National Aeronautics and Space Administration

Momentum and Impulse

Educator Notes

Learning Objectives

Students will:

- Understand momentum as the mass of an object multiplied by its velocity
- Demonstrate impulse is a force applied over time to an object resulting in a change to the object's momentum

Challenge Overview

For an object in linear motion, its momentum can be defined as $p=mv$, or the momentum of an object (p) is equal to its mass (m) multiplied by its velocity (v). Momentum is a conserved quantity in a closed system, meaning if no outside forces act on the system, its total momentum will always stay the same. When you apply force to an object, it causes a change in the object's velocity, thus changing its momentum. You can apply this force suddenly or gradually over time. This amount of force applied over time, and thus the total change in momentum, is known as impulse. Objects which are accelerated (or decelerated) slowly, such as when falling due to gravity, are subjected to the same total impulse as objects which are accelerated (or decelerated) very quickly, such as when colliding with the ground. Spreading the force of a collision over a longer period of time decreases damage and reduces the risk of injury.

Challenge Preparation

The educator should:

- Read through and become familiar with this activity
- Prepare the listed materials

Introduce the Challenge

To activate prior knowledge, ask students the following questions:

- You can play the game of tennis on a variety of surfaces. Courts made of clay, grass, or hard surfaces each affect the way the ball bounces, and professional tennis players must adapt to each playing surface. Have you ever noticed how a ball bounces differently on a variety of surfaces? Why do you think this is?
- Have you ever dropped an object on a hard surface causing it to break? A dish…an egg…a phone? What would have happened if you had dropped it on a softer surface, such as grass or carpet? Why?

Facilitate the Challenge

Engage

Grades 6 to 12

Suggested Pacing

45 minutes

Materials for Each Pair of Students

- Student Activity Sheet
- Variety of three small balls (These can be marbles, golf balls, ping pong balls, bouncy balls, etc.)
- Variety of surfaces to drop balls on (These can be a tile floor, textbook, doormat, carpet, sidewalk etc.)
- Meter stick
- Egg or Water Balloon

National STEM Standards

- MS-PS2-1

Orion spacecraft splashdown test. The Orion Spacecraft splashes down into the ocean after parachuting to lower the impulse of landing. **Credits: NASA**

Momentum and Impulse

- Show the STEMonstration: Momentum and Impulse available at https://www.nasa.gov/stemonstrations
- Think/Pair/Share: How does changing the surface the ball collided with change the way it bounced?

Explore

1. Divide students into pairs and pass out the student handouts, meter sticks, and one type of each ball to each group.
2. Challenge students to identify three different surfaces on which to drop their balls. They will list these surfaces in the chart on their handout.
3. Students will then perform drop tests with each type of ball on each type of surface for a total of nine tests.
    a. One student will hold the meter stick vertically on the surface and drop the ball from a height of one meter.
    b. The other student will observe the height to which the ball bounced. This measurement will be recorded on the chart in their handout for each of the drop tests.
4. After completing their drop tests and recording the results, have students complete the questions in the "Share" section of their worksheet.

Share

1. Regroup the class to discuss of their results.
2. How is the experiment you performed like the one shown by European Space Agency (ESA) astronaut, Andreas Mogensen, in the STEMonstration video?
    a. Possible answers:
        i. We both bounced balls on different surfaces.
        ii. We both observed how quickly balls bounced.
3. How is the experiment you performed different from the one shown aboard the International Space Station?
    a. Possible answers:
        i. We used small solid balls, but the astronaut used an inflatable ball.
        ii. We dropped our balls, but the astronaut had to throw his.
        iii. We recorded the height of our bounces.
4. What type of ball bounced the best?
    a. Why do you think that is?
5. What type of surface caused the balls to bounce the highest?
    a. Why do you think that is?
6. What made the bigger difference, the type of ball or the type of surface?

Elaborate

1. Explain to your students that the surface an object impacts during a collision can determine how the object feels that impulse. A hard surface, such as a tile floor or concrete, has very little give, so the force decelerating the object during a collision is very sudden. An equal and opposite force is then directed back into the falling object, causing it to either bounce or break. This change in momentum in the opposite direction shows a large impulse. Softer surfaces, such as carpet and grass, deform in a collision and decelerate the object over a greater distance and longer period of time. Since some of the energy goes into deforming the surface, the objects do not bounce back as high, resulting in a lower overall impulse. Finding ways to slow down gradually during a collision is important for safety. As shown in the video, we use airbags to slow the deceleration, and therefore, the impulse felt by a passenger during a collision reduces serious injury.
2. Bring students outdoors and return them to their pairs.
3. Demonstrate to students a high impulse impact by dropping an egg or water balloon from a height of one meter onto a hard surface, such as a sidewalk.
4. Distribute an egg or water balloon to each pair of students and challenge them to find a surface outdoors to drop their item on from a height of one meter while trying to keep it from breaking.
5. Each pair should receive your approval for the surface they have chosen before conducting their drop test.

