# Momentum

Physics Sample Lesson

# Scope (Unit) Momentum

## Explore (Lesson) Scientific Investigation - Conservation of Momentum

The following pages introduce lesson resources that guide you through the STEMscopes NGSS Physics lesson. This sample lesson does not include all the elements and features of our digital and print science curriculum.

## Resource List:

The following resources, as well as additional Scope resources not listed, can be found in the digital curriculum *Physics Scope, Momentum.*

**Home**
- Standards Alignment
- Sample Lesson Plan
- Teacher Scope Presentation
- Teacher Background
- CCC and SEP Scoring Rubric
- Answer Keys
- Materials List

**Engage**
- Investigative Phenomena – Introductory activity that facilitates a connection between the content and real-world phenomena and encourages students to ask why or how something happens.
- Graphic Organizer – Students fill this in as they work through the elements of this Scope.
- Accessing Prior Knowledge – A brief probing activity to gauge students' prior knowledge before engaging in the inquiry process.
- Hook – An engaging activity that includes instructor preparation, supplemental resources, and ready-made handouts for students.

**Explore**
- Explore 1: Inquiry Investigation
- Explore 2: Scientific Investigation – This lesson sample.
- Explore 3: Engineering Solution

**Explain**

- Picture Vocabulary – Key terms explained through pictures and by definition.
- Linking Literacy – Strategies to help students comprehend difficult informational text.
- STEMscopedia – Reference materials that include parent connections, career connections, technology, and science news.
- Communicate Science – A class activity in which students use different forms of communication to discuss scientific topics connected to the content of this Scope.
- Concept Review Game – An interactive game that helps students review important concepts.
- Content Connections Video – A short video that supports student understanding of the content.

**Elaborate**

- Math Connections
- Science Today
- Reading Science
- Career Connections
- Scientist Spotlight
- PhET: Simulation Practice

**Evaluate**

- Claim-Evidence-Reasoning
- Open-Ended Response Assessment
- Multiple Choice Assessment

**Intervention**

- Guided Practice
- Independent Practice
- Concept Attainment Quiz

**Acceleration**

- Extensions
- Science Art
- Books on Topic

# Table of Contents

# Scope (Unit) Overview
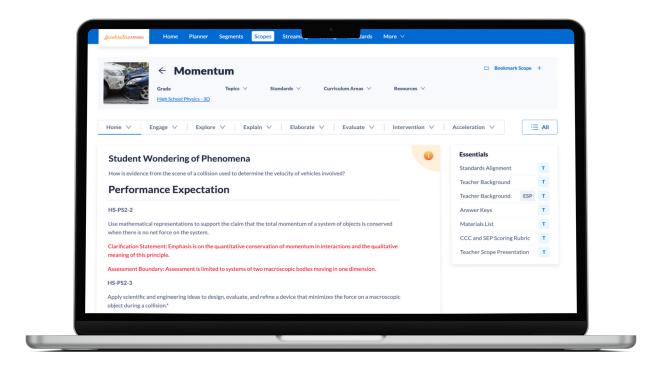
**Scope (Unit) Momentum**



## *Student Wondering of Phenomena*

How is evidence from the scene of a collision used to determine the velocity of vehicles involved?

## *Performance Expectations*

**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.

**Clarification Statement:** Emphasis is on the quantitative conservation of momentum in interactions and the qualitative meaning of this principle.

**Assessment Boundary:** Assessment is limited to systems of two macroscopic bodies moving in one dimension.

**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.*

**Clarification Statement:** Examples of evaluation and refinement could include determining the success of the device at protecting an object from damage and modifying the design to improve it. Examples of a device could include a football helmet or a parachute.

**Assessment Boundary:** Assessment is limited to qualitative evaluations and/or algebraic manipulations.

**HS-ETS1-1** Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.

**HS-ETS1-2** Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

**5**

# Scope (Unit) Overview

**Scope (Unit) Momentum**

*Three-Dimensional Focus*

| Science and Engineering Practice | Disciplinary Core Idea | Crosscutting Concept |
|---|---|---|
| Using Mathematics and Computational Thinking<br>Use mathematical representations of phenomena to describe explanations.<br><br>Constructing Explanations and Designing Solutions<br>Apply scientific ideas to solve a design problem, taking into account possible unanticipated effects. | PS2.A: Forces and Motion<br><br>PS2.A.2 Momentum is defined for a particular frame of reference; it is the mass times the velocity of the object.<br><br>PS2.A.3 If a system interacts with objects outside itself, the total momentum of the system can change; however, any such change is balance by changes in the momentum of objects outside the system.<br><br>ETS1.A: Defining and Delimiting Engineering Problems<br><br>ETS1.A.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.<br><br>ETS1.C: Optimizing the Design Solution<br><br>ETS1.C.1 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. | Systems and System Models<br><br>When investigating or describing a system, the boundaries and initial conditions of the system need to be defined.<br><br>Cause and Effect<br><br>Systems can be designed to cause a desired effect. |

# Momentum

### 🔍 Explore 2: Scientific Investigation - Conservation of Momentum

## Description

Students will investigate conservation of momentum, using an inelastic collision with a ball and a stationary cup.

