Teacher Guide: Pendulum Clock

Learning Objectives

Students will:

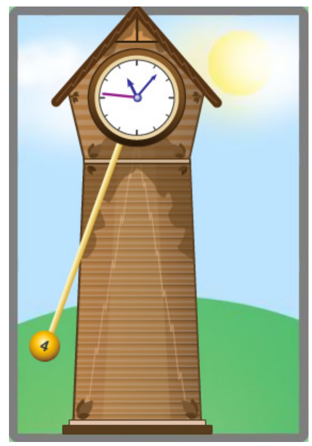
- Discover the properties of a pendulum.
- Measure the period of a pendulum.
- Design controlled experiments to determine the effect of length, mass, starting angle, and gravity on the period of a pendulum.
- Apply knowledge to create a pendulum clock that will tell time accurately.

Vocabulary

bob, calibrate, controlled experiment, gravity, mass, pendulum, period, variable

Lesson Overview

In the *Pendulum Clock* Gizmo™, students can manipulate the length, mass, and starting angle of a pendulum located on Earth or on Jupiter. A clock ticks one second every time the pendulum reaches the left or right limit of its swing.



Pendulum clock

The Student Exploration sheet contains three activities:

- Activity A – Students use a controlled experiment to find the effect of length on the pendulum period.
- Activity B – Students examine how mass, angle, and the strength of gravity affect the pendulum period.
- Activity C – Students use what they have learned to calibrate a clock on Earth and Jupiter.

Suggested Lesson Sequence

1. **Pre-Gizmo activity: Rock drop** (5 – 15 minutes)
   First go to the highest slide or jungle gym on the playground. Tell students that you are going to drop some heavy items (with greater mass) and light items (with less mass). Make sure you select items that will not be influenced by air resistance. Have students predict which items will fall to the earth first. Students will observe that items of all sizes and shapes will fall at the same speed. Explain that gravity is the force that pulls things towards the earth.

   Next, take students to the swings. Discuss what would happen if they were swinging and the swing broke. What force would bring them down to Earth? Help your students realize that gravity is bringing them back down toward earth (as they swing back and forth) just like it did when items were dropped.

   Try several experiments on the swings. Measure the period as you vary the weight of the swinger (adult vs. child), the angle of the swing, and the length of the pendulum (use swings of different lengths if possible).

2. **Prior to using the Gizmo** (10 – 15 minutes)
Before students are at the computers, pass out the Student Exploration sheets and ask students to complete the Prior Knowledge Questions. Discuss student answers as a class, but do not provide correct answers at this point. Afterwards, if possible, use a projector to introduce the Gizmo and demonstrate its basic operations, such as how to change the length, angle, or mass of the pendulum and how to mark time.

3. **Gizmo activities** (15 – 20 minutes per activity)
Assign students to computers. Students can work individually or in small groups. Ask students to work through the activities in the Student Exploration using the Gizmo. Alternatively, you can use a projector and do the Exploration as a teacher-led activity.

4. **Discussion questions** (20 – 30 minutes)
As students are working or just after they are done, discuss the following questions:
   - How does the length of the pendulum affect the pendulum period?
   - How does the mass of the pendulum affect the pendulum period? Does this surprise you? (If you did the pre-Gizmo activity, ask students to relate what they learned about falling objects to what they observe with swinging objects—in both cases the mass does not matter!)
   - Is the angle of the swing always important to pendulum period?
   - At what angle did you begin to see a change in the pendulum period? [Up to 30 degrees or so the angle makes almost no difference to the period. The period does get longer when the starting angle is greater than 30 degrees.]
   - What happened to the clock when it was on Jupiter? Why?
   - If you took a clock to the Moon, would it run faster or slower than on Earth?
   - If you had a grandfather clock that was running too slow, how could you fix it?

5. **Follow-up activity: Pendulum experiments** (1 – 2 days)
After students have used the Gizmo, they are ready to work in pairs or small groups to design and construct their own pendulums. Provide a variety of materials for the bob and an assortment of strings and wires. Have children find the period of their pendulum using a stopwatch. Ask students to record their data to share with their classmates.

Scientific Background
A **pendulum** is weight hung from a fixed point so that it can swing back and forth. Ideally, a simple pendulum would consist of a weighted bob on a massless string or wire suspended to swing back and forth without friction. The bob swings down due to gravity. After it passes its lowest point, the bob is slowed by gravity until it reaches the same height as its starting height. The **period** of a pendulum is the amount of time that it takes a pendulum to complete one full back and forth cycle (**oscillation**).

Galileo Galilei (1564 – 1642) was one of the first to study the scientific properties of pendulums. As a student, he became interested in their characteristics after observing a swaying chandelier in the cathedral of Pisa. (One can imagine the young Galileo was not paying close attention to the sermon at the time!) Using his pulse to measure the time, Galileo noticed that the period of the chandelier seemed to be the same regardless of the size of the angle of its swing. It wasn't until about 20 years later, in 1602, that Galileo began to experiment with pendulums. He made several claims based on these experiments.

- The period of the pendulum is independent of the mass of the bob. (Galileo had already proved that the acceleration of a falling object was the same regardless of its mass. He imagined the pendulum bob was also falling to the lowest point in its arc as it swung.)

- The length of a pendulum determines its period. (In fact, the period of a pendulum is proportional to the square root of the length. If you quadruple the length, the period doubles. If you multiply the length by a factor of 9, the period is multiplied by 3.)

- The period of the pendulum is independent of the angle from which it is released. (This idea was later proved false. It is true that pendulum periods do not change much with starting angles up to 30 degrees. Greater starting angles do yield longer periods.)

The other major factor affecting the pendulum period is gravity. The greater the gravitational force, the greater the acceleration of the pendulum bob at the start of its swing. A pendulum clock will run much faster on Jupiter, where gravity is stronger than on Earth, and more slowly on the Moon.

Historical Connection

Galileo's observation of a church chandelier and later experiments with pendulums paved the way to accurate timekeeping. Shortly before his death Galileo had plans to build a pendulum clock based on the principles that he had discovered, but he never completed it. A Dutch mathematician named Christiaan Huygens made the first pendulum clock in 1656. It was quite accurate for the time, having an error of less than a minute per day.

One of the most famous pendulum clocks is the Great Clock of Westminster, popularly known as Big Ben. The pendulum has an effective length of 3.9 meters (13 feet), giving it a period of 4 seconds. Every few days, the pendulum is fine-tuned by adding or subtracting old penny coins from a stack on the pendulum. Adding pennies shortens the effective length of the pendulum by raising its **center of gravity**. Each added penny speeds up the clock by about 2/5 of a second per day. The Great Clock has been keeping time in London since 1859, stopping only a handful of times. It even kept ticking through the blitz bombings of World War II! The clock's 150th anniversary will be celebrated in 2009.

Westminster Clock Tower

Selected Web Resources

How Pendulum Clocks Work: http://electronics.howstuffworks.com/clock.htm
The Zoom Pendulum @ PBS Kids: http://pbskids.kids.us/games/pendulum/index.html
Galileo's Experiments: http://www.pbs.org/wgbh/nova/galileo/experiments.html
Amusement Park Physics: http://www.learner.org/exhibits/parkphysics/pendulum.html
History of timekeeping: http://physics.nist.gov/GenInt/Time/time.html
Great Clock of Westminster: http://en.wikipedia.org/wiki/Big_Ben