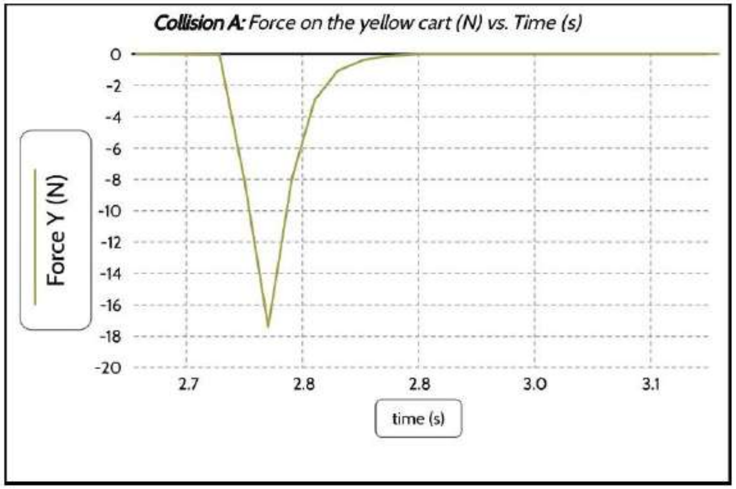
Generated using Vernier Graphical Analysis® software

Compare to Our Predictions



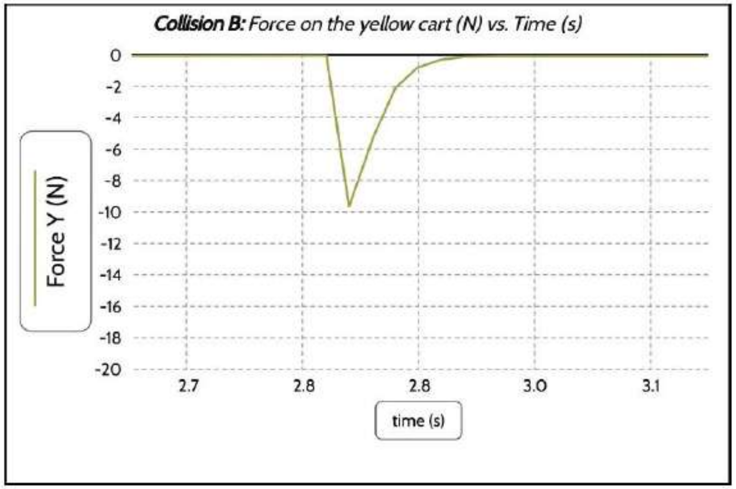
With your class

Time (s)	Velocity (m/s)	Force Y (N)
1.34	0.89	-0.01
1.36		-0.01
1.38	0.80	-0.01
1.40		0.00
1.42	0.78	-0.02
1.44		-8.19
1.46	0.69	-17.48
1.48		-8.14
1.50	0.39	-3.13
1.52		-1.15
1.54	-0.09	-0.42
1.56		-0.17
1.58	-0.40	-0.07
1.60		-0.09
1.62	-0.49	-0.03
1.64		-0.01
1.66	-0.52	-0.01
1.68		-0.01
1.70	-0.52	-0.02
1.72		-0.01
1.74	-0.52	-0.01
1.76		-0.02
1.78	-0.52	-0.01
1.80		-0.07
1.82	-0.51	-0.01
1.84		-0.01
1.86	-0.51	-0.01



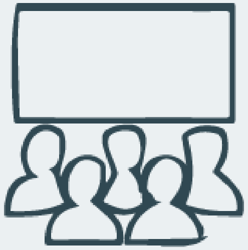
How is our predicted force value related to the data points above and below it?

Time (s)	Velocity (m/s)	Force Y (N)
2.64		-0.01
2.66	0.40	-0.01
2.68		-0.01
2.70	0.39	-0.01
2.72		-0.01
2.74	0.39	-0.01
2.76		-0.02
2.78	0.39	-0.02
2.80		-0.02
2.82	0.35	-0.05
2.84		-9.61
2.86	0.23	-5.30
2.88		-2.14
2.90	0.01	-0.80
2.92		-0.30
2.94	-0.17	-0.12
2.96		-0.05
2.98	-0.22	-0.02
3.00		-0.02
3.02	-0.23	-0.01
3.04		-0.01
3.06	-0.24	-0.01
3.08		-0.01
3.10	-0.24	-0.01
3.12		-0.01
3.14	-0.24	-0.01
3.16		-0.01



Slide N

Compare the Averages to Our Predictions



With your class

How does the average force over this time period compare to our predictions?

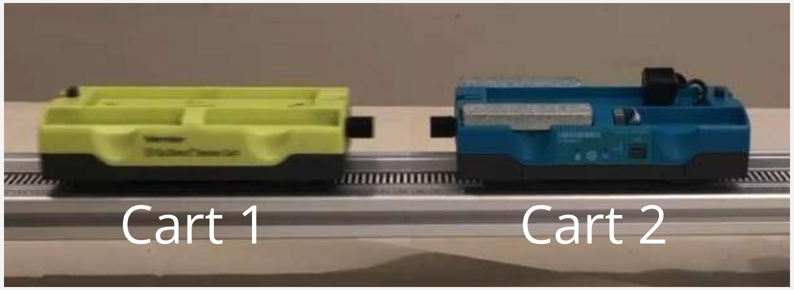
Collision A	
start time (s)	1.42
end time (s)	1.66
Δt (s)	0.24
Δv (m/s)	-1.30
Avg. F (N)	**-2.99**

Collision B	
start time (s)	2.78
end time (s)	3.02
Δt (s)	0.24
Δv (m/s)	-0.62
Avg. F (N)	**-1.42**

Slide O

Brainstorm How to Extend Our Model

In some vehicle collisions, the mass of the 2 vehicles is not the same.



