Topic 6: Momentum and Collisions

Source:	*Conceptual Physics* textbook, laboratory manual concept-development book and CPO physics text and laboratory manual
Types of Materials:	Textbooks, laboratory manuals, demonstrations, worksheet and activities and websites and good stories
Building on:	Momentum is a vector and should be treated as such, so at an introductory level, focus on vector drawings in addition to the standard math approach. This topic expands on vectors, kinematics and dynamics after studying Newton's 2nd and 3rd law by presenting another vector application of a physical phenomena occurring in everyone's lives.
Leading to:	Momentum plays a role in circular motion, angular momentum, such as a rotating bicycle wheel, vibration and for photons, such as light particles carrying small amounts of momentum. Emphasis on momentum in sports is a good way to keep young people's attention. An example is when a shot putter throws the shot and momentum is transferred. Atoms and the particles that make up atoms, such as the electron or proton that are used in particle accelerators, carry momentum.
Links to Physics:	Momentum is important in mechanics. A few examples include car collisions, billiards, rockets or any matter that is moving. Momentum plays a role in radiation as in X-ray photons penetrating a piece of metal or a human, UV photons passing through a cloud, or light photons passing through glass. On the atomic level, Einstein showed how light carries a discrete amount of energy and momentum to further explain the exciting of an atom or the release on an electron from the atom through the use of Albert's photoelectric effect. High-energy physics shows how particles and photons carry momentum and energy and by using the conservation laws of nature such as momentum and energy, the creation of new subatomic particles can be explained.
Links to Chemistry:	As mentioned under physics, the ionization of atoms is very important to a chemist. The derivation of the kinetic theory of gases uses momentum to develop the concept. If atoms sharing the same space are subject to reacting, the increase in temperature increases their momentum and chances for collision, resulting in a faster reaction rate. Other examples include diffusion, osmosis and thermal heat conduction by heat conduction.
Links to Biology:	Like chemistry, reaction rates are affected by atoms temperature/momentum. Photosynthesis can be understood using the momentum transfer process. Food energy is converted into motion of the limbs in the human body as in running.

Materials:

(a) Hewitt
Lab 19 – Go Cart
Lab 20 – Tailgated by a Dart

(b) Hsu
Lab 3A – Momentum and the Third Law

(c) My Labs
Linear Momentum on an Air Track (or Dynamics Carts)

(d) Worksheets
Hewitt – Concept-Development Book – 7.1 Momentum
Text (Chapter 7 Review – End of Chapter)

Hsu
3.1 & 3.3 in Text (Questions and Problems – End of Chapter)

My Worksheet
Momentum Worksheet/Activities

(e) Demonstrations
1. Jump from a Chair
2. Happy and Sad Balls

(f) Websites and Videos
1. http://www.hazelwood.K12.mo.us/~grichert/sciweb/applets.html
   Choose pdf Physics Applets - www.walter-fendt.de/ph14e (Java 1.4) - Mechanics – Elastic and Inelastic Collisions. (You change the values, then calculate the kinetic energy before and after the collision and repeat for the momentum.)
2. ESPN SportsFigures “Relaxing with Impulse” Video Guide (Football)
3. Momentum in Collisions Lab Sims (Java)

(g) Good Stories*

Topic 6: Momentum Lab

Collisions on an Air Track (or Dynamics Carts Colliding)

Purpose: To observe and apply the conservation of momentum to elastic and inelastic collisions.

(a) Elastic Collisions (with springs)

Procedure: (After leveling the air track)

1. Push one glider toward a second stationary glider of <u>equal</u> mass and write your observations for the:

   Moving glider –

   Stationary glider -

   Explain why the gliders behave as they do.

2. Push one glider toward a second stationary glider of <u>greater</u> mass and write your observations for the:

   Moving glider –

   Stationary glider –

   Explain why the gliders behave as they do

3. Push one glider toward a second stationary glider of <u>less</u> mass and write your observations for the:

   Moving glider –

   Stationary glider –

   Explain why the gliders behave as they do.

