Subject: Physics

Title: Conservation of Momentum

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Grade Level: 9

Standards Met:

Physics Standards

Conservation of Momentum

Next Generation Science Standards

HS.PS-FM Forces and Motion, performance standards (b) generate and analyze data to support the claim that the total momentum of a closed system of objects before an interaction is the same as the total momentum of the system of objects after an interaction, (c) use algebraic equations to predict the velocities of objects after an interaction when the masses and velocities of objects before the interaction are known, and (e) construct a scientific argument supporting the claim that the predictability of changes within systems can be understood by defining the forces and changes in momentum both inside and outside the system

Science and Engineering Practices: Planning and carrying out investigations, Analyzing and interpreting data, Using mathematics and computational thinking, Constructing explanations and designing solutions, Developing and using models

ACT Standards

Scientific Investigation – Predict the results of an additional trial or measurement in an experiment (24-27), Determine the experimental conditions that would produce specific results (24-27), Identify an alternate method for testing a hypothesis (28-32)

Evaluation of Models, etc - Select a simple hypothesis, prediction, or conclusion that is supported by a data presentation or a model (20-23)

Time Needed: 60 minutes

Objective(s): Demonstrate conservation of momentum in two body collisions

Summary: Students will design their own experiment to demonstrate the effects of mass and velocity on a two-body collision. Students will analyze the effects of varying momentum in collisions.

Vocabulary: Mass, Velocity, Momentum, Conservation of Momentum, Collisions

Student Prerequisites: mass, velocity

Teacher Materials Needed: None

Student Materials Needed: None

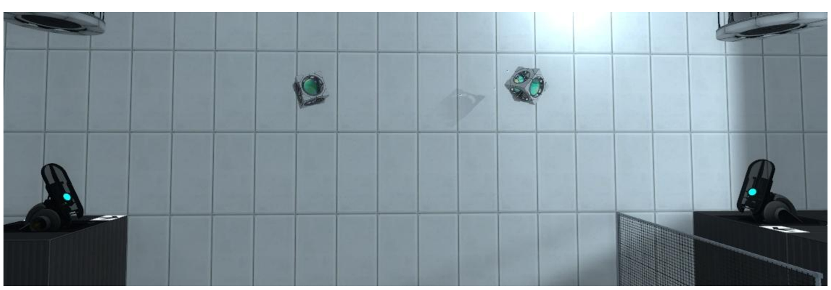
This lesson plan was developed with the idea that the educator understands physics and the basics of Portal 2. *The lesson itself should flow from an introduction, into a main lab activity, and then finish with follow up questions and a homework assignment. The* ***Introductory Activity*** *section starts with questions to ask students at the beginning of class or in the class prior. The* ***Implementation*** *section gives instructions to the instructor as to how to set up the main lab activity. The* ***Closing Activity*** *section lists questions for students after they complete the main lab activity. The* ***Homework*** *section suggests questions to assign as homework after the lab. The* ***Grading Advice*** *section gives answers to all of the questions in the* ***Introductory Activity****,* ***Implementation****,* ***Closing Activity****, and* ***Homework*** *sections. I'm always looking for better lessons or ideas. If you have any questions or comments, please contact me at: cameron *dot* w *dot* pittman *at* gmail *dot* com.*

Introductory Activity:

1. In the level Column Blocker, two reflection cubes get launched, hit each other in midair, and then fall straight down.
    a. If both cubes have the same velocity, how do their masses compare?
    b. If cube 1 has a velocity that is greater than that of cube 2, how do their masses compare?
2. GLaDOS frequently pokes fun of Chell's weight. To prove to herself that she isn't fat, Chell goes ice skating with her companion cube, which has a mass of 20 kg. While standing still on the ice, Chell throws her companion cube away at a velocity of 5 m/s. If Chell recoils backwards at a velocity of 2 m/s, what is her mass?

Implementation:

- Instruct students to build a test chamber that collides cubes in midair, like so.



- Instruct students to build two separate collisions; one where the cubes hit going the exact same speed and fall straight down, and another where one cube has significantly more speed.
- Instruct students that they will be changing the masses of the cubes and making calculations. As they proceed, they need to fill out the Lab Notes Worksheet.
- Instruct students to build a third collision, where cubes of different masses strike each other in midair but still fall straight down.
- Once students finish the attached worksheet, instruct them to find an alternate way to test conservation of momentum with regards to cube collisions.
- Students will be creating objects with different masses. You'll need to check with the teacher forum (http://forums.steampowered.com/forums/forumdisplay.php?f=1249) for info on how to do that.