**Materials:**

**Printed Material**
1 Scientific Investigation: Conservation of Momentum (per student, group, or class)

**Reusable**
3 Metersticks (per group)
1 Golf ball or similarly sized sphere between 30 g and 100 g (per group)
1 Cup (plastic or paper) large enough to catch and hold a golf ball (per group)
3 Quarters (per group)
2 Stopwatches (per group)
2 Rods, wooden, 70 cm to 100 cm long, of equal diameter (per group)
1 Scale, digital (per group)
1 Board, 100 cm x 15 cm (per group)
6 Book, hardback (per group)

**Consumable**
Masking tape, strip, 15 cm (per group) for attachment of weights
Masking tape, strip, 50 cm (per group) for track assembly
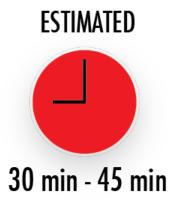Glue, wood, bottle, 8 oz (per teacher)

**Preparation**

- Scientific Investigation: Conservation of Momentum can be printed individually for student use, printed as a reusable class set, or assigned online.
- The picture embedded in this description should be used to help with the track setup. You may decide to set up tracks for classes ahead of time to facilitate the investigation.

### STEMcoach in Action

The skills inherent in designing and implementing a scientific investigation are applicable to many situations outside of the science classroom. Skills such as observing, asking questions, collecting and analyzing data, and drawing and communicating reasonable conclusions are important to all individuals. When we say "cultivating scientific investigation" we are describing the practices that help students develop the skills associated with scientific investigation. For more information on Cultivating Scientific Investigations, please click on the provided link.
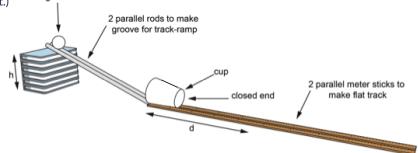
Site

## Procedure and Facilitation Points

- Tell students they will be investigating momentum and how it is influenced when more than one object is involved.
- Distribute copies of Scientific Investigation: Conservation of Momentum and pose the following questions:
  - Theoretically, 100% of momentum is conserved in collisions. You will measure as accurately as you can to observe the effect of an open system on the conservation of momentum. What needs to be measured to determine the initial momentum?
    Momentum is equal to the mass of an object multiplied by the velocity of the object. You need to measure the mass of the object and calculate the distance the object traveled as well as the time it took to travel the distance. Momentum is a vector, so you also need to determine the direction the object is traveling.
  - When two cars collide, what is considered the system during the collision?
    The two vehicles are the system.
- Instruct the students that they will be investigating a system that includes a ball and cup that will be colliding. Have the students read through the procedure, clarify any questions, and begin the investigation.

**Student Procedure**

Track Setup

1. Set up the tracks by placing two metersticks parallel to each other on a table or other flat surface. Position the meter sticks to be the same distance apart as the opening to the cup. The cup should rest easily between the two meter sticks.
2. Construct the ramp portion using a board with two wooden rods taped on it to create a groove for the ball to travel in.
3. Set up the ramp using books. The ramp should meet the meterstick track on the table.
4. Tape three quarters on one side of a cup and lay the cup on the metersticks at the point where the two tracks meet. The mouth of the cup should be facing the angled ramp, and the weights should be on the bottom of the cup. (Refer to the diagram to verify you have the setup correct.)



Investigation

5. Measure the distance the ball will travel from the point where it starts on the ramp to the point it reaches the cup.
6. Measure and record the mass of the ball and the mass of the cup with the added weight.
7. Practice releasing the ball at the top of the ramp to verify that your setup will work. The ball should roll down the ramp and enter the cup. Then the ball and cup should travel along the track.
8. Once you have verified your setup works, you will run this investigation in two parts to make things easier.
9. First, complete three trials releasing the ball at the top of the ramp and timing it until the ball enters the cup. At this time, do not concern yourself with the distance the cup and ball travel or the time the cup and ball travel together. You are only interested in recording the time it takes for the ball to roll down the ramp.
10. Record your times on Data Table 1 under the column "Time On Angled Track," and calculate the average.
11. You are now able to calculate the velocity and momentum to complete Data Table 1.
    - Velocity is calculated by dividing the distance traveled by the time taken (v=d/t).
    - Momentum is calculated by multiplying the mass times the velocity (p=mv).

12. Next, you will complete three trials of releasing the ball, but this time you will time the entire journey the ball takes from the top of the ramp until the ball/cup combination stops. You will also record the distance traveled by the ball/cup combination by noting the initial position of the open end of the cup (probably 0 meters) and the final position of the open end of the cup.

