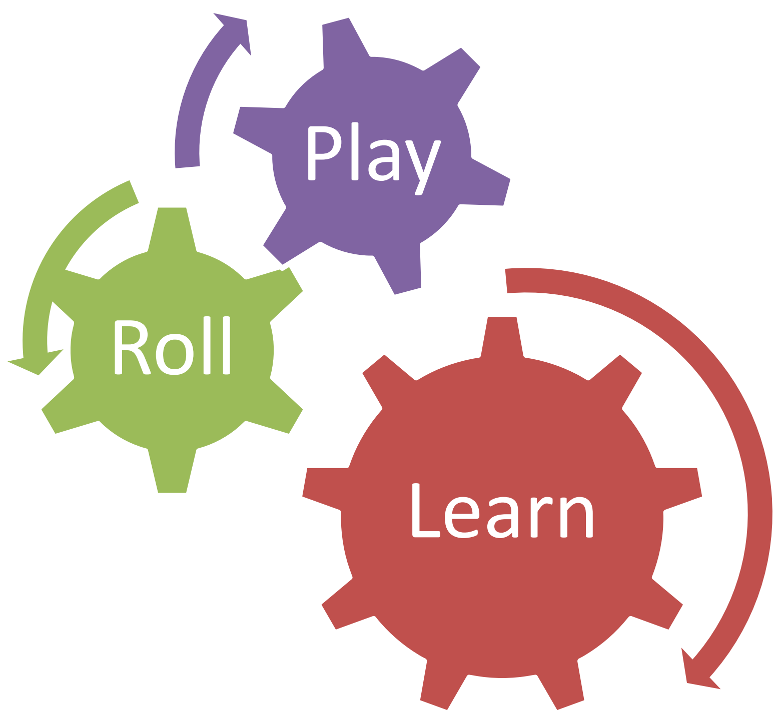
SPS on a roll

Which will roll down a hill faster...

A can of Dr. Pepper or a bowling ball?

A marble or a bike tire?

A can of chicken broth or cream of chicken soup?



FUTURE FACES OF PHYSICS
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Speedsters and Crawlers

Students roll pairs of items down a ramp and categorize objects as "speedsters" or "crawlers". Then they explore the similarities between the objects in the two categories to see what factors affect how fast an object rolls.

Estimated time: 20-30 minutes

Objectives:
- Engaging students in physics through a fun activity.
- Helping students see the connections between an object's properties and how fast it rolls.
- Exploring student predictions about factors that affect the speed of a rolling object.

Materials Included:
- Nine pairs of rolling objects
    1. Small metal cylinder & sharpie
    2. Large metal cylinder & rubber ball
    3. Ping pong ball & golf ball
    4. Golf ball & tennis ball
    5. Ping pong ball & small rubber ball
    6. Small pvc pipe filled & empty
    7. Large pvc pipe & wooden cylinder
    8. Cans of cream of chicken soup & chicken broth
    9. Water bottle & bottle of gravel

Materials Needed:
- A ramp (we used a long board propped up on one end)
- A small board at least the width of the ramp (called "release board" in the rest of the lesson)
- Water

Advance Preparation:
- Set up the ramp and draw a starting and finishing line, as shown in the picture.
- On a large poster board, make a table with two columns: *Speedsters* and *Crawlers*.
- Fill one of the small PVC pipes with play-doh and the empty water bottle with water.
- Make copies of the handout if you decide to distribute them.

In the Classroom:

Note: We suggest designating a "roller" and a "catcher" for each of the pairs, and rotating through these positions until everyone in the group has had a chance.

Rolling Technique
Place the release board directly on top of the starting line as shown in the picture. Rest the two rolling objects against the back of the board. To release the objects, in one fluid motion move the board forward (toward the finish line) and up. If you pull the board directly up, smaller objects will have an advantage.

1. Select a student and have him/her choose a pair of objects from Box 1.

2. Let the student feel the objects, and then ask the student to predict which of the objects is a "speedster" and which is a "crawler."

3. Have the students vote on their predictions.

4. Roll the objects and discuss the results with the group.
   Which object was the crawler? The speedster?
   Why do think this one was the speedster?

5. Record the results in the Speedster/Crawler table.

6. Repeat steps 1-5 until you have rolled all of the pairs in Box 1.

7. When the items from Box 1 have all been rolled, discuss the similarities among the speedsters and the crawlers, and, if necessary, lead students to notice that the speedsters are all solid and the crawlers are all hollow.
   Is the heavier/lighter/smaller/larger object always the speedster?