With a partner

What changes would we need to make to one or both of these equations to keep track of the interactions and outcomes for **both** vehicles/carts?

Our equations

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

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

Slide P

Orient to the Two-Cart Collisions

With your class

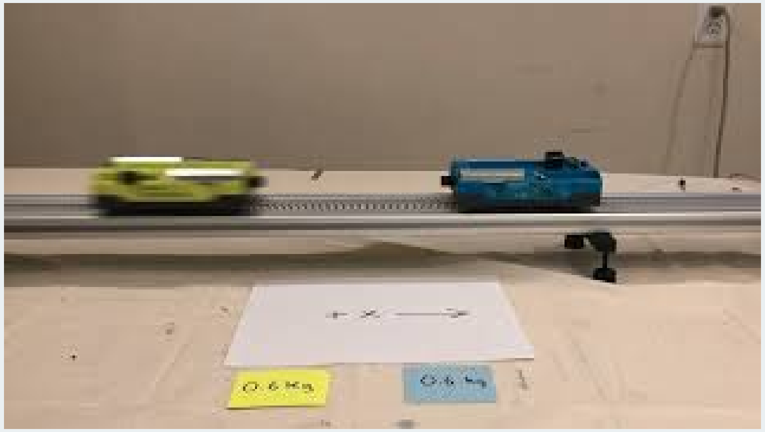
Make initial observations of 3 collisions (D, E, and F) between 2 carts.

Collision D:

The carts have equal mass.

Collisions E and F:

One cart is double the mass of the other.

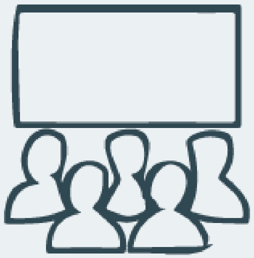


Slide Q

Make Predictions

Collision D: equal-mass carts

Collisions E and F: different-mass carts



With your class

Take a poll: Predict how the contact force(s) will compare between collisions D, E, and F.

1. There will be **equal**-magnitude forces on each cart in every collision.
2. There will be **unequal**-magnitude forces on each cart in every collision.
3. There will be **equal**-magnitude forces on each cart in some collision(s) and **unequal**-magnitude forces in other(s).

Slide R

Analyze and Interpret Data

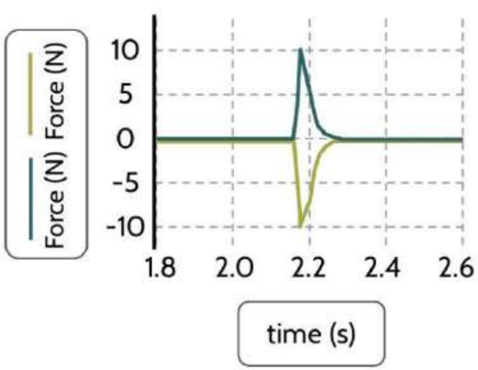
With your class

What patterns do you notice across the forces in the 3 collisions?

Collision D

The mass of both carts is the same (0.6 kg per cart).

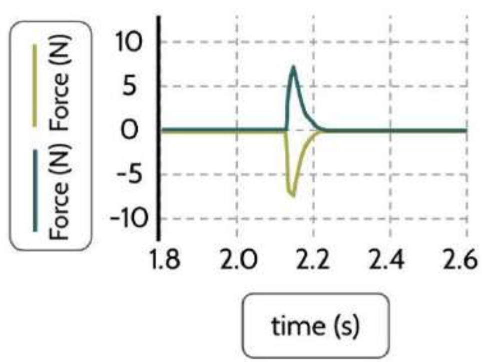
The green cart is moving at ~0.8 m/s to the right before it collides into a stationary blue cart.



Collision E

The mass of the green cart is 0.6 kg.
The mass of the blue caert is 0.3 kg.

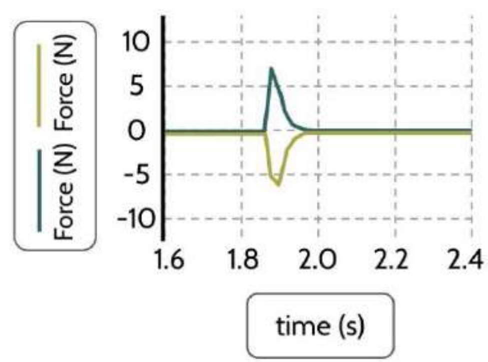
The green cart is moving at ~0.8 m/s to the right before it collides into a stationary blue cart



Collision F

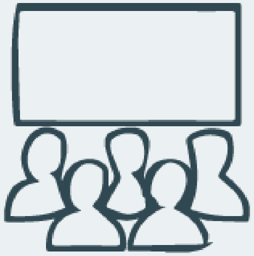
The mass of the green cart is 0.3 kg.
The mass of the blue cart is 0.6 kg.

The green cart is moving at ~0.8 m/s to the right before it collides into a stationary blue cart.