13. By timing the entire journey of the ball, and subtracting the time it takes for the ball to travel down the ramp (which you recorded in Data Table 1), you will be able to determine the time the ball/cup combination traveled together.

14. Record this time on Data Table 2 under the column "Time Traveled On Track."

15. Record the distance traveled by the ball/cup combination on Data Table 2 under the column Distance.

16. You are now able to calculate the velocity and momentum of the ball/cup combination to complete Data Table 2.

**Data Analysis**

Data will vary depending upon the mass of the ball, the cup, and the height of the angled track.

| Data Table 1: Data for Initial System (Ball Only) | | | | | |
|---|---|---|---|---|---|
| Trial | Mass of Ball (kg) | Distance (m) | Time on Angled Track (s) | Velocity (m/s) | Momentum (kg · m/s) |
| 1 | | | | | |
| 2 | | | | | |
| 3 | | | | | |
| Average | | | | | |

| Data Table 2: Data for Final System (Cup with Three Quarters + Ball) | | | | | | |
|---|---|---|---|---|---|---|
| Trial | Mass of Ball (kg) | Mass of Cup (kg) | Distance (m) | Time Traveled on Track (s) | Velocity (m/s) | Momentum (kg · m/s) |
| 1 | | | | | | |
| 2 | | | | | | |
| 3 | | | | | | |
| Average | | | | | | |

**Data Analysis**

1. What was the average momentum for the ball as it moved down the bottom of the ramp?
   Answers will vary.

2. What was the initial momentum of the cup before the ball collided with it?
   The initial momentum should have been zero, since the cup had no velocity before the ball collided with it.

3. What was the average momentum of the system when the ball was in the cup?
   Answers will vary but should reflect data from Data Table 2.

4. The law of conservation of momentum states that momentum is conserved; therefore, in an inelastic collision, the sum of the initial momentum should equal the final momentum. Using your answers for questions 1–3, show the mathematical representation for this.
   Answers will vary but should represent p (ball at bottom of ramp) + p (cup initial) = p (system).

5. Did this investigation prove the law of conservation of momentum in collisions?
   Explain your answer. Answers will vary.

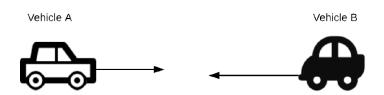6. If there was a discrepancy, explain why you think that may have happened.
   Ideally, there would be no net force on a system that shows the law of conservation of momentum. In this case, there was possibly friction on the cup that was not taken into account. Also, the measurements of time could have been inaccurate, resulting in inaccurate velocity that would impact the momentum.

7. How would you modify the investigation to address the conditions of the system resulting in more accurate data?
   Having a longer distance for the ramp would allow for more time and possibly more accurate measurements. A track with no friction would remove any additional forces from the system.

- At this time, you could introduce the following terms, using the Picture Vocabulary found in the Explain section:
  - Elastic collision
  - Inelastic collision
  - Law of conservation of momentum
  - Mass
  - Momentum
  - Thermal energy
  - Velocity
  - Open system
  - Vector
  - System
  - Net force
  - Forces
  - Energy
  - Mechanical energy
- **(CCC)** Why is it important to know the boundaries and conditions of the system for this investigation?
  It is important to know the boundaries and conditions of the system because the investigation is testing the conservation of momentum within a system that is influenced by outside net forces. Understanding which forces are part of and which are outside the system is important when analyzing the resulting data.
- **(SEP)** Why do we use models to investigate the conservation of momentum?
  By using models to investigate the conservation of momentum, we are able to control the boundaries and initial conditions of the system and limit the outside net forces that act on the system.
- What are some factors that cause limitations to the data analysis for this investigation?
  Time measurement dependent on human reaction can result in measurement error for this investigation, although the use of video helps minimize this error. Also, not having a way to measure the effect of friction on the system is a limiting factor in data analysis.

- **(CCC)** Our investigation attempts to observe the conservation of momentum within a system. Does the collected data make sense with what we know about the real world? Explain.

  Yes, the collected data makes sense with what we know about the real world. The data indicates a loss of momentum within the system from before the collision to after the collision. This makes sense since in the real world, we would expect the force of friction to act as a net force from outside the system. This would reduce the velocity of the ball and the velocity of the ball and cup, transforming some of the energy in the system from mechanical to thermal energy and reducing the momentum.

- After students complete their task, they will use the data and observations they have gathered in the investigation to write a scientific explanation that includes a claim, evidence, and reasoning (CER).

Vehicle A                    Vehicle B



Two vehicles have a head-on collision. The vehicles essentially stick together and travel a certain distance for 20 seconds before coming to a complete stop. You are able to obtain the mass of both vehicles, the initial velocity for Vehicle A, and the final velocity for both vehicles immediately after the crash. Can you determine the momentum of both vehicles before the collision?

Write a **claim** that answers your question.
Yes, you can determine the momentum for both vehicles.

