Lesson 3: Energy, Momentum, and Understanding Car Crashes

Many of us have lost students to violent motor vehicle crashes. In the United States, motor vehicle crashes are the number one cause of death among 16-19 year olds, accounting for more than 40% of all deaths in this age group (US Dept of Transportation, 2000). While multiple factors contribute to the high number of traffic fatalities involving teenagers the two most common errors are speeding and not wearing a seat belt (Jiles, 2005). This unit describes how forces, momentum and energy determine the outcome of a car crash. A recent study found only 54% of teenagers were wearing their seat belts while being dropped off at school by adults (IIHS, 2002). Maybe after learning they cannot argue with the laws of physics if they are involved in a collision, more students may decide to buckle up.

Newton's Laws and Car Crashes

Newton's second law of motion states that if you wish to accelerate something, you must apply a force to it. Newton's first law of motion then says, once an object is moving it will remain moving (unless friction or another outside force, like a wall, stops it). This is inertia. When Newton described the relationship between force and inertia, he spoke in terms of two other physics concepts: momentum and impulse.

WATCH THIS ICON:
View this short clip from the Insurance Institute for Highway Safety DVD called <u>"Understanding Car Crashes – It's basic physics."</u>

Questions:

While watching the DVD clips, fill in the blanks of the statements below.

Test Track Laws

1. Why did the dummy get left behind? It's called __________ , the property of matter that causes it to____.

2. Isaac Newton's ______________________ Law of Motion states: A body at rest remains at __________ unless acted upon by an external _____________ , and a body in ______________ continues to move at a constant _____________ in a straight line unless it is acted upon by an external force.

Crashing Dummies

3. Now watch what happens when the car crashes into a barrier. The front end of the car is crushing and absorbing _____________, which slows down the rest of the car.
4. In this case, it is the steering wheel and windshield that applies the _____________ that overcomes the dummy's __________

Crash-Barrier Chalkboard

5. Newton explained the relationship between crash forces and inertia in his ______________ Law of Motion.

(Fill in the blanks to explain what each letter in the formula represents.)

6. $F = m \times a$ F = ______________ m = ______________ a = ____________________

7. $F = m\,\Delta v \div \Delta t$ Δv = _____________________ Δt = ____________

8. $Ft = m\Delta v$ Ft = ______________ $m\Delta v$ = _________________

Surfers, Cheetahs, and Elephants ...oh my!

9. Momentum is _________________ in motion. It is the product of an object's_________________ and its _________________.
10. Which has more momentum? An 80,000-pound big rig traveling 2 mph or a 4,000 pound SUV traveling 40 mph? _______________________________________

Soccer Kicks, Slap Shots, and Egg Toss

11. What is it that changes an object's momentum? _________________. It is the product of ________________ and the _________________ for which it acts.
12. If the eggs are of equal mass and are thrown at the same velocity they will have the same _________________. The wall and the sheet both apply equal _________________.
13. The wall applies a _______________ force over a _______________ time, while the sheet applies a ________________ force over a ________________ time.

More Crash Questions

Answer the following questions after viewing the DVD clips from "Understanding Car Crashes – It's basic physics."

14. Show mathematically why an 80,000 pound (36,000 kg) big rig traveling 2 mph (0.89 m/s) has the SAME MOMENTUM as a 4,000 pound (1,800 kg) sport utility vehicle traveling 40 mph (18 m/s).

15. During the Egg-Throwing Demonstration, which egg experienced the greater impulse, the egg that hit the wall or the bed sheet? (Be careful here!) Which egg experienced the greater force of impact? Which egg experienced the greater time of impact?

16. Explain how the fortunate race car drivers survived their high speed crashes.

More on Momentum and How to Change It

The momentum of a moving object is related to its mass and/or velocity. A rolling marble can be stopped more easily than a bowling ball. Both balls have momentum. However, the bowling ball has more momentum than the marble. A moving object has a large momentum if it has a large mass, a large velocity, or both.

Momentum = mass of object x velocity of object

[link momentum to

http://www.glenbrook.k12.il.us/gbssci/Phys/Class/momentum/u4l1a.html]

Newton defined impulse as the quantity needed to change an object's momentum. To change an object's momentum the mass, velocity, or both must change. If the mass remains constant, then the velocity changes and the object accelerates. In his second law, Newton said in order to accelerate (or decelerate) a mass a force must be applied. The way its often expressed is with the equation F=ma. The force "F" is what's needed to move mass "m" with an acceleration of "a". The greater the force on an object, the greater its acceleration, or the greater its change in velocity, and therefore, the greater its change in momentum.