Closing Activity:

1. When velocities and masses are equal, where do the cubes land?
2. When velocities are equal but masses are *not*, how does mass determine where the cubes land?
3. When velocities are *not* equal but masses are equal, how does velocity determine where the cubes land?
4. In the situation where neither mass nor velocity is equal, things get trickier. If cube 1 has a mass of 40 kg and a velocity of 4 m/s to the right at impact and cube 2 has a mass of 20 kg and a velocity of 9 m/s to the left at impact, which way will the cubes move after impact?
5. In perfectly elastic collisions, kinetic energy is conserved. In an inelastic collision, some kinetic energy is lost. Describe the collisions between reflection cubes as elastic, inelastic, or some combination. Provide evidence for your reasoning.

Homework:

1. Two reflection cubes strike each other in midair. Cube 1 has a velocity of 15 m/s and a mass of 12 kg, and cube 2 has a mass of 24 kg. With what velocity must cube 2 be traveling so that both cubes fall straight down? Assume an inelastic collision.
2. In the original *Portal*, GLaDOS tells the player that "momentum, a function of mass and velocity, is conserved between portals." In layman's terms, what did she mean?

Grading Advice:

Introductory Activity

1. a. Their masses must be equal if they fall straight down.
   b. Cube 2's mass must be larger.
2. Starting with the equation for conservation of momentum for an inelastic collision
   $$MV = m_1 v_1 + m_2 v_2 \quad (1)$$
   where M is the combined mass, V is their initial velocity. $V = 0$, so the equation is rearranged to
   $$m_1 v_1 = m_2 v_2 \quad (2)$$
   If we let Chell be object 1 and the cube be object 2, we rearrange to solve for Chell's mass
   $$m_1 = \frac{m_2 v_2}{v_1} \quad (3)$$
   Plugging in, we find that $m_1 = 50$ kg.

Implementation

Their descriptions should show that cubes with higher momentums will dictate the direction the cubes travel after colliding. In instances where a large slow cube interacts with a fast small cube, students should note that the result should be somewhat as if they had the same mass and velocity.

Closing Activity

1. Cubes land below their point of impact.
2. The cube with the larger mass dictates the direction of motion after impact.
3. The faster cube dictates the direction of motion after impact.

4. Cube 1 has a momentum of 160 kg-m/s. Cube 2 has a momentum of 180 kg-m/s. As cube 2 has a larger momentum and is moving to the left, they will tend towards the left after impact.
5. Cube interactions are somewhere between elastic and inelastic. While the cubes bounce off each other, it is clear that not all kinetic energy is conserved (as is *nearly* the case for objects like super balls).

Homework

1. Starting with equation 1 where M is their combined mass and V is their combined velocity, we set $V = 0$ and rearrange to find equation 2. Solving equation 2 for v_2 yields
$$v_2 = \frac{m_1 v_1}{m_2} \tag{4}$$
Plugging in, we find that $v_2 = 7.5$ m/s.
2. To quote the game: "Speedy thing goes in, speedy thing goes out." Whatever speed an object has entering a portal is the same speed they have when they leave the other.

Additional Activities:

- Slide cubes into each other on propulsion gel rather than colliding in midair (RECOMMENDED. LOTS OF FUN!)
- Coat cubes in repulsion gel first then collide them together for elastic collisions.

TEACHWITHPORTALS™

Lab Notes Worksheet

Velocities Equal

Cube 1: Normal Mass Cube 2: Normal Mass

Description of the collision: ____

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Cube 1: Low Mass Cube 2: Normal Mass

Description of the collision: ____

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Cube 1: High Mass Cube 2: Normal Mass

Description of the collision: ____

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Cube 1: High Mass Cube 2: Low Mass

Description of the collision: ____

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Velocities Inequal

Fast Cube: Normal Mass Slow Cube: Normal Mass

Description of the collision: ____

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Fast Cube: Low Mass Slow Cube: Normal Mass

Description of the collision: ____

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Fast Cube: Normal Mass Slow Cube: Low Mass

Description of the collision: ____

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Fast Cube: High Mass Slow Cube: Low Mass

Description of the collision: ____

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APERTURE LABORATORIES