8. Next, repeat steps 1-5 with the two water bottles and then with the broth/soup. These should initiate new predictions and discussions, as we are now introducing liquids into the activity. Point out that as the liquid-filled bottle is rolling the bubble stays at the top. This indicates that the water is not rotating with the bottle, which is a clue as to why it is a speedster.

9. (optional) As a finale, we like to bring out a bowling ball and 2-liter bottle of pop (or soda…). Students invariably predict that the bowling ball will win, despite step 8.

10. Wrap up the discussion by summarizing the main points (see below), and encouraging students to further explore the science of rolling at home using the handouts provided.

Key Observations and Results:

- Hollow objects roll slower than solid objects.
- Objects filled with liquids roll even faster than solid objects.
- Objects with thin liquids roll faster than objects with thick liquids.

Important Notes for SPS Members:

- Review the science behind rolling (page 5) and decide the level of explanation appropriate for your participants. We have used this activity with students as young as 5 years old and with adults—all are engaged. For example, you might discuss conservation of energy using terms like potential, rotational, and kinetic energy with high school students, but not even bring up the term “conservation of energy” with 5 year olds.

- Make sure that you focus the activity on the science, as students may get distracted with the activity itself. The activity should be presented as a **fun method of learning science and not as a competition regarding whose object will “win” the race.** We have seen that the science gets overlooked if the students identify too strongly with the “winning” objects. The science is better conveyed and recalled, in our view, when both categories are seen as meritorious.

- **Practice the activity before going in front of a live audience!**

The Science behind Rolling Objects

Mechanical energy is the energy associated with the motion or position of an object. It is the sum of potential and kinetic energy. If a rigid object (say a tennis ball or a skate board) with total mass M is allowed to roll along a horizontal straight line then there will be no change in the potential energy, since the center of mass remains at the same height from the ground. On the other hand, if the object is allowed to roll along an incline, the potential energy of the object changes as it rolls because the center-of-mass height is changing. In this activity we will be considering an object rolling along an incline.

As the object rolls, the potential energy changes with the height. The potential energy of the object, relative to a reference height h_0=0, is given by

$$U = Mgh, \tag{1}$$

where U is the potential energy of the object, M is the total mass of the object, g is the acceleration due to gravity and h is the height of the center of mass of the object.

As the object rolls down the incline, its height gradually goes to zero. As the height decreases, the potential energy changes into kinetic energy. Basically, $\Delta K = -\Delta U$. The kinetic energy is the sum of the translational (K_t) and rotational energy (K_r) and can be written:

$$K_T = K_t + K_r$$

$$K_T = \frac{1}{2}Mv^2 + \frac{1}{2}I\omega^2, \tag{2}$$

where v is the translational speed of the center of mass of the object, I is the moment of inertia of the rotating part (the entire tennis ball, for example, or in the case of the skateboard, only the wheels) and ω is the angular velocity of the rotating part of the object. This equation involves both the linear and the angular velocity so it is helpful to express the equation in terms of either v or ω. If we have rolling without slipping then the relation between the two is given by:

$$v = \omega\, R, \tag{3}$$

where R is the radius of the rotating part (from the axis of rotation). After using Eq. (3) we can find the total kinetic energy in terms of linear velocity. Also, by the law of conservation of energy, if the object is released from a height h and rolls to a height zero, the amount of potential energy lost, and the amount of kinetic energy gained, is the full Mgh. If the object was initially at rest, then the initial kinetic energy was zero and final kinetic energy is also Mgh.

$$Mgh = \frac{1}{2}Mv^2 + \frac{1}{2}I\left(\frac{v^2}{R^2}\right) \tag{4}$$

Often, we can write

$$I = \alpha m R^2$$

where α is a constant which varies according to the geometry of the object being rolled, and m is only that part of the total mass that is actually rotating (α is ~ 2/3 for a tennis ball since it can be modeled as a spherical shell; solid cylinders have α = ½). Substituting for I in Eq. (4) and solving for v will enable us to get the velocity of the rolling objects. The final equation is given as follows:

$$v = \sqrt{\frac{2gh}{1+\alpha m/M}} \tag{5}$$

The above model predicts the surprising result that the final speed v at the bottom of the incline is not determined by either the radius or total mass, but rather, on the amount and distribution of mass that is actually rotating—on m/M and α, but not R and M, in other words.

We will be using this concept in the activity to help students understand different factors that affect the speed of rolling objects. With pre-college students we cannot use the technical language of the concept, so we will help them learn by using simple words.