4. Push a small glider toward a large glider that is moving at the same speed <u>but</u> in the opposite direction.

   What happened?

   Which glider experienced the greater <u>change</u> in velocity?

   Which glider experienced the greater <u>change</u> in momentum?

(b) Inelastic Collisions (without springs)

Procedure:

1. Push one glider without a spring toward a second stationary glider of equal mass without a spring, but with clay attached to the end of one or both of the gliders and write your observations for the:

   Moving glider -

   Stationary glider –

   Explain why the gliders behave as they do.

2. Push two <u>equal mass</u> gliders at each other at <u>equal speeds</u>. One glider should have clay attached to an end and the second glider could also have the small piece of clay. Explain why the gliders behave as they do.

Momentum

Topic 6: Momentum Worksheet/Activity (D)

Momentum is defined as a mass moving, or $m\vec{v}$. $\vec{V}$ is a vector so momentum is a vector, with mass being a scalar. In the SI measuring system, mass is measured in kilograms (kg) and velocity is in units of (m/s), so momentum is measured in units of kg m/s, or $\vec{p}$ is in units of kg m/s.

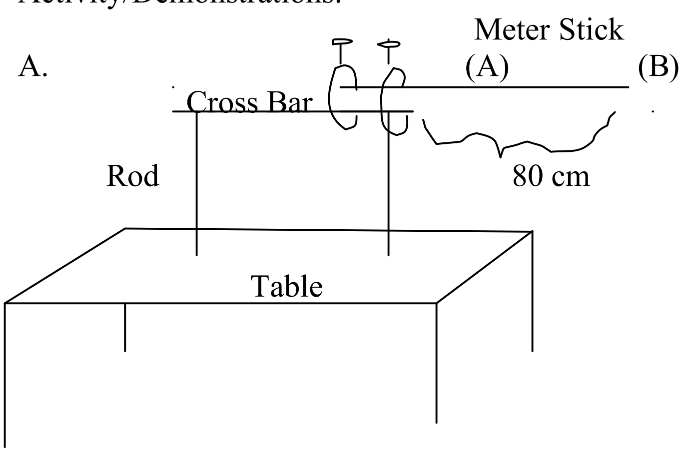
Example: Consider a 2 kg ball moving north at 3m/s. Its momentum is 6 kg m/s going north.

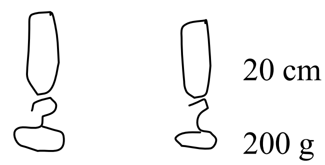
Impulse: Since we have discovered that $F = MA$ and $A = \Delta V / \Delta T$, we get $F = M\Delta V / \Delta T$. So, $F\Delta T = M\Delta V$.

Putting this in words, the equation says: The impulse (force times the time of acting) given to a body changes its momentum by the same amount.

Activity/Demonstrations:

A.





Apparatus: Insert two table support rods into a lab table (or make a tripod support pole very secure). Attach a horizontal cross bar. Clamp about 20 cm of a meter stick to the cross bar (see sketch), leaving 80 cm free to move up and down. Make two 20 cm loops of thread and attach 200 g to each loop.

Procedure/Discussion:

1. Place one loop over the free end of the meter stick until about 10 cm from the end of the cross bar.
2. Lift the weight by the thread until the weight almost touches the meter stick. Use a clean release to drop the weight around 10 cm from the end of the cross bar (A).
3. (a) What occurred?

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(b) Why?

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4. Repeat procedures 1 and 2 using the second loop and weight, but this time near the end of the meter stick (B).

5. (a) What resulted?

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   (b) Why?