Slide S

Navigate



With your class

- What did we figure out last time?
- Does what we figured out mean that different-mass vehicles should be equally safe if they collide with each other?
- What evidence would we need to support or refute our arguments?

Student Content Advisory

We are about to look at data on fatalities related to collisions.

If for any reason you need additional social or emotional support to engage with this content, please let your teacher know privately, so they can connect you to resources.

If at any point in the unit you find you need additional support, let your teacher or another trusted adult know how you are feeling.

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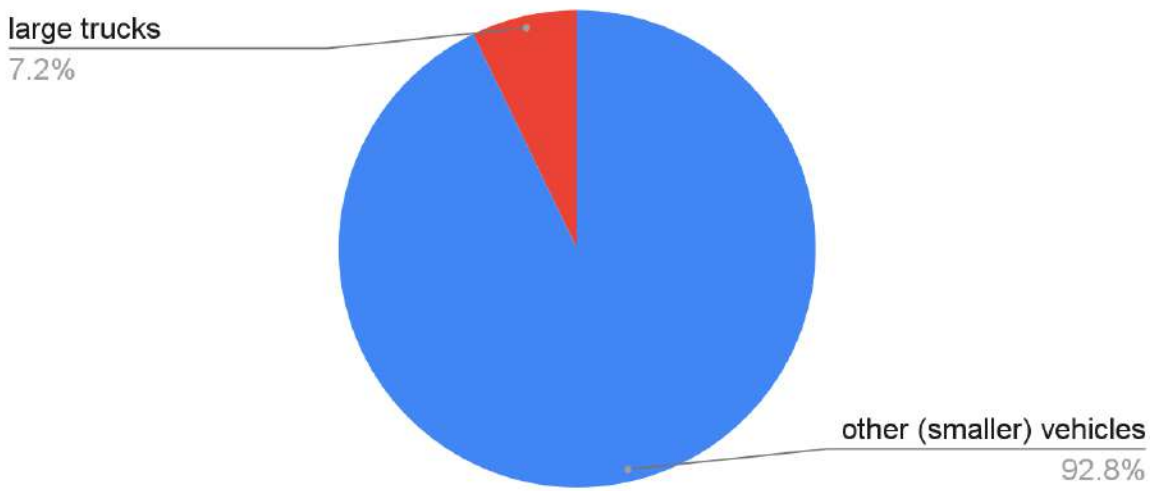
Slide U

Argue from Evidence

Turn and Talk

% of total fatalities in multi-vehicle collisions that involved a large truck, by vehicle occupancy (1996-2020)



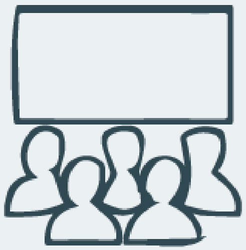
Data Source: Fatality Analysis Reporting System (FARS), National Highway Traffic Safety Administration (2020)

What does this tell us about who is most at risk in a collision between a large truck and a smaller vehicle?

→ Be ready to share your ideas with the class.

Slide V

Argue from Evidence



With your class

If we know that the forces on both vehicles will be equal in magnitude over the duration of the collision, then ...

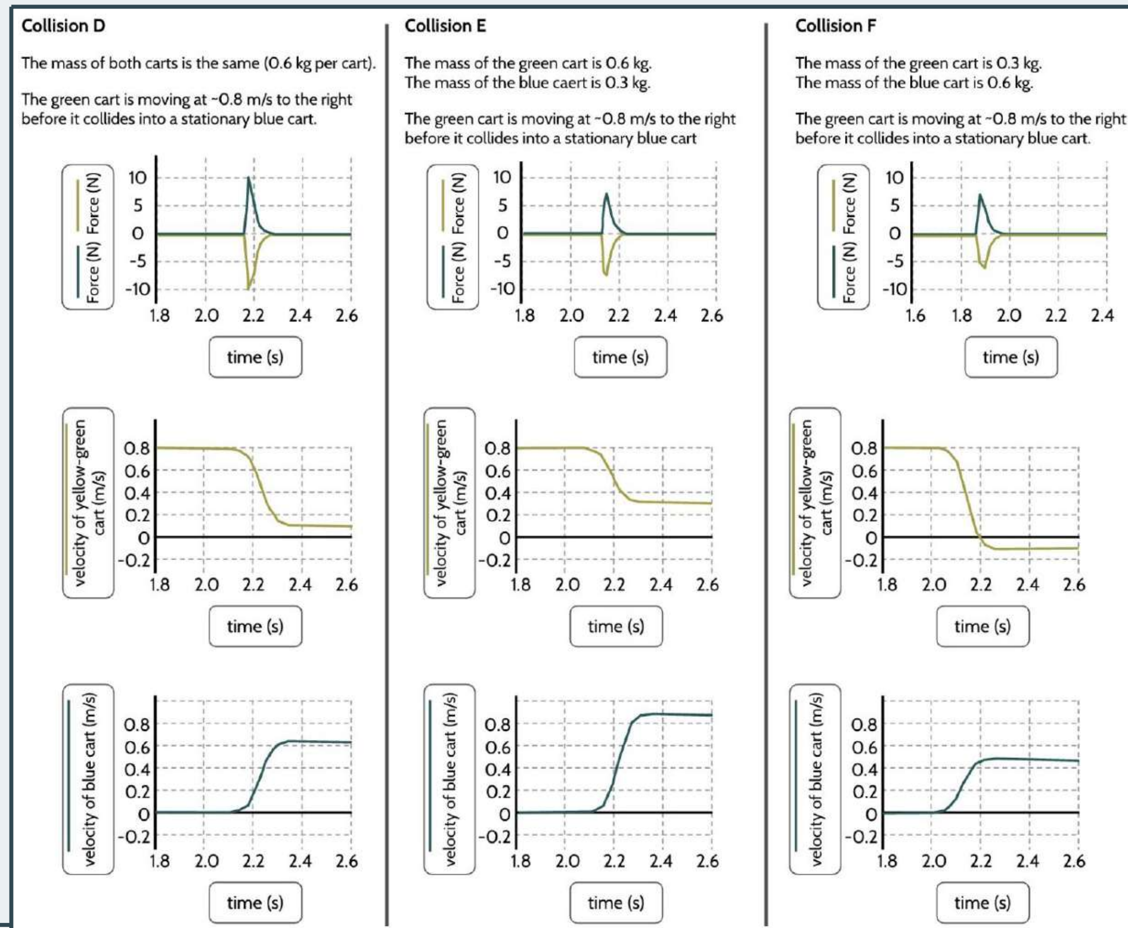
... why would large trucks be more dangerous for the other vehicles they collide with?

