Teacher Guide: Gravity Pitch

Learning Objectives

Students will:

- Observe that gravity causes objects to fall toward the center of Earth.
- Observe that when a ball is thrown, its path is bent by gravity toward Earth.
- Notice that when the ball is thrown with a high enough velocity, it will go into orbit around Earth. If it is thrown even harder, it will fly off into space.
- Find the orbital velocity and escape velocity of objects on Earth and other planets.
- Use controlled experiments to discover that gravity becomes stronger as a planet's mass increases and weaker as a planet's radius increases.

Vocabulary

escape velocity, gravity, orbit, orbital velocity, trajectory, velocity

Lesson Overview

In the *Gravity Pitch* Gizmo™, students recreate Newton's famous cannonball thought experiment (a baseball was substituted for Newton's cannonball). Newton realized that gravity, the force that causes objects to fall, was also the force that caused objects to orbit planets and stars.

The Student Exploration sheet contains three activities:

- Activity A – Students relate the velocity of a ball to its trajectory. If the velocity is high enough, the ball will go into orbit or escape the planet completely.
- Activity B – Students pitch baseballs to compare the force of gravity on Earth, Venus, and Mars.
- Activity C – Students pitch baseballs to find how the mass and radius of a planet affect its gravity.

Will the ball go into orbit?

Suggested Lesson Sequence

1. **Pre-Gizmo activity: Gravity preconceptions** (5 – 15 minutes)
   Show students a globe and ask them to draw a circle on their paper to represent Earth (add an equator and poles). Ask students to draw a stick figure to represent a person standing on the North Pole and a second stick figure to represent a person standing on the South Pole. Ask students to draw what would happen if each person dropped a ball. Discuss student ideas. Repeat the survey after using the *Gravity Pitch* Gizmo.

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.

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** (15 – 30 minutes)
As students are working or just after they are done, discuss the following questions:
   - What happens when a person on the South Pole drops a ball?
   - What is the relationship between the velocity of the pitch and how far it goes?
   - What must be true for a ball to go into orbit?
   - Are all orbits circular? (The oval shapes are called **ellipses**.)
   - Does the baseball ever crash into the planet after passing the halfway point?
   - What are two ways to increase the gravity of a planet?

5. **Follow-up activity: Orbiting water balloons** (15 – 30 minutes)
You can model how gravity and velocity are balanced to create orbits with a simple demonstration. Tie a strong string or rope securely to a heavy but safe object such as a water balloon, a tetherball or even a shoe. The object represents a moon. Take your class outside and have students take turns whirling the "moon" around in circles.

   There are several things to notice here:
   - If the "moon" isn't being whirled fast enough, it won't achieve a stable orbit. This is analogous to a slow pitch crashing into Earth on the Gizmo.
   - The only force that students can possibly exert on the moon is inward, toward the hand that is whirling it around. (String won't transmit a sideways force or a pushing force.) Basically, the student is exerting a gravitational pull on the orbiting moon.
   - Try changing the length of the string. Notice that the longer the string, the slower the moon needs to go to stay in orbit. (In the Gizmo, the orbital velocity will decrease as the radius increases.)
   - Spin around for a while, then let go of the moon. Notice that the path of the moon is straight once it is launched. In the Gizmo, the ball travels in a straight line once it has escaped from the planet's gravity or in a zero-gravity situation.

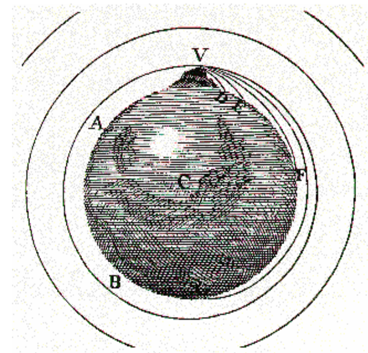
Scientific Background

Many people have heard of Newton and the apple, but few know what he actually figured out on that day in 1766. Newton was not the first to see an apple fall from a tree. He was also not the first to notice that the Moon orbits Earth. But Newton *was* the first to make a connection between these phenomena—they are both caused by gravity.

Prior to Newton, scientists such as Johannes Kepler imagined that planet motions were driven by a mysterious force that radiated from the Sun like the spokes of a wheel. Newton realized that a force pulling the planets *in*—gravity—was the only force necessary to keep them in orbit.

Newton explained his reasoning with a thought experiment. Imagine a horizontal cannon on top of a tall mountain. If the cannon were fired, the cannonball would travel a short distance before Earth's gravity pulled it down to the ground. If the cannonball were launched with a greater velocity, it would travel farther before it finally landed.

At just the right velocity, the cannonball would fall at the same rate as Earth was curving beneath it. In other words, the cannonball would be falling toward Earth, but Earth would be falling *away* from the cannonball. As a result the cannonball would stay at the same height all the way around, eventually crashing into the mountain.



Newton's cannon (from *Principia*)

So, orbits result from a balance between the velocity of the projectile and the force of gravity that causes the path to curve. The strength of gravity depends on the mass of each object and the distance between them. Newton summarized this in his *Law of Universal Gravitation*:

$$F_G = Gm_1m_2 / r^2$$

In this equation, m_1 and m_2 are the two masses, r is the distance between them, and G is the gravitational constant. In other words, gravity increases with mass and decreases with distance.

Astronomy Connection

After Uranus was discovered in 1781, scientists noticed that its orbit did not exactly conform to the path predicted by Newton's laws. Astronomers conjectured that the orbit of Uranus was perturbed by the presence of an undiscovered planet. During the 1840s, several teams of mathematicians worked to determine this planet's position. In September of 1846, using these calculations as a guide, the German astronomer Johann Galle located Neptune.

While universal gravitation worked beautifully in the discovery of Neptune, it did not explain the odd orbit of Mercury very well. In 1915, Albert Einstein's *Theory of General Relativity* introduced a new way of thinking about gravity. Einstein conceived of gravity as a curvature in spacetime. (A large planet could warp space like a bowling ball could warp a sheet of thin rubber.) General relativity accounted for Mercury's orbit and also predicted that the light from distant stars would be bent by the Sun's gravity—something that Newton's laws would not allow as light has no mass. When the predicted bending of starlight was observed during a 1919 eclipse, general relativity was confirmed and Einstein became an international celebrity.

Selected Web Resources

"Phun" physics: http://phun.physics.virginia.edu/topics/gravity.html
The "real" Isaac Newton: http://slate.com/id/2108438/
Newton biography: http://galileoandeinstein.physics.virginia.edu/lectures/newton.html
Newton's cannon:
http://galileoandeinstein.physics.virginia.edu/more_stuff/flashlets/NewtMtn/NewtMtn.html
General relativity: http://archive.ncsa.uiuc.edu/Cyberia/NumRel/GenRelativity.html
Free Fall Tower Gizmo: http://www.explorelearning.com/gizmo/id?650