What **evidence** did you gather that supports your claim?
To determine momentum, you need mass and velocity. You have the mass and velocity for the vehicles after the collision so you can determine the final momentum.

You have enough information to determine the initial momentum for Vehicle A.

What scientific **reasoning** connects the evidence to the claim?
Based on the law of conservation of momentum, the total momentum of the vehicles before the collision should equal the total momentum after the collision. If you have the initial momentum on one vehicle and the final momentum of both vehicles, you can determine the unknown momentum, using the following equation:
p (i) Vehicle A + p (i) Vehicle B = P (f) Vehicles A and B

- When appropriate, close the activity by referring students to the Investigative Phenomena/Graphic Organizer and fill in the appropriate information.

## Connection to the Investigative Phenomena

Once students have completed the activity, have them refer to the Investigative Phenomena question, anchor their learning, and revise their thinking.

**ELL Strategies**

**Claim-Evidence-Reasoning:**

Have students work in pairs to develop their CER. After completing the CER, students should read another student's reasoning and ask questions to make sure they understand what was written. Then have students write a rebuttal or reflection based on the other student's CER responses. Allow students to complete the sentence stems before the discussion portion. Example sentence stems: "My claim is __. My evidence is __. My reasoning is __. I heard you say __, and I hadn't thought about that before. However, I think __."

**Explore**

**Explore Lesson**

Name: _____ Date: _____

# Conservation of Momentum

**Introduction**
In inelastic collisions, momentum is conserved, resulting in the objects "sticking" together as they move forward. In real-life collisions, cars can smash together as the wreckage slides to a stop.

**Question**
How do the velocity and momentum change when an inelastic collision occurs?

**Hypothesis**


**Materials**

**Printed Material**
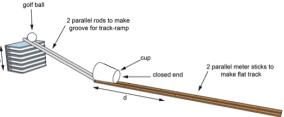1 Student Journal (per student, group, or class)



**Consumable**
Masking tape, strip, 15 cm (per group) for attachment of weights
Masking tape, strip, 50 cm (per group) for track assembly

**Reusable**
3 Meter sticks (per group)
1 Golf ball or similarly sized sphere between 30 g to 100 g (per group)
1 Cup (plastic or paper) large enough to catch and hold golf ball (per group)
3 Quarters (per group)
2 Stopwatch (per group)
2 Rods, wooden, 70 cm to 100 cm long, of equal diameter (per group)
1 Scale, digital (per group)
6 Book, hardback (per group)

What, if any, safety steps need to be taken?

# Explore

**Student Procedure**

**Track Setup**

1. Set up the tracks by placing two meter sticks parallel to each other on a table or other flat surface. Position the meter sticks to be the same distance apart as the opening to the cup. The cup should rest easily between the two meter sticks.
2. Construct the ramp portion using a board with two wooden rods taped on it to create a groove for the ball to travel in.
3. Set up the ramp using books. The ramp should meet the meterstick track on the table.
4. Tape three quarters on one side of a cup and lay the cup on the meter sticks at the point where the two tracks meet. The mouth of the cup should be facing the angled ramp, and the weights should be on the bottom of the cup. (Refer to the diagram to verify you have the setup correct.)

**Investigation**

5. Measure the distance the ball will travel from the point where it starts on the ramp to the point it reaches the cup.
6. Measure and record the mass of the ball and the mass of the cup with the added weight.
7. Practice releasing the ball at the top of the ramp to verify your setup will work. The ball should roll down the ramp and enter the cup. Then the ball and cup should travel along the track.
8. Once you have verified your setup works, you will run this investigation in two parts to make things easier.
9. First, complete three trials releasing the ball at the top of the ramp and timing it until the ball enters the cup.  At this time, do not concern yourself with the distance the cup and ball travel or the time the cup and ball travel together. You are only interested in recording the time it takes for the ball to roll down the ramp.
10. Record your times on Data Table 1 under the column "Time On Angled Track," and calculate the average.
11. You are now able to calculate the velocity and momentum to complete Data Table 1.
    - Velocity is calculated by dividing the distance traveled by the time taken ($v=d/t$).
    - Momentum is calculated by multiplying the mass times the velocity ($p=mv$).
12. Next, you will complete three trials of releasing the ball, but this time you will time the entire journey the ball takes from the top of the ramp until the ball/cup combination stops.  You will also record the distance traveled by the ball/cup combination by noting the initial position of the open end of the cup (probably 0 meters) and the final position of the open end of the cup.
13. By timing the entire journey of the ball, and subtracting the time it takes for the ball to travel down the ramp (which you recorded in Data Table 1), you will be able to determine the time the ball/cup combination traveled together.
14. Record this time on Data Table 2 under the column "Time Traveled On Track."