Slide W

Analyze and Interpret Data

With a partner

Discuss and annotate any patterns you notice across the new graphs for the 3 collisions.



Slide X

Analyze and Interpret Data

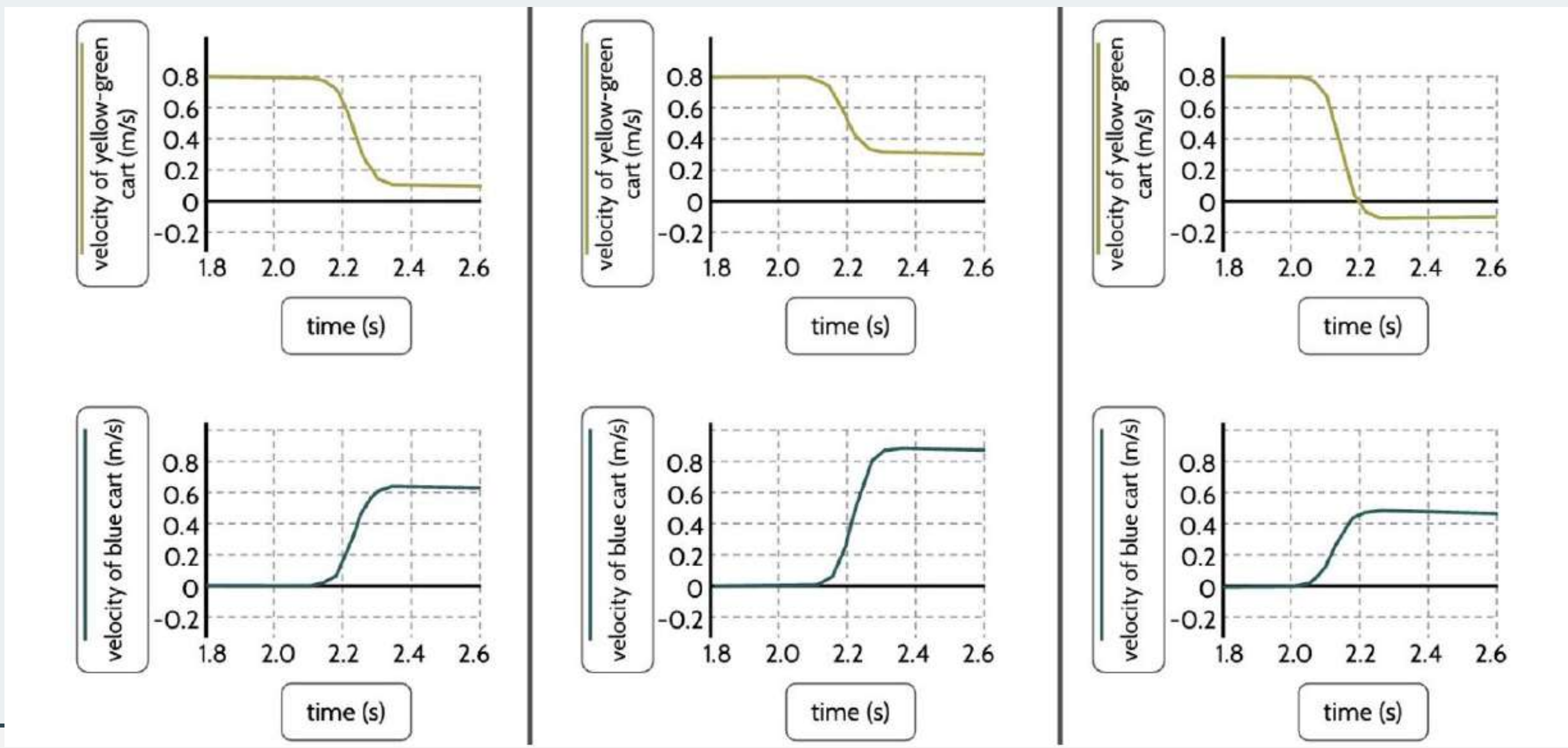
With your class

How does the Δv compare?

Collision D

Collision E

Collision F



Slide Y

Use Mathematical Thinking

With a partner

How does the Δv for each cart compare?

