JOURNEY through the UNIVERSE

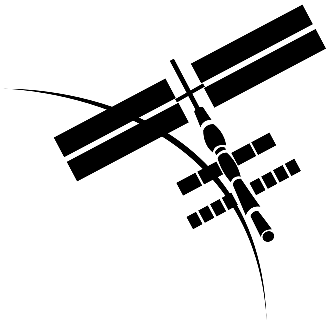
Building a Permanent Human Presence in Space

Grades 5-8

Lesson 1: Weightlessness

The United States and its partners around the world are building the International Space Station (ISS), arguably the most sophisticated engineering project ever undertaken. The ISS is an orbiting laboratory where astronauts conduct research in a variety of disciplines including materials science, physiology in microgravity environments, and Earth remote sensing. The ISS provides a permanent human presence in low Earth orbit. This lesson is one of many grade K-12 lessons designed to bring the ISS experience to classrooms across the nation. It is part of *Building a Permanent Human Presence in Space*, one of several Education Modules developed for the *Journey through the Universe* program. *Journey through the Universe* takes entire communities to the space frontier (http://journeythroughtheuniverse.org.)

August 2009



Lesson 1: Weightlessness

Lesson at a Glance

Lesson Overview

There is no lack of gravity in space. In fact, it is gravity that keeps the Space Shuttle in orbit around the Earth. In essence, the Space Shuttle is falling around the Earth. Why then do astronauts have the feeling and appearance of weightlessness? In this lesson, students will create models of an astronaut and the Space Shuttle to investigate why a falling astronaut feels like he or she is weightless.

Lesson Duration

One 45-minute class period

Core Education Standards

National Science Education Standards

Standard B2: Motions and Forces

- The motion of an object can be described by its position, direction of motion, and speed. That motion can be measured and represented on a graph.

Standard D3: Earth in the Solar System

- Gravity is the force that keeps planets in orbit around the sun and governs the rest of the motion in the solar system. Gravity alone holds us to the earth's surface and explains the phenomena of the tides.

Essential Question

- Why do astronauts feel weightless in space?

Concepts

Students will learn the following concepts:

- The Space Shuttle stays in orbit because of gravity; it is actually falling around the Earth.
- Astronauts are falling at the same rate as the Space Shuttle, giving them the feeling and appearance of weightlessness.

Objectives

Students will be able to do the following:

- Construct a Space Shuttle model.
- Predict what happens to a space shuttle and its contents when they are in a state of free fall.
- Explore the effect of free fall on the model shuttle and on an astronaut inside the shuttle.

Science Overview

Gravity extends far beyond the Earth's surface. Gravity is the force that holds together the Earth and the Moon, and it is the force that binds the planets into orbits about the Sun, which is vastly bigger and more massive than any of the planets. The more massive an object is, the greater is the gravitational force it exerts on other objects. Gravity holds stars together to form galaxies, and holds galaxies together to form galactic clusters and superclusters.

There is gravity in the empty space between celestial bodies: a rock set free in interplanetary space will be accelerated by the combination of gravitational forces from all the different objects around it. Gravity is not equally strong everywhere. The gravitational force from an object decreases with distance from the object's center, reaching zero only at an infinite distance away. The motion of astronauts and spacecraft in Earth orbit is very much under the influence of Earth's gravity, even though the force of gravity is slightly weaker (very slightly) at orbital altitude than it is at the surface, due to increased distance from Earth's center. In fact, the force that holds a spacecraft into an orbit is the force of gravity. Without gravity, the spacecraft would just sail off into empty space.

If gravity is at work everywhere, how is it that astronauts in orbit appear to be weightless? What keeps a spacecraft in orbit around the Earth from falling down to the ground? In fact, astronauts and spacecraft actually are in the process of falling at all times. If a spacecraft were sitting on the ground, then an astronaut inside it would be held up from the ground by the bottom of the spacecraft. A bathroom scale between an astronaut and the spacecraft deck would measure the astronaut's weight. When both the astronaut and the spacecraft are off the ground and falling together, the spacecraft falls in the same direction and with the same acceleration that the astronaut falls. In this case, the falling spacecraft would not resist the astronaut's acceleration and there would be no force between them. As a result, the astronaut would have no measurable weight. If the spacecraft were simply falling straight down, however, it would have to reach the ground eventually—and then, the astronaut definitely would notice the force of gravity at work! What keeps a spacecraft in orbit, instead of hitting the ground?

In his comic novel *So Long, and Thanks for all the Fish*, Douglas Adams claimed that the secret to flying is "to throw yourself at the ground and miss." Real flight actually involves aerodynamic forces created by an object's motion through air, of course, but this humorous statement is a moderately good description of orbital motion: a spacecraft is set in motion, aimed in such a way that it misses the ground, over and over and over again (Figure 1). Once the spacecraft is in orbit, it does not need any more thrust from rocket motors to keep it going, so long as there is no friction to slow it down. Real spacecraft in Low Earth Orbit (LEO, about 230 to 350 miles above the surface) need a periodic boost from rocket motors to correct for the very small but continual friction with the Earth's tenuous upper atmosphere.