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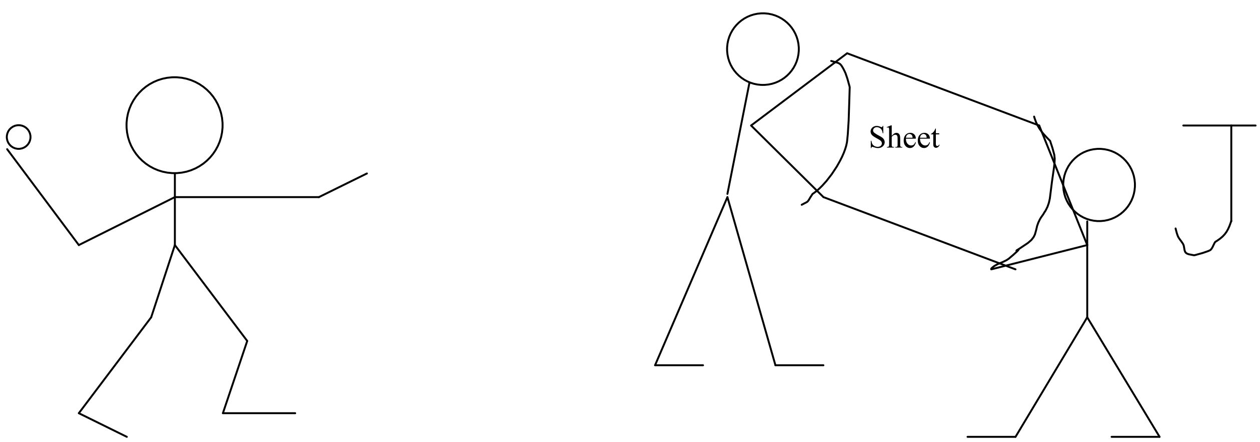
B. Throw a raw egg into the center of a bed sheet that is held by two students as shown in the sketch.



Have two students get a GOOD grip on the corners of the sheet to form a vertical letter J (see sketch). After the "hit," make the J into a U so the egg doesn't roll out.

Explain the outcome. ____

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What would have happened if you through the egg into a brick wall? (Please don't do!)

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Explain the wall/egg outcome. ____

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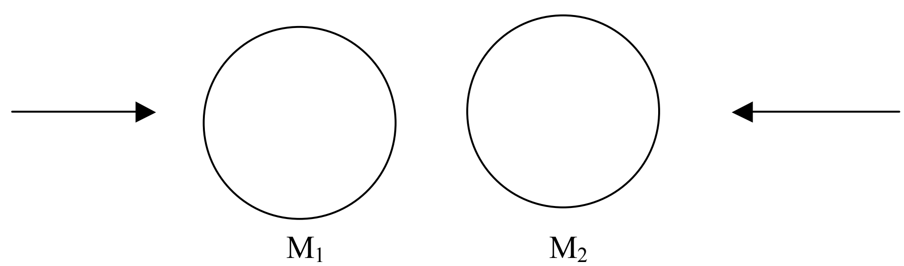
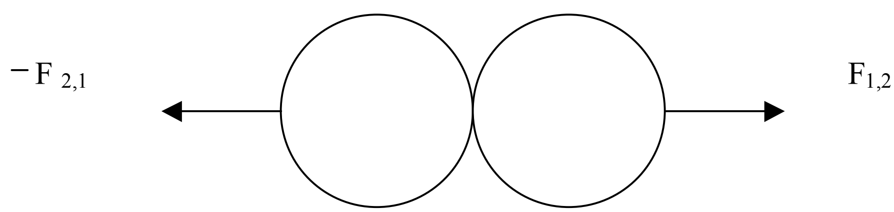
Conservation of Momentum:

The conservation of momentum is a result of Newton's 3rd law. A standard approach to the conservation derivation is as follows:



Two spheres, M_1 and M_2, approach each other along a straight line with velocities V_1 and V_2 respectfully. According to Newton's 3rd law, a pair of equal forces exists between the two spheres at the same time, but in opposite directions, thus,



Mass 1 feels a force of mass 2 on it (called $F_{2,1}$) but opposite to the force on mass 2 caused by mass 1 (called $F_{1,2}$) so $F_{2,1}$ is (-), or in the opposite direction, compared to $F_{1,2}$.

