SPACE SHUTTLE ORBITER

grades 9–12

Objective

To demonstrate how orbits are created by a force pulling toward the center using a paper model of a Space Shuttle attached to a string.

Introduction

Satellites in orbit around the Earth do not need engines to "drive" them around. They are able to orbit the Earth because they have a rapid forward speed that prevents gravity from pulling them to the ground. Earth's gravitational pull bends their forward motion just enough to make their path curve in an orbit around the Earth.

A stable orbit requires a balance between this forward motion and gravity. Without the force of gravity pulling orbiting objects toward Earth, they would fly off into space in a straight line. Without a rapid forward motion, however, Earth's gravitational force would pull them down to the ground.

This activity simulates an object in orbit. A paper Space Shuttle is swung in a circle on a string. The string provides a pull toward the center of the orbit, simulating the force of gravity. (This force toward the center is called a **centripetal force**). Whether the centripetal force is provided by gravity, as with the real Space Shuttle, or by a string, as in this simulation, centripetal forces are what cause the shuttle's path to curve in an orbit instead of continuing in a straight line. An extension to this activity demonstrates how changing the strength of the centripetal force affects orbital speed.

Background Reading for Educators

Gravity: It's Universal, available at
http://www.amnh.org/education/resources/rfl/pdf/du_x05_gravity.pdf

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Materials

Bic Round Stic® pen

4-foot piece of string

Roll of masking or transparent tape

Black marker

Empty 20 oz. plastic soda bottle
(with cap)

15 oz. of water

Measuring cup or graduated cylinder to measure water

Template of Space Shuttle
(This can be downloaded and printed from http://spacelink.nasa.gov/Instructional.Materials/NASA.Educational.Products/Space.Shuttle.Glider/)

Procedure

Part One: An Orbit Requires a Force Toward the Center

1] Tie the roll of tape to a four-foot piece of string. Hold the string about a foot from the tape roll and swing the tape around in a circle.
Ask: How would your students describe the tape's motion around your hand?
Explain: The tape can be considered to be in orbit around your hand.

2] Spin the tape roll again and let go of the string, allowing the tape to fly off tangentially.
Ask: Why did the tape fly off instead of staying in a steady orbit about your hand like the planets do about the sun?
Explain: The reason the planets do not fly off into space is that gravity pulls them toward the Sun. This force causes their path to curve around the Sun instead of continuing in a straight line. In the case of the twirling tape, you provided a similar force toward the center by pulling on the string. This force caused the path of the orbiting tape to curve. When you let go of the string, and the force toward the center disappeared, the string continued in a straight line. (All bodies in motion continue moving in a straight line unless some force acts upon them.)

Part Two: Creating an Orbit by Simulating the Force of Gravity

3] Cut out and make the model of the Space Shuttle. (To simplify this demonstration, you can leave out the model and just keep using the roll of tape.)

4] Remove the inner parts of the pen to create a hollow tube. You will need to pry off the stopper in the back and pull out the writing tip and the tube full of ink out from the front, leaving an empty plastic tube.

5] Slip the free end of the string tied to your tape roll through the gutted Bic pen. Tie the end of the string around the neck of your soda bottle. The neck of the bottle and the roll of string should be about 30 inches apart, with the pen tube between them on the string. You should still be able to take the cap on and off. Fill the soda bottle with 3/4 cup of water and screw the cap back on tightly.

6] Attach the model of the Space Shuttle to the roll of tape so that it will face forward when you twirl the string.

7] Use the black marker to make a mark on the string 7 inches away from the roll of tape. When you twirl the tape, you should try to make this mark line up with the top of the pen tube.

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Note that when twirling the orbiter the mark on the string should line up with the top of the pen tube.

8] Tell the students that you are going to launch the shuttle into orbit. Hold the pen tube without touching the string itself. Starting with the orbiter resting on the floor, begin swinging the string so the orbiter lifts off the ground and flies in circles around your hand. Hold the pen tube so that the black mark on the string is level with the top of the tube. Spin the shuttle rapidly and raise your hand until the bottle lifts off the ground. Swing the orbiter just fast enough to keep the bottle from pulling the string down through the pen tube. Remember to keep the black mark on the string even with the top of the tube.
Ask: How would you describe the motion of the spinning object? Why is the object able to maintain its orbit?
Explain: Even though you are not touching the string, the shuttle orbits your hand because the weight of the bottle supplies a force that pulls on the string. Without this centripetal force, the shuttle would fly off in a straight line as the tape roll did before. In space, the gravitational attraction of massive bodies like the Sun provides a force toward the center of the orbit. In the classroom, the inward pull created by the weight on the string produces the orbit.

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Completed orbiter in motion.

9] Additional discussion for advanced students:
Ask: Are there any other forces involved in this activity? What would happen if the spinning string did not rub against the pen cap?
Explain: Another force involved in this activity is friction. Friction causes the orbiter to slow down so you have to continually add velocity to the system by slightly rotating your wrist. If there were no friction, once the shuttle began moving, it would keep spinning around your hand forever.

In space there is no friction. Since there is nothing to cause an orbiting body to slow down, no additional forward force is required to keep objects moving. That is why the shuttle stays in orbit even with its rockets turned off. Similarly, the Moon keeps orbiting Earth, and Earth keeps orbiting the Sun, even though neither has an "engine" pushing them forward. The only force required to create an orbit in space is the center-pulling force of gravity!

Part Three: Optional Extension: Changing the Mass of the Orbited Body

10] Now change the mass of the hanging soda bottle by pouring out $^1/_2$ cup of water so you are left with just $^1/_4$ cup.
Ask: What will happen to the force on the string now that the bottle has less mass? What would have to happen to the Sun to cause a similar change in the gravitational force it exerts on the Earth?
Explain: The lighter bottle will provide a weaker pull on the string. To weaken the force of gravity attracting Earth to the Sun in an equivalent way, you would have to remove mass from the Sun.

11] Begin spinning the shuttle. Make sure the black mark on the string lines up with the top of the pen so that your rotating system has same radius as in Part 2.
Ask: Does the system spin faster or slower if you change the mass of the hanging soda bottle? What would happen to the speed of the Earth's orbit if the Sun were heavier or lighter then it is now?
Explain: When you decrease the weight of the hanging soda bottle, it pulls the tape toward the center with a weaker force, and the tape revolves at a slower rate. If the Sun were less massive, its gravitational force would be weaker, and the Earth would revolve around it at a slower rate.