**Explore**

15. Record the distance traveled by the ball/cup combination on Data Table 2 under the column Distance.
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**Data Analysis**

| Data Table 1: Data for Initial System (Ball only) | | | | | |
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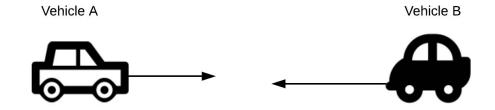| Data Table 2: Data for Final System (Cup with Three Quarters + Ball) | | | | | | |
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**Explore**

**Data Analysis**

1.  What was the average momentum for the ball as it moved down the bottom of the ramp?

2.  What was the initial momentum of the cup before the ball collided with it?

3.  What was the average momentum of the system when the ball was in the cup?

4.  The law of conservation of momentum states that momentum is conserved; therefore, in an inelastic collision, the sum of the initial momentum should equal the final momentum. Using your answers for questions 1–3, show the mathematical representation for this.

5.  Did this investigation prove the law of conservation of momentum in collisions? Explain your answer.

6.  If there was a discrepancy, explain why you think that may have happened.

7.  How would you modify the investigation to address conditions of the system resulting in more accurate data?

**Explore**

**CER**

Vehicle A                                        Vehicle B

Two vehicles have a head-on collision. The vehicles essentially stick together and travel a certain distance for 20 seconds before coming to a complete stop. You are able to obtain the mass of both vehicles, the initial velocity for Vehicle A, and the final velocity for both vehicles immediately after the crash. Can you determine the momentum of both vehicles before the collision?

**Claim:**

**Evidence:**

**Reasoning:**

**Explore**

Name: _____ Date: _____

# Conservation of Momentum

**Introduction**
In inelastic collisions, momentum is conserved, resulting in the objects "sticking" together as they move forward. In real-life collisions, cars can smash together as the wreckage slides to a stop.

**Question**
How do the velocity and momentum change when an inelastic collision occurs?

**Hypothesis**
I think the velocity will decrease, because mass increases and momentum is conserved.

**Materials**

**Printed Material**
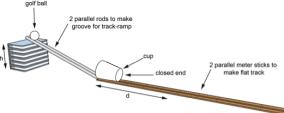1 Student Journal (per student, group, or class)

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2 Stopwatch (per group)
2 Rods, wooden, 70 cm to 100 cm long, of equal diameter (per group)
1 Scale, digital (per group)
6 Book, hardback (per group)

What, if any, safety steps need to be taken?
Students will add safety precautions here.

**Explore**

**Student Procedure**

Track Setup
1. Set up the tracks by placing two metersticks parallel to each other on a table or other flat surface. Position the meter sticks to be the same distance apart as the opening to the cup. The cup should rest easily between the two meter sticks.
2. Construct the ramp portion using a board with two wooden rods taped on it to create a groove for the ball to travel in.
3. Set up the ramp using books. The ramp should meet the meterstick track on the table.
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Investigation
5. Measure the distance the ball will travel from the point where it starts on the ramp to the point it reaches the cup.
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13. By timing the entire journey of the ball, and subtracting the time it takes for the ball to travel down the ramp (which you recorded in Data Table 1), you will be able to determine the time the ball/cup combination traveled together.
14. Record this time on Data Table 2 under the column "Time Traveled On Track."
15. Record the distance traveled by the ball/cup combination on Data Table 2 under the column Distance.

 **Explore**

16. You are now able to calculate the velocity and momentum of the ball/cup combination to complete Data Table 2.

**Data Analysis**
Data will vary depending upon the mass of the ball, the cup, and the height of the angled track.

| Data Table 1: Data for Initial System (Ball only) | | | | | |
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| Trial | Mass Ball (kg) | Distance (m) | Time on Angled Track (s) | Velocity (m/s) | Momentum (kg · m/s) |
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| 2 | | | | | |
| 3 | | | | | |
| Average | | | | | |

| Data Table 2: Data for Final System (Cup with Three Quarters + Ball) | | | | | | |
|---|---|---|---|---|---|---|
| Trial | Mass Ball (kg) | Mass Cup (kg) | Distance (m) | Time of traveled on track (s) | Velocity (m/s) | Momentum (kg · m/s) |
| 1 | | | | | | |
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| 3 | | | | | | |

**Explore**

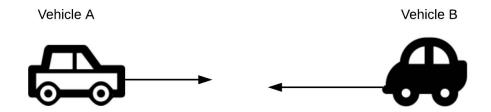| Average | | | | | | |
|---------|--|--|--|--|--|--|

**Data Analysis**

1.  What was the average momentum for the ball as it moved down the bottom of the ramp?
    Answers will vary.

2.  What was the initial momentum of the cup before the ball collided with it? The initial momentum should have been zero, since the cup had no velocity before the ball collided with it.

3.  What was the average momentum of the system when the ball was in the cup? Answers will vary but should reflect data from Data Table 2.

4.  The law of conservation of momentum states that momentum is conserved; therefore, in an inelastic collision, the sum of the initial momentum should equal the final momentum. Using your answers for questions 1–3, show the mathematical representation for this.
    Answers will vary but should represent p (ball at bottom of ramp) + p (cup initial) = p (system).