Collision D

Yellow cart	
mass (kg)	0.6
start velocity (m/s)	0.78
end velocity (m/s)	0.11
Δvelocity (m/s)	

Blue cart	
mass (kg)	0.6
start velocity (m/s)	0.00
end velocity (m/s)	0.67
Δvelocity (m/s)	

Collision E

Yellow cart	
mass (kg)	0.6
start velocity (m/s)	0.79
end velocity (m/s)	0.33
Δvelocity (m/s)	

Blue cart	
mass (kg)	0.3
start velocity (m/s)	0.00
end velocity (m/s)	0.92
Δvelocity (m/s)	

Collision F

Yellow cart	
mass (kg)	0.3
start velocity (m/s)	0.80
end velocity (m/s)	-0.12
Δvelocity (m/s)	

Blue cart	
mass (kg)	0.6
start velocity (m/s)	0.00
end velocity (m/s)	0.46
Δvelocity (m/s)	

Use Mathematical Thinking

With your class

How does the Δv for each cart compare?

Collision D

Yellow cart	
mass (kg)	0.6
start velocity (m/s)	0.78
end velocity (m/s)	0.11
Δvelocity (m/s)	-0.67

Blue cart	
mass (kg)	0.6
start velocity (m/s)	0.00
end velocity (m/s)	0.67
Δvelocity (m/s)	0.67

Collision E

Yellow cart	
mass (kg)	0.6
start velocity (m/s)	0.79
end velocity (m/s)	0.33
Δvelocity (m/s)	-0.46

Blue cart	
mass (kg)	0.3
start velocity (m/s)	0.00
end velocity (m/s)	0.92
Δvelocity (m/s)	-0.92

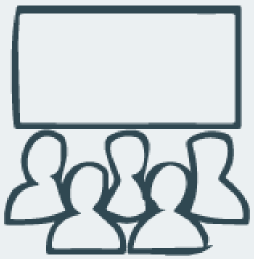
Collision F

Yellow cart	
mass (kg)	0.3
start velocity (m/s)	0.80
end velocity (m/s)	-0.12
Δvelocity (m/s)	+0.92

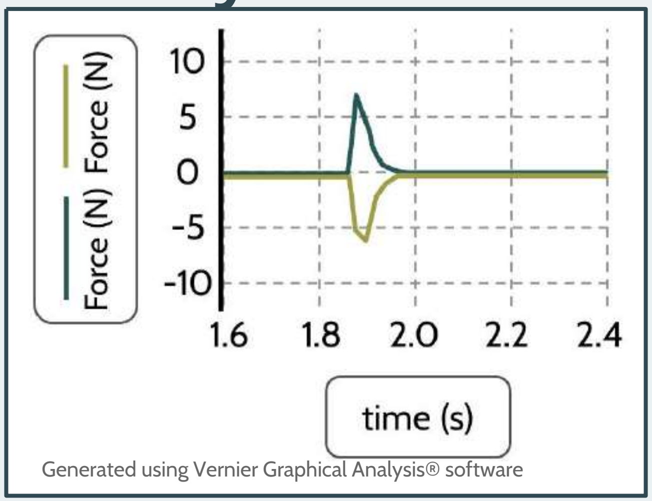
Blue cart	
mass (kg)	0.6
start velocity (m/s)	0.00
end velocity (m/s)	0.46
Δvelocity (m/s)	-0.46

Slide AA

Develop a Mathematical Model



With your class



Apply contact force symmetry to help isolate the only variables that can be different in these 2-vehicle collisions.

Our equations

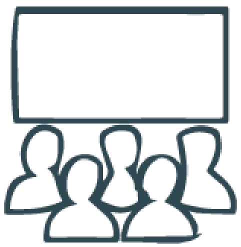
$$F_1 = \frac{m_1 * \Delta v_1}{\Delta t}$$

$$F_2 = \frac{m_2 * \Delta v_2}{\Delta t}$$

Slide BB

Test Our New Mathematical Model

$$m_1 * \Delta v_1 + m_2 * \Delta v_2 = 0$$



With your class

Does our new equation predict these Δv values?

Collision D

Yellow cart	
mass (kg)	0.6
start velocity (m/s)	0.78
end velocity (m/s)	0.11
Δvelocity (m/s)	-0.67

Blue cart	
mass (kg)	0.6
start velocity (m/s)	0.00
end velocity (m/s)	0.67
Δvelocity (m/s)	0.67

Collision E

Yellow cart	
mass (kg)	0.6
start velocity (m/s)	0.79
end velocity (m/s)	0.33
Δvelocity (m/s)	-0.46

Blue cart	
mass (kg)	0.3
start velocity (m/s)	0.00
end velocity (m/s)	0.92
Δvelocity (m/s)	-0.92

Collision F

Yellow cart	
mass (kg)	0.3
start velocity (m/s)	0.80
end velocity (m/s)	-0.12
Δvelocity (m/s)	+0.92

Blue cart	
mass (kg)	0.6
start velocity (m/s)	0.00
end velocity (m/s)	0.46
Δvelocity (m/s)	-0.46

Slide CC

Use a Mathematical Model

$$m_1 * \Delta v_1 + m_2 * \Delta v_2 = 0$$

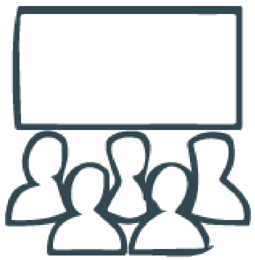
Individual Think Time

If these carts collide, how would the change in velocity of these carts compare if the green cart were **4 times** more massive than the blue one?