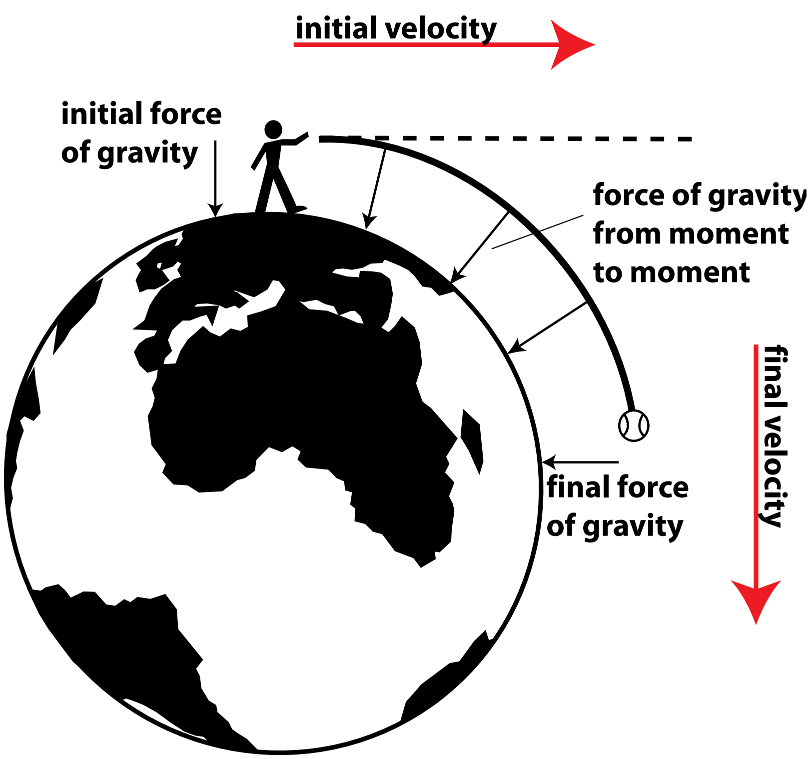


Figure 1: If an object is moving fast enough, then by the time it has fallen far enough to hit the ground, it will have traveled far enough that the curvature of the Earth has taken the ground out of the way. The object is in orbit about the Earth and will continue to miss the ground. Sketch is not to scale.

Throwing an object so it misses the ground is not easy—it takes a very powerful "throw." An object thrown horizontally, over level ground, will travel until the downward acceleration that it experiences from the force of gravity has moved it downward far enough for it to strike the ground. An object always takes the same amount of time to fall through a certain height, so the distance that a falling object can travel horizontally depends on how fast it is going and, thus, how far it can go in that limited length of time. An object thrown horizontally from the top of a building or the top of a hill will travel farther than an object thrown over level ground, however, because the ground drops away compared to the object's initial direction of travel. If the ground continued sloping away, the object could keep falling. In the time it takes to fall to the ground, a slow-moving object can travel only a little way across the ground, while a fast-moving object can travel a long way. If the amount by which the ground drops away depends on how far the object has traveled (like throwing away from a hillside), then a fast-moving object can travel farther than a slow-moving object, even though gravity works equally well on both.

There really is no such thing as level ground. The Earth is spherical, to a very good approximation, so the surface is curved even on "level ground." The ground bends away in all directions. People do not ordinarily notice the curvature of Earth's surface because humans are very small by comparison. If an object were moving fast enough over the surface, then in the time it takes to fall to the ground it could move far enough that the Earth's surface would have curved away noticeably from the object's original path. If it were moving extremely fast, then in the time it takes to fall to the ground, the curvature of the Earth could have curved the ground away from the initial path so far that the object still would be the same height above the ground at the new position as at the original position, like the illustration in Figure 1. In this case, the object would become a satellite, in a circular orbit around the Earth.

Figure 1 shows a highly simplified sketch of a satellite in a circular orbit around the Earth. In the time that it takes for the satellite to travel forward by one Earth radius due to its initial velocity, gravity causes it to travel a distance of one Earth radius perpendicular to its original direction. As a result, the satellite ends at the same height above the surface that it was at the beginning of its journey, but a quarter of the way around the world. Over that distance, the acceleration of gravity has changed the direction of the satellite's velocity, so that at the end the satellite travels in a new direction down the sketch, still parallel to the curved surface of Earth. The force of gravity always is directed toward the center of Earth. At the end of the travel shown, the force of gravity is directed toward the center of the Earth at the new position, opposite the original velocity and perpendicular to the direction of the force of gravity at the start of the travel. Because the satellite is in a circular orbit, this is not really the end of the satellite's journey. Still traveling, with a constantly changing direction that keeps the motion parallel to the surface of the Earth, the satellite will keep missing the ground, and thus stay in orbit, forever.