5.  Did this investigation prove the law of conservation of momentum in collisions? Explain your answer. Answers will vary.

6.  If there was a discrepancy, explain why you think that may have happened. Ideally, there would be no net force on a system that shows the law of conservation of momentum. In this case, there was possibly friction on the cup that was not taken into account. Also, the measurements of time could have been inaccurate, resulting in inaccurate velocity that would impact the momentum.

7.  How would you modify the investigation to address conditions of the system resulting in more accurate data? Having a longer distance for the ramp would allow for more time and possibly more accurate measurements. A track with no friction would remove any additional forces from the system.

 **Explore**

**CER**

Vehicle A                                                    Vehicle B



Two vehicles have a head-on collision. The vehicles essentially stick together and travel a certain distance for 20 seconds before coming to a complete stop. You are able to obtain the mass of both vehicles, the initial velocity for Vehicle A, and the final velocity for both vehicles immediately after the crash. Can you determine the momentum of both vehicles before the collision?

Write a **claim** that answers your question.
Yes, you can determine the momentum for both vehicles.

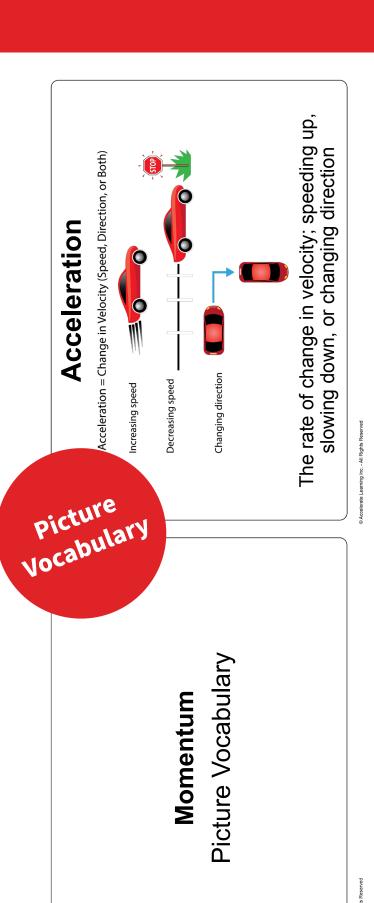What **evidence** did you gather that supports your claim?
To determine momentum you need mass and velocity. You have the mass and velocity for the vehicles after the collision so you can determine the final momentum.
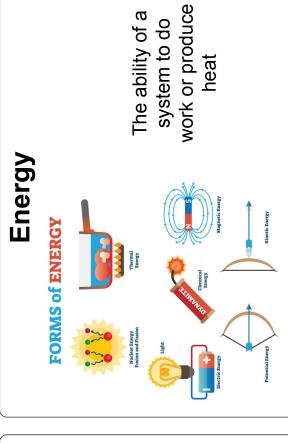
You have enough information to determine the initial momentum for Vehicle A

What scientific **reasoning** connects the evidence to the claim?

Based on the law of conservation of momentum, the total momentum of the vehicles before the collision should equal the total momentum after the collision. If you have the initial momentum on one vehicle and the final momentum of both vehicles, you can determine the unknown momentum, using the following equation:
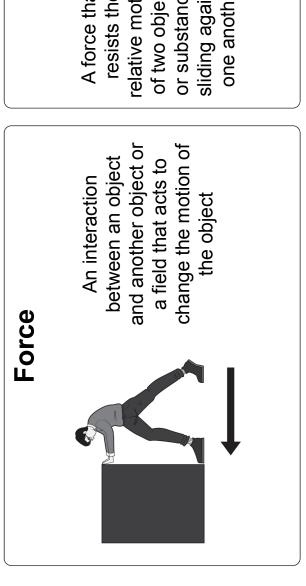p (i) Vehicle A + p (i) Vehicle B = P (f) Vehicles A and B

## Acceleration

Acceleration = Change in Velocity (Speed, Direction, or Both)

Increasing speed

Decreasing speed

Changing direction

The rate of change in velocity; speeding up, slowing down, or changing direction

## Energy

FORMS of ENERGY

Thermal Energy

Magnetic Energy

Kinetic Energy

Nuclear Energy Fusion and Fission

Chemical Energy

Light

Electric Energy

Potential Energy

The ability of a system to do work or produce heat

## Picture Vocabulary

## Momentum
Picture Vocabulary

## Elastic Collision

Elastic

Before collision

Collision

After collision

An encounter between objects in which the total kinetic energy of the objects before and after the collision is equal

# Frictional Force

$F_{applied}$

$F_{normal}$

$F_{weight}$

$F_{friction}$

A force that resists the relative motion of two objects or substances sliding against one another
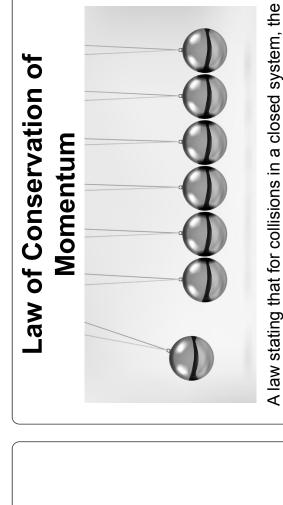
# Inelastic Collision