Wilensky, U. (1999). NetLogo. http://ccl.northwestern.edu/netlogo/. Center for Connected Learning and Computer-Based Modeling, Northwestern University, Evanston, IL.

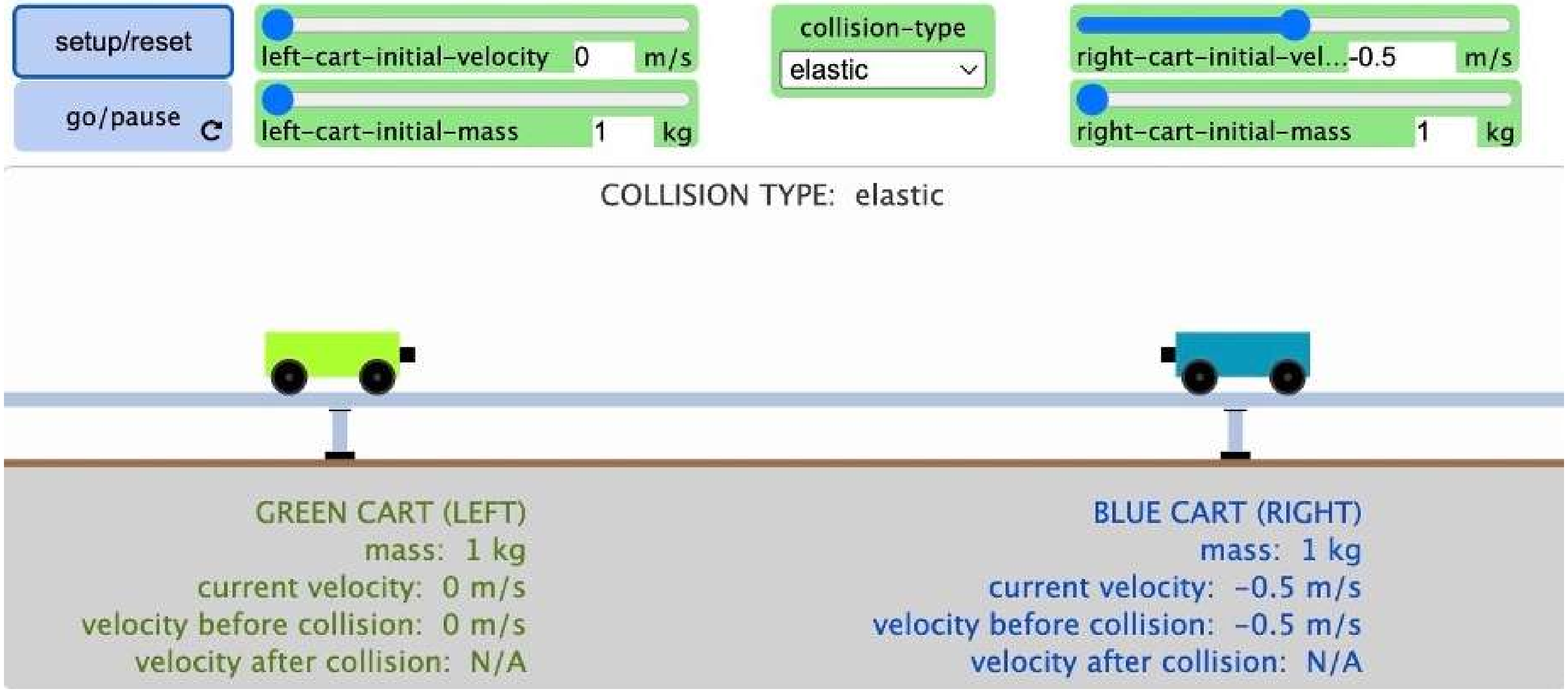
Slide DD

Orient to a Simulation



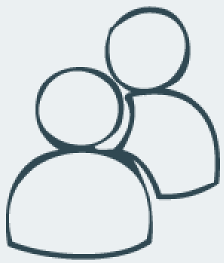
With your class

Orient to a simulation that we can use to collect data on various collision conditions.



Wilensky, U. (1999). NetLogo. http://ccl.northwestern.edu/netlogo/. Center for Connected Learning and Computer-Based Modeling, Northwestern University, Evanston, IL.

Carry Out an Investigation



With a partner

(5 minutes) Use the simulation to test at least 1 elastic collision and 1 inelastic collision.

https://www.openscied.org/simulation/collision-cart/

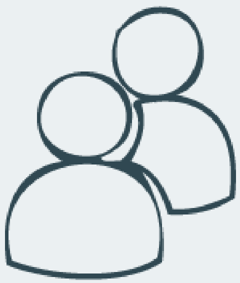
For each collision, record the following:

- type of collision (elastic or inelastic)
- mass of each cart (m_1 and m_2)
- velocities of each cart (starting and final)

Slide FF

Test Our Model

$$m_1 * \Delta v_1 + m_2 * \Delta v_2 = 0$$



With a partner

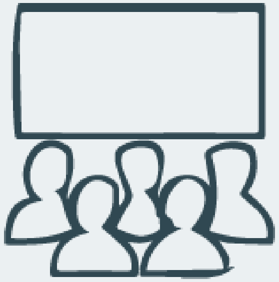
Does the mathematical relationship we developed above hold for none, one, or both of the collisions you tested in the simulation?

- Document the calculations using the equation above for 1 collision. Write large enough so these are easily visible to share with the class.