This cartoon sketch of an orbit is very simplified. In reality, the force of gravity continuously accelerates the satellite toward the center of the Earth. In every tiny step of time that the satellite's velocity carries it parallel to the surface, the force of gravity causes it to fall a little toward the Earth. Since the motion due to gravity always is crossways (perpendicular) to the motion at the beginning of each step in time, gravity changes the satellite's direction of motion, but not its speed. If the satellite's initial velocity is carefully chosen, then the curvature of the satellite's path may match the curvature of the Earth's surface and thus the satellite will be in a circular orbit. A circular orbit is not the only choice, however. A different choice for a satellite's initial velocity leads to the more common case of an elliptical orbit whose distance from Earth is variable, illustrated in Figure 2.

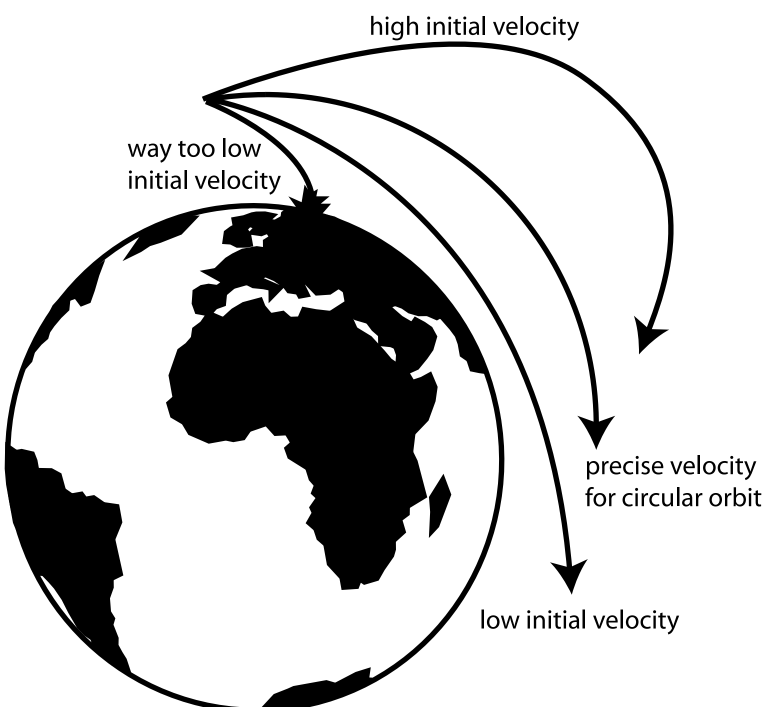


Figure 2: An object must have a precise velocity parallel to the ground in order to have a circular orbit. Faster or slower velocities lead to elliptical orbits. Much slower velocities lead to impact, while much higher velocities lead to escape trajectories that do not orbit the Earth. Sketch is not to scale.

All stable orbits are elliptical. Even a circular orbit is just a special kind of an ellipse. If a satellite starts out with a low initial velocity, acceleration by gravity brings it closer to the ground and increases its speed (not just changing its direction), until it is fast enough for its motion to carry it beyond the curved surface. If the satellite starts out with even lower initial velocity then it may fall far enough to hit the surface, just as with a thrown ball, before its horizontal velocity can carry it beyond the curved surface of Earth. If the satellite starts out very fast, then it may travel farther from the Earth before the bending of its path and the slowing of its motion by gravity is enough to curve its path around. At that point, the satellite's motion is just like the case of low initial velocity, but starting from greater altitude. Only by special effort and attention can a real spacecraft orbit be made to closely resemble a circle around the spherical Earth. Real elliptical orbits have a point of closest approach and a point of farthest retreat from Earth. For orbits around the Earth, closest approach is called perigee and farthest retreat is called apogee; for orbits around any other object, closest approach is called periapsis and farthest retreat is called apoapsis. The orbital velocity of the Space Shuttle, in a roughly circular orbit at about 200–300 nautical miles altitude (230–345 miles; 370–556 km) above the surface of Earth, is about 27,000 km/hr (about 16,500 mi/hr).