Before

$V_i$

$m_1$

$m_2$

After

$V_f$

$m_1 + m_2$

An encounter between objects in which some of the kinetic energy is converted into other forms of energy

# Force

An interaction between an object and another object or a field that acts to change the motion of the object

# Impulse

A force exerted over a time interval that causes a change in an object's momentum

# Law of Conservation of Momentum



A law stating that for collisions in a closed system, the total momentum remains the same
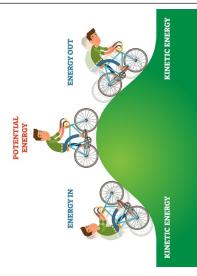
# Mechanical Energy



The sum of the potential energy and kinetic energy of an object; changes when work is done on the object

# Kinematics



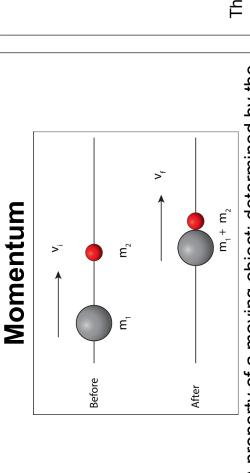The study of motion

# Mass



A measure of how much matter is present in a substance

# Motion



The change in an object's position with respect to time and in comparison to the positions of other objects used as reference points

# Newton (N)



The SI unit of force, or mass times acceleration

# Momentum
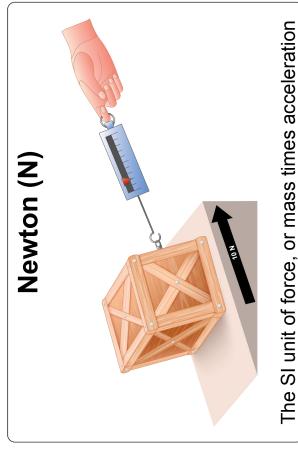


A property of a moving object; determined by the product of its mass and velocity

# Net Force



The overall force acting on a system or object after opposing or balanced forces cancel each other out

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# System



Respiratory System

Pulley System

Force

Load

Solar System

A group of interacting, interrelated, or interdependent elements forming a complex whole

# Vector Quantity



40 miles west
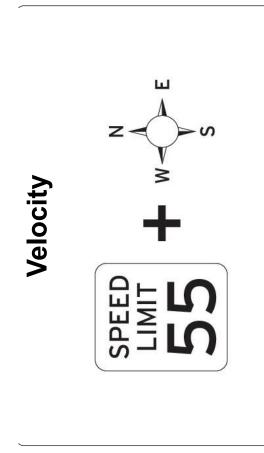
A quantity with both a magnitude and a direction

# Sound Energy



A form of energy that is made by vibrations traveling as waves and requires a medium (air, water, or solids) in order to travel

# Thermal Energy



The internal energy of a system, including the kinetic and potential energy of its particles

## Velocity

SPEED LIMIT **55**

**+**

N
W
E
S

The rate of change of position of an object moving in a specific direction

# Math Connections

Name: _____   Date: _____

**Use the following information to solve questions 1–5.**

**Momentum** is the quantity of motion an object has. The amount of an object's momentum depends on its mass and velocity, and it can be calculated using the following equation.

**momentum (p) = mass (m) × velocity (v)**

1. If the mass of an object is measured in kg and the velocity is measured in m/s, what is the unit for momentum?

2. The mass of a fully loaded Boeing 747 is about 4,082,331.33 kg. If it is cruising eastward at a velocity of 253 m/s, what is its momentum?

3. How fast does a 142-gram baseball have to be traveling to achieve a momentum of 3.905 kg • m/s?

4. The 500 series bullet train travels between Tokyo and Hakata, Japan. If it is heading north with a momentum of 13,194,098.64 kg • m/s and at a velocity of 261.8 km/h, what is its mass?

5. What is the momentum of a water balloon with a mass of 0.035 kg traveling through the air at a velocity of 11.176 m/s?

# Math Connections

**Use the following information to answer questions 6–9.**

The following table contains data about the effect of the mass of a jockey on the amount of momentum a horse has when racing. The mass of the jockeys, the mass of the horse, and the velocity of the horse are shown below.
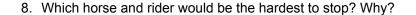
| Riders | Mass of Jockey (kg) | Mass of Horse (kg) | Velocity (m/s) | Momentum (kg • m/s) |
|--------|--------------------|--------------------|--------------|--------------------|
| Rider 1 | 110 | 489.88 | 0.82 | |
| Rider 2 | 115 | 489.88 | 0.82 | |
| Rider 3 | 120 | 489.88 | 0.82 | |
| Rider 4 | 125 | 489.88 | 0.82 | |

6. Calculate the total momentum of the horse and jockey for each jockey, and input the data in the table.

7. Plot the combined mass of the horse and jockey compared to the total momentum of the horse and jockey on the graph below.