Slide GG

Argue from Evidence

$$m_1 * \Delta v_1 + m_2 * \Delta v_2 = 0$$



With your class

Does the mathematical relationship we developed above hold for none, some, or all of the collisions we tested in the simulation?

Slide HH

Consider Other Conserved Quantities

$$m_1 * \Delta v_1 + m_2 * \Delta v_2 = 0$$

Turn and Talk

Based on our work in prior units, what are some other physical quantities that are conserved?

→ Be ready to share your example(s) with the class.

Use Mathematical Thinking

Prepare to develop a **geometric way** to visualize why adding these together cancels them out:

$$m_1 * \Delta v_1 + m_2 * \Delta v_2 = 0$$

Turn and Talk

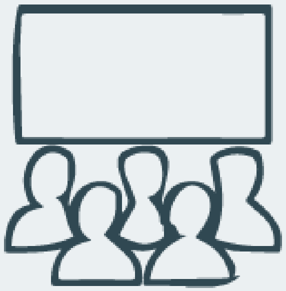
What **shapes** have we used in math class to represent a quantity that is the product of 2 variables (a * b)?

Use Mathematical Thinking

Consider this new scenario:

A 3-kg cart is stationary at first. It has a velocity of +4 m/s after a collision with another cart.

$$m_1 * \Delta v_1 + m_2 * \Delta v_2 = 0$$

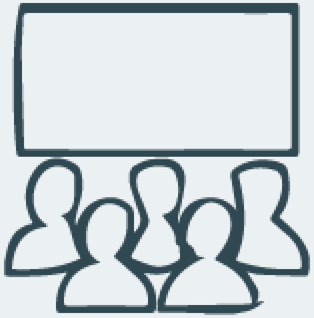


With your class

Use the shapes you chose to represent the amount of change that occurs for each cart ($m * \Delta v$).

Slide KK

Evaluate the Geometric Model



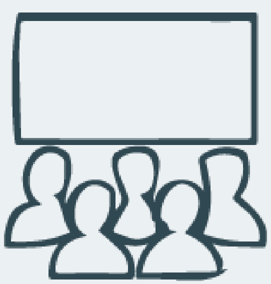
With your class

- What did the geometric representations help us visualize?
- What were some limitations of the geometric representations?

Use Mathematical Thinking

$$m_1 * \Delta v_1 + m_2 * \Delta v_2 = 0$$

- $m * \Delta v$ is the **change in momentum**.
- It has 2 variables as well as a Δ symbol.
- Let us consider what **momentum** is by recalling how we determine the change (Δ) for a single variable.



With your class

How did we use data to determine the change in a single variable (i.e., Δt, Δv)?

Add to Your Personal Glossary

On your own

Add to or record a new definition for any of the following terms in your Personal Glossary:

- *velocity*
- *elastic collision*
- *inelastic collision*
- *momentum*

Use Mathematical Thinking

$$m_1 * \Delta v_1 + m_2 * \Delta v_2 = 0$$

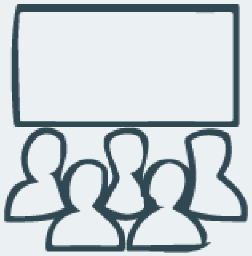
$m_{1\text{-start}} * v_{1\text{-start}} + m_{2\text{-start}} * v_{2\text{-start}} = m_{1\text{-end}} * v_{1\text{-end}} + m_{2\text{-end}} * v_{2\text{-end}}$

On your own

Use either of the conservation of momentum equations to solve for an unknown variable in 1 of the 3 collision scenarios.

Slide OO

Orient to the Self-Assessment and Reflection



With your class

- Orient to the key and the related questions.
- Discuss its role in helping to identify parts of the process you feel confident about and parts you would like additional practice or help with before our next assessment.

Slide PP

Use and/or Reflect on Mathematical Thinking

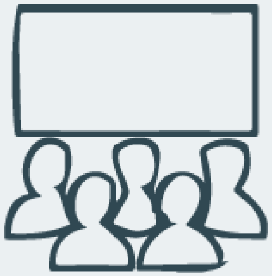
Home Learning

- Complete each practice problem and check your work with the key before trying another.
- Complete questions A-C in the self-assessment and reflection.
- Turn these in on the agreed-upon due date.

Navigate

Constants in a collision between different-mass vehicles:

- the magnitude of contact forces on both vehicles at the same points in time
- the total momentum in the system



With your class

- What is changing in a collision between a large truck versus a small car that could affect passenger safety?
- What new questions does this raise for us?

Optional Collision Introduction

The *Optional Collision Introduction* teacher reference describes a more-scaffolded sequence that can be used to introduce the sensor cart.

To use this sequence, paste the following slides (C1-C4) instead of slide D above. This sequence will add 20-25 minutes to the lesson.

Slide C1

Navigate

Turn and Talk

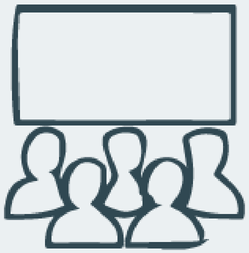
Watch this crash test of a car hitting a fixed object. What do you notice?

Would you model this collision as

- *a bounce?*
- *a sudden stop?*

Science Karate

Make Initial Observations



With your class

A “sensor cart” can measure velocity and force with sensors. In a real-life crash, we cannot usually measure force directly, but we can model it.