How long the force acts is also important. Apply the brakes briefly to a coasting car, and you produce a small change in its momentum. Apply the same braking force over an extended period of time and you produce a greater change in the car's momentum. So to change something's momentum both force and time are important. The product of force and the time it is applied is called impulse.

Impulse = force of impact x time of impact [link impulse to http://www.glenbrook.k12.il.us/gbssci/Phys/Class/momentum/u4l1b.html]

What does it take to stop a truck? [link to http://hyperphysics.phy-astr.gsu.edu/Hbase/truckc2.html#c1]

Two trucks have a head-on collision. Which truck will experience the greatest force, impulse, and change in momentum? [link to http://hyperphysics.phy-astr.gsu.edu/Hbase/truckc.html#c1]

CLASSROOM ACTIVITY ICON: IIHS Crash Course Activity #2 Momentum Bashing

1. Download the PDF file for IIHS Crash Course Activity #2 Momentum Bashing (Jones, G., 2000, Teacher Activity Guide for the DVD "Understanding Car Crashes – It's basic physics, " Insurance Institute for Highway Safety)
2. Read the Teacher notes below.
3. Assemble the materials.
4. Conduct the investigation and collect data (either with your students or by yourself).
5. Answer the Post-Activity Crash questions from the student activity sheets with your class (Crash Course Activity #2: Momentum Bashing). Some of the questions are included in this lesson for you to answer as well.

Teacher Notes for IIHS activity "Momentum Bashing" from "Understanding Car Crashes – It's basic physics"

Key question(s)

- What determines if one car has more momentum than another in a two-car collision?
- Does increasing an object's mass increase its momentum or "bashing power?"

Grade levels: 9–12

Time required: 15–20 minutes

Objectives

Students will:

- understand and apply the definition of momentum:

  momentum = mass x velocity
- conduct semi-quantitative analyses of the momentum of two objects involved in
one-dimensional collisions
- describe automobile technologies that reduce the risk of injury in a collision

National Science Education Standards

Standard A: Science as Inquiry

- Identify questions and concepts that guide scientific investigations
- Design and conduct scientific investigations

Standard B: Physical Science

- Motion and forces
- Conservation of energy

Standard F: Science in Personal and Social Perspectives

- Natural and human-induced hazards

Standard G: Nature of Science

- Nature of scientific knowledge
- Historical perspective

Materials needed

For each group:

- ruler with center groove
- 4 marbles, same size
- 5-ounce (148 ml) paper cup
- scissors
- meter sticks (2)
- book to support track (3–4 cm height)

Procedure

1. Explain how scientific knowledge changes by evolving over time, almost always building on earlier knowledge (refer to background information). Tell students this lesson builds on their knowledge of force, inertia, and speed to better understand what happens in a crash. Begin the activity with a discussion of the following open-ended questions on momentum.
   a. Momentum is often used by sports commentators or political analysts to describe a team's or candidate's performance, yet in physics it has a specific meaning. Can they explain the difference?
   b. What determines if one car has more momentum than another in a two-car collision?
2. Explain that momentum has often been loosely defined as the amount of

"oomph" or "bashing power" of a moving object. It is the measurement of an object's inertia in motion or more specifically, **momentum = mass x velocity** In this activity students will see how an object's mass affects its "oomph" or "bashing power."

3. Distribute "Momentum Bashing" activity sheets and supplies to each group. Instruct each group to cut the section from their paper cup and set up their ramp. Long flat tables or tile floors work well for this activity.
4. Circulate and assist groups. Have students measure the distance the cup moves to the nearest 0.1 cm. With good techniques, this simple equipment can produce results that are consistent enough to have students conclude that increasing the number of marbles increases the bashing power or momentum.

Post-Activity Crash Questions

Report data from your experiment.

Number of marbles	Trial #1 (cm)	Trial #2 (cm)	Trial #3 (cm)	Average distance cup moved (cm)

Analysis

1. Describe the relationship between the number of marbles hitting the cup and the distance the cup moves.
2. What determines if one car has more momentum than another in a two-car collision?

For further study

- Do you want a non-stretching seatbelt? Read about seatbelts and what would happen if they did NOT stretch. http://hyperphysics.phy-astr.gsu.edu/Hbase/seatb.html
- What force is required to stop a car going 30 mph in a distance of one foot? http://hyperphysics.phy-astr.gsu.edu/Hbase/carcr.html#cc1
- How do accident investigators calculate the minimum stopping distance for an automobile? http://hyperphysics.phy-astr.gsu.edu/Hbase/crstp.html#c1