# Math Connections

8. Which horse and rider would be the hardest to stop? Why?

9. What is the relationship between the mass and the momentum of an object moving at a constant velocity?

**Use the following information to answer questions 10–11.**
In a collision, an object experiences a force (or impulse) for a certain amount of time, which changes the momentum of the object. When an impulse is encountered, the object's mass either speeds up or slows down. We can describe **the impulse-momentum change** using the equation below.

$$F \times t = m \times \Delta v$$

10. If a 1,279 kg car is moving at 26.82 m/s when it hits a truck, resulting in a 20,000 N force that slows the car down to 10 m/s, for how long did the car experience the force?

11. If a 110 kg go-cart traveling at 13.41 m/s has a collision and experiences an impulse of 615 N for 1 s, what is its change in velocity?

Momentum

# Claim-Evidence-Reasoning

Name: _____ Date: _____
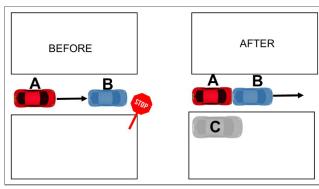
**CER Assessment**

## Scenario

On an icy day, a police officer was using his radar gun to catch speeding cars when he wit...
rear-end collision. The officer drew a diagram of the accident in his police report, and a reproduction
of it is shown below. In the diagram, each car is represented by a box with the appropriate letter
labeled, and Car C represents the police officer. There is also some data that has been collected by a
team of lawyers hired by the the driver of Car A. The driver of Car A claims that he was not speeding
at the time of the collision.

## Prompt

Based on the information the officer collected at the scene of the crime, write a scientific explanation
that determines whether or not Car A was speeding when it collided with Car B. Be sure that you
make a claim, provide mathematical evidence, and present reasoning based on scientific principles
that can be understood by the team of lawyers.

## External Data



|  | Car A | Car B |
|---|---|---|
| Model | Mini Cooper | Subaru Outback |
| Mass | 1,550 kg | 2,100 kg |
| Initial Velocity | Unknown | 0 m/s |
| Final Velocity | 6.64 m/s | 6.64 m/s |

| Speed Limit | 15.64 m/s |
|---|---|
| Road Conditions | Icy |
| Time of Day | 3:27 p.m. |

**Claim-Evidence-Reasoning**

Name: _____     Date: _____

# Momentum

## Rubric for Writing a Scientific Explanation

| Points Awarded | 2 | 1 | 0 |
|---|---|---|---|
| **Claim** | Makes an accurate claim or answers the question. | Makes an inaccurate claim. | No claim, or does not answer the question. |
| **Evidence** | Cites comparative data, uses labels, and addresses variables. | Cites some, but not all, appropriate data, or does not use labels or statistical analysis. | No evidence, or cites changes but does not use data from the data table. |
| **Reasoning** | Cites the scientifically accurate reason, using correct vocabulary, and connects this to the claim. Is able to show accurate understanding of the concept. | Cites a reason, but it is inaccurate or does not support the claim. Reasoning does not use scientific terminology or uses it inaccurately. | No reasoning, or restates the claim but offers no reasoning. |
| **Rebuttal** | Rebuttal provides reasons for different data in the class data or outliers in the data. Can also provide relevance to the real world or other uses for the findings. | Rebuttal is not connected to the investigation or is inaccurate. | Does not offer a rebuttal. |

Momentum

**Claim-Evidence-Reasoning**

Name: _____ Date: _____

**Claim**:

**Evidence**:

**Reasoning**:

**Rebuttal**:

Momentum

# Claim-Evidence-Reasoning

Name: _____ Date: _____

**Claim:**
States that either Car A was not speeding (driving the speed limit) before the collision.

**Evidence:**
States that the collision was inelastic because both cars moved as one mass.
$m_a v_a = (m_a + m_b) v_b$
$m_a = 1550$ kg
$v_a = ?$
$m_b = 2100$ kg
$v_b = 6.64$ m/s

$v_a = ( (1550 + 2100) 6.64 )/1550$
$v_a = 15.63$ m/s

**Reasoning:**
Discusses law of conservation of momentum as well as inelastic collisions. In an inelastic collision, the momentum before the collision has to equal the momentum after the collision of the two vehicles.  That information can be used to determine the velocity of Car A before the impact based on conservation of momentum. With the data given, it is determined that Car A was travelling at 15.63 m/s which is under the speed limit of 15.64 m/s.

**Rebuttal:**
It's possible that all the momentum was conserved but we were limited by the accuracy with which we could measure it. For example: Human error in recording the velocity of the vehicles after the collision, the road conditions could have produced some friction, or differences in masses of the vehicles.

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