6. Have students record the surface type and the results of their drop test in their student handouts.

Reflect

Engage students with the following discussion questions:

- On what surface did you choose to drop your object?
- Did you predict it would land successfully or break? Was your hypothesis correct?
- What would you have chosen as the ideal surface to drop your object onto?
- Why would that chosen surface have kept your object safe?
- How does that relate to the momentum of your falling object and the impulse it would have received during impact?
- As a group, come up with a list of five items you use in your everyday lives which lower the impulse of impacts/collisions
- Possible Answers: Cushioned soles in shoes, pillows on our bed, shock absorbers in cars, pads in sports equipment, etc.

Extensions

Like protecting eggs from disaster? Try the Eggstronaut Parachute Challenge
Want to see how NASA performs impact tests? Take a virtual tour of NASA's Ballistic Impact Facility

Momentum and Impulse

Student Handout

Engage

- Watch the STEMonstration: Momentum and Impulse video featuring European Space Agency (ESA) Astronaut, Andreas Mogensen
- With a partner, discuss how the different surfaces the ball collided with affected the way it bounced

Explore

1. Your teacher will group you into pairs and distribute a meter stick and three different types of small balls.
2. Look around the classroom and identify three different surfaces on which you can safely drop your balls from a height of one meter. Try to choose a variety of soft and hard surfaces. List your three ball types and three surface types in the table below.

Table 1: 1 Meter Bounce Heights (cm)

	Ball 1: _____	Ball 2: _____	Ball 3: _____
Surface 1: _____			
Surface 2: _____			
Surface 3: _____			

3. You will now perform drop tests with each type of ball on each type of surface for a total of nine tests.
    a. One student will hold the meter stick vertically on the surface and drop the ball from a height of one meter.
    b. The other student will observe the height, in cm, to which the ball bounced. This measurement will be recorded in the table above.
4. After completing your drop tests, complete the questions in the "Share" section below.

Share

- How is the experiment you performed like the one shown by astronaut Andreas Mogensen in the STEMonstration video?

_____

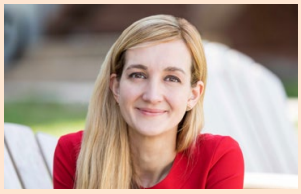
_____

Career Corner

NASA studies collisions to learn about everything from the effects of micrometeor impacts on spacesuits to deflecting asteroids out of Earth's orbital path. Elana Adams is a systems engineer at the Applied Physics Lab at Johns Hopkins University. She led the Double Asteroid Redirection Test (DART) Mission team to build and launch a spacecraft that could change the trajectory of an asteroid by impacting it. On Sept. 26, 2022, the DART Mission spacecraft impacted a small asteroid, Dimorphos, and changed its orbit around a larger asteroid, Didymos. The mission demonstrated that an asteroid on a collision course with Earth could potentially be redirected using the force of an impact from a spacecraft.

Learn more: Behind the Spacecraft with Elana Adams

Double Asteroid Redirection Test (DART) Mission



Elena Adams,
Systems Engineer

- How is the experiment you performed different from the one shown aboard the International Space Station?

_____

_____

- What type of ball bounced the best? _____
  - Why do you think it that is? _____

_____

- What type of surface caused the balls to bounce the highest? _____
  - Why do you think that is? _____

_____

- What made the bigger difference, the type of ball or the type of surface? _____
- Your teacher will regroup the class to discuss your answers to these questions.

Elaborate

1. After a discussion about impulse and the use of softer surfaces to cushion collisions, your teacher will direct your groups outside to demonstrate a collision with an object and a hard surface.
2. After the demonstration, your teacher will distribute one of those objects to you. You are challenged to search the area designated by your teacher for a surface you think will most likely protect your object from a drop of one meter in height. After selecting a surface and receiving approval from your teacher, drop your object from a height of one meter and determine if it survives the impact with the surface.
3. What type of surface did you choose? _____
4. Did your object survive the impact from the drop? _____

Reflect

- Answer the following questions and be prepared to discuss them with your class.
- What type of surface did you choose to drop your object onto? _____
- Did you predict it would land successfully or break? _____
- Did it land successfully, or did it break? _____
- What would you have chosen as the ideal surface to drop your object onto? _____
- Why would that surface keep your object safe? _____

_____

- How does that relate to the momentum of your falling object and the impulse it would have received during impact?

_____

_____

- As a group, come up with a list of five items you use in your everyday lives which lower the impulse of impacts/ collisions.
  1. _____
  2. _____
  3. _____
  4. _____
  5. _____