The message that we are trying to communicate is that the solid objects roll faster (the speedsters) than the hollow objects (the crawlers). A second part of the lesson shows that if the object is filled with a "slippery" liquid, or otherwise has parts that don't rotate as it rolls down the incline, as in a skateboard or tricycle, then that object will roll faster in comparison to rigid solids, because the former have a smaller fraction of their relative mass in rotation and the latter have more of their kinetic energy in rotation rather than translation, thus resulting in slower center-of-mass speed.

The following table shows the objects being rolled with their respective explanations for winning and losing. We do not advocate explaining all this and then showing the results, but rather, the idea is to engage the students in rolling races and identifying the *Speedsters* (objects that roll down the incline faster) and the *Crawlers*. After several races, the students should be able to characterize the traits that best predict to which category a new object belongs.

	Crawler	**Speedster**
	BOX 1	
Pair 1	Small metal pipe	Sharpie marker
Pair 2	Large metal pipe	Rubber ball
Pair 3	Ping pong ball	Golf ball
Pair 4	Tennis ball	Golf ball
Pair 5	Ping pong ball	Small rubber ball
Pair 6	Small PVC pipe	Filled small PVC pipe
Pair 7	Large PVC pipe	Wooden cylinders
	BOX 2	
Pair 8	Bottle filled with gravel	Bottled filled with water
Pair 9	Can of cream of chicken soup	Can of chicken broth

-"Hollow" objects are slower because a higher fraction of their mass is far from the center of rotation.
-"Solid" objects roll faster because more of their mass is close to the center of rotation.

-Objects with "thin liquids" inside are fast because a smaller fraction of their energy is rotational, since the liquid does not rotate initially (note the air bubble stays at the top during the rolling). That is, m/M is smaller.

Note: The model doesn't include subtleties like the roughness of the incline which can affect the results in some cases.

For More Information

Online Rolling Resources:

Society of Physics Students, rolling information data collection www.spsnational.org/programs/rolling/

Connecxions http://cnx.org/content/m14391/latest/

PBS Kids- Their rendition of a rolling experiment
http://pbskids.org/curiousgeorge/parentsteachers/activities/pc_ramp_n_roll.html

University of California in Los Angeles
http://www.physics.ucla.edu/demoweb/demomanual/mechanics/rotional_inertia/rolling_objects.html

Year of Science 2009 http://www.yearofscience2009.org/themes_physics_technology/general/physics-experiment.html

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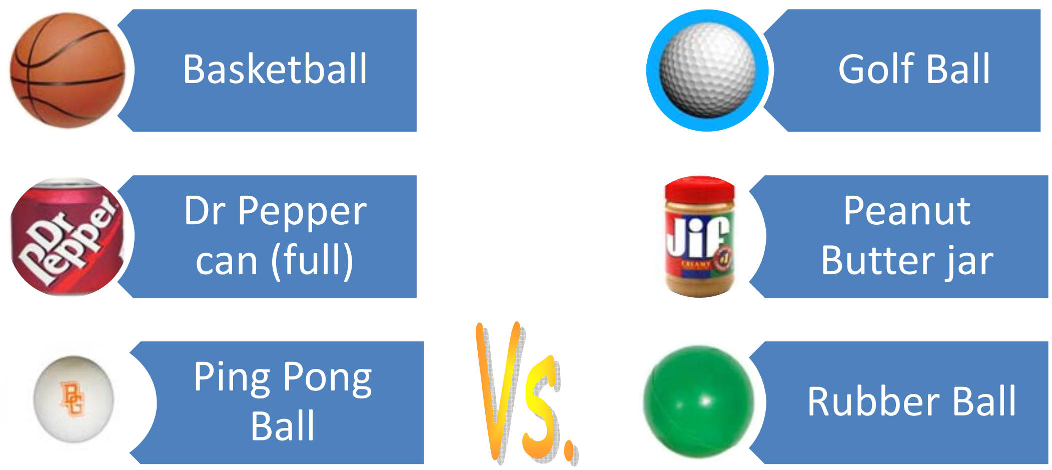
Theron, W. F. D. "The Rolling Motion of an Eccentrically Loaded Wheel", AJP, Vol. 68, # 9, p. 812, Sept. 2000.
"And the Winner Is...", Mad About Physics, Christopher P. Jargodzki and Franklin Potter, p. 95, 231.

Are you ready to roll?

Challenge your friends and family to see if they know as much about rolling as you do. Here are few suggestions for things that you can use:



Which are the crawlers and which are the speedsters?

Do the experiment, be a scientist, and see how things roll!

Then, add your information to Society of Physics Students' rolling database…

www.spsnational.org/programs/rolling