How could we use our sensor cart to collect the data we need to model force predictions about real car crashes?

$$F = \frac{m * \Delta speed}{\Delta t}$$

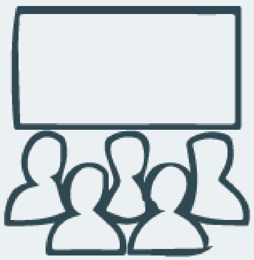
Slide C3

Safety Protocols

With your class

- Read the safety protocols on the lab handouts, follow the activity instructions, and only conduct the assigned activities.
- Dress appropriately: closed-toe shoes, long hair and loose clothing tied back, and safety glasses.
- Keep workspace and floor clear and check equipment for damage.
- Stay a safe distance from the collision area.

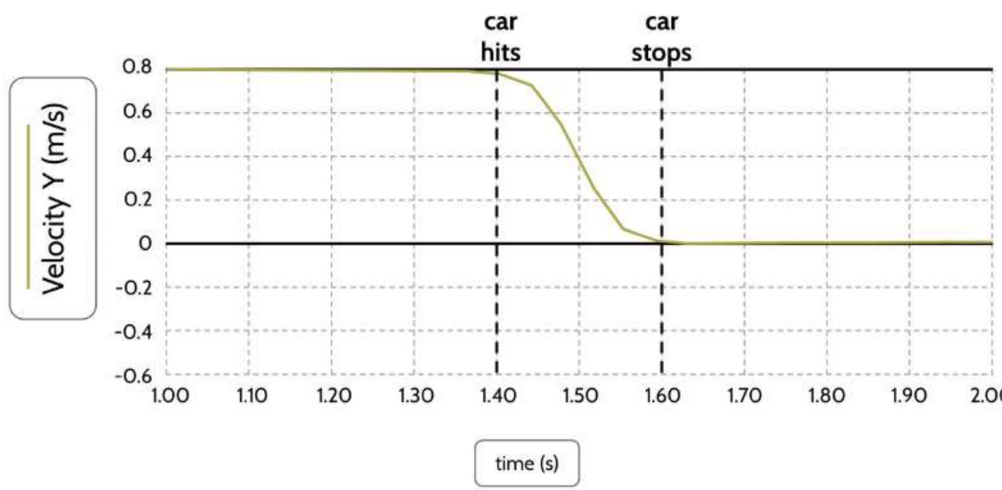
Analyze and Interpret Data



With your class

Analyze the graph to find Δ speed and Δt and calculate force.

How would we know if this value is valid?



Collision 0

Variables	
m (kg)	0.6 kg
Δt (s)	
Δv (m/s)	
F (N)	

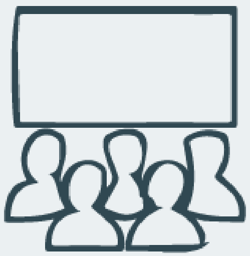
Equation:

$$F = \frac{m * \Delta speed}{\Delta t}$$

Calculations:

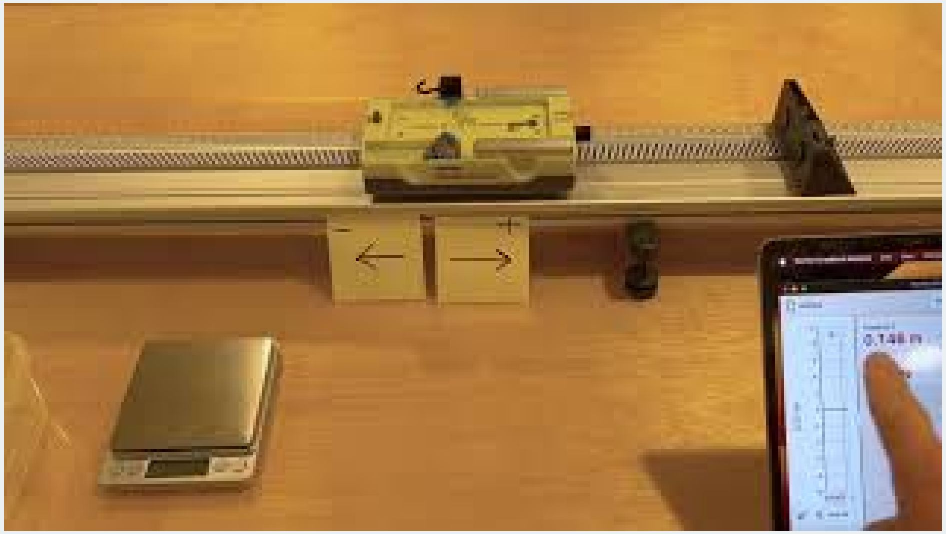
Slide C5

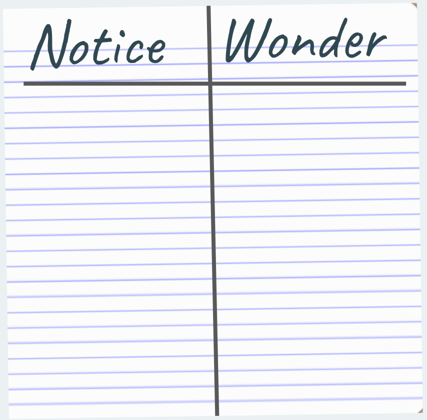
Make Initial Observations



With your class

Orient to how data were collected from a 0.6 kg cart before, during, and after a collision with a barrier.





→ Be ready to share your ideas with the class.

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