Since $F = MA$, and $-F_{2,1} = F_{1,2}$,

Giving $-M_1A_1 = M_2A_2$, so, $-M_1\Delta V_1 / \Delta T_1 = M_2\Delta V_2 / \Delta T_2$,

And the times of impact are equal on each sphere ($\Delta T_1 = \Delta T_2$),

Thus, $-M_1\Delta V_1 = M_2V_2$.

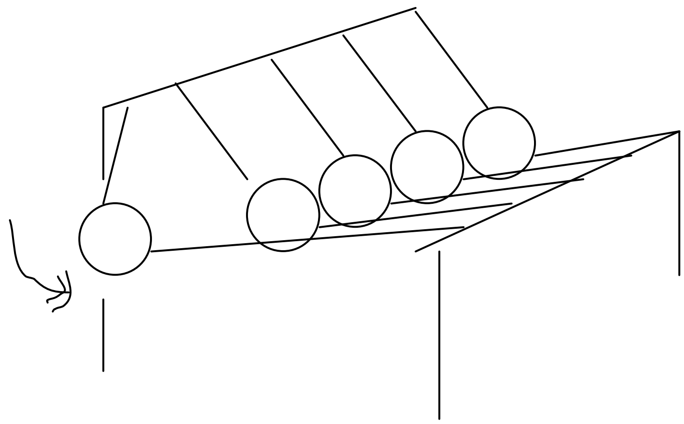
In words, the loss in momentum of mass 1 is equally gained by mass 2. Placing the negative sign on the other side of the equation says mass 1 gains momentum that was lost by mass 2 (THE CONSERVATION OF MOMENTUM).

Or, rewriting, $0 = M_1\Delta V_1 + M_2\Delta V_2$.

Which says that the total change in momentum is zero, or that the total momentum doesn't change—or MOMENTUM IS CONSERVED!!!

This could be written as $0 = \Delta p_1 + \Delta p_2$, saying again, momentum is conserved.

C. Newton's Cradle – Try pulling back one sphere and releasing.



What happened? ____

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Explain using the conservation of momentum. ______________________

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D. Go to the websites in the ARISE presentations and load Java, http://www.java.com/en/index.jsp, and do Momentum in Collisions Lab Sim (Java).

Summarize your findings:

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Topic 6: (e) Demonstrations – Momentum and Collisions

1. Jump from a Chair

   Purpose: To conceptually view impulse and momentum transfer.

   Procedure: Stand on a sturdy chair (be careful) and tell the class you are going to jump and keep your legs straight and your knees locked. Ask: Is that OK with you? Most will say don't do it! Others will say go right ahead and let's see what happens. Jump, but bend your knees upon impact and say that due to my great understanding of physics, I choose to bend my knees!

   Ask:
   Why do I bend my knees?

   Answer:
   Do this demo after talking about impulse or as a lead in to impulse, since $F\,\Delta t = m\,\Delta v$.

   And the change in momentum is the same whether one keeps his/her legs straight or bent upon impact (the starting velocity and the impact velocity are the same); the impulse is the same for both ways. Since impulse is $F\,\Delta t$, one can alter the force with the knees locked or bent. So bending the knees reduces the average force, as the time of impact is much longer, thus you don't break your legs!!

   Locked   Bent

$$\underset{\text{Locked}}{\mathbf{\Large F}\,\Delta t} \quad = \quad \underset{\text{Bent}}{F\,\mathbf{\Large \Delta t}}$$

2. Happy and Sad Balls

   Purpose: This, like the jumping from the chair, conserves momentum but modifies the time and thus the force of impact.

   Procedure: Hold these spheres high above your head at equal heights. Ask students to observe and explain. Drop them and observe that one rebounds as an elastic rubber ball and the second goes thud.

Explanation: They look the same but the molecular make-up is different to change the elasticity of the nonbouncy ball—it hits like a brick! Therefore, we have again,

$$\Large F \, {\scriptstyle \Delta t} \quad = \quad {\scriptstyle F} \, \Delta t$$

Sad – nonbouncy happy - bouncy