The effect of weightlessness occurs because the astronaut in a spacecraft and the spacecraft itself both are independently in orbit. It is easy to see this would be true for two objects side-by-side. Side-by-side, both objects follow independent orbits. If one of them were not there, the other one would follow its orbit just the same. If they start from the same place at the same time and at the same speed then they will keep pace with each other. An astronaut inside the spacecraft is no different from an astronaut next to the spacecraft. Gravity works just as much on the mass of the astronaut and on the mass of the spacecraft. They both accelerate toward the ground at exactly the same rate, and so they keep the same orbit. It is only on the ground that objects are held up against the force of gravity. The Earth's gravitational attraction pulls things to the center, and the ground counters that pull by holding things up. It is the force between an object and the surface that supports it that is measured as weight. If an object is not supported, then it falls freely and it effectively has no weight—until it lands. An astronaut in an orbiting spacecraft falls freely and so has no weight because the walls of the spacecraft apply no force to hold the astronaut up against the force of gravity.

There are a number of different words used to describe the experience of weightlessness. Each term tends to imply things that are either inaccurate or uncomfortable, even as the term tries to correctly describe the experience of space flight. If there were just one perfectly accurate term, no others would be needed. Keeping track of the different terms is useful in order to know whether two people actually are talking about the same thing in news reports and popular accounts of space flight.

The word "weightless" poses problems, because it suggests that something actually is removed from a "weightless" object during the trip to orbit. Nothing is removed. The only thing that is changed between an object on the ground and an object in orbit is that in orbit there is no force between the object and the floor, since the object and whatever it might rest upon are both accelerating together under the influence of gravity. To a physicist, this term is reasonably precise, because weight is measured only when the force of gravity on an object is resisted by another object.

"Zero-G" is a term that probably comes from the test-pilot heritage of the first NASA astronauts. "G-force" describes the forces experienced by a pilot during an aircraft maneuver, measured as a multiple of the force due to gravity at the Earth's surface. G-force is the combined force of gravity and the force causing some other acceleration, like looping an aircraft. In a "2-G" maneuver, the pilot would experience a force equal to twice the force of gravity as the aircraft swings itself and the pilot around in a tight curve. A "zero-G" maneuver would be a carefully-controlled "1-G" dive in which the aircraft accelerates toward the ground while the force of gravity accelerates the pilot toward the ground at 1-G, as well. Since the aircraft does not restrain the pilot from freely falling toward the ground in this case, the pilot truly experiences weightlessness. This is the technique used in NASA's training aircraft, famously nicknamed the "Vomit Comet," which provides astronaut trainees with several seconds of weightlessness before the aircraft needs to pull out of the dive in order to avoid the ground. The weightless scenes in the film *Apollo 13* (1995, dir. Ron Howard) were filmed in short takes during such flights.

The term "zero gravity" is never correct and should not be used. It is simply an expansion of the term "zero-G," but it fails to consider that "G-force" is a reference to any force, not gravity in particular.

"Free fall" probably is the most accurate term to describe what happens to create apparent weightlessness, and accurately describes the feeling of the experience for the astronaut. A "drop-coaster" at amusement parks can create this effect, freely dropping people and their seats for several meters before slowing down the seats to bring them safely to

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rest. Laboratory experiments actually use this technique to perform short experiments simulating the orbital environment, by dropping devices in the interior of a tower. "Free fall" suggests an uncontrolled plummet toward the ground, however, which is not a thought that anyone wishes to entertain, explaining why it is rarely used in describing manned spaceflight.

The preferred term in the field of space exploration today is "microgravity," meaning a condition in which the gravitational forces that appear to be acting between objects are extremely small. Two balls inside a can that is falling, for instance, would be in microgravity conditions because there is little force acting between the balls and the can, until the can reaches the ground and stops. The term correctly recognizes that it is not possible to absolutely eliminate all forces, as there are minuscule gravitational forces between masses in a spacecraft, as well as minuscule accelerations from the motions of astronauts and other tiny forces acting on a spacecraft. Unfortunately, microgravity also suggests that there actually is little or no gravity in space, which is not correct.

"Anti-gravity" is a term for a force that has never been demonstrated, a force that works like gravity but that pushes objects apart in proportion to their mass. The existence of anti-gravity is doubtful, but physicists always are eager for opportunities to overturn current understanding. Something like anti-gravity might someday be discovered. "Artificial gravity" is equally imaginary. The term occasionally is used to describe simulating the effect of gravity by spinning a spacecraft like a centrifuge. However, this is a simulation of the effect of gravity, not an artificial creation of gravity.

NOTES:

Conducting the Lesson

Warm-Up & Pre-Assessment

Teacher Materials

- Chalkboard
- Optional: small, soft objects that are safe to throw inside the classroom such as a foam ball

Preparation & Procedures

1. Ask the students to describe what happens on Earth when a ball is thrown horizontally. (*Desired answer: The ball will travel in a downward curve as it falls to the Earth*) Ask students what will happen if the ball is thrown harder. (*Desired answer: The harder the throw, the further it will go before it finishes falling to the ground.*)

2. Ask students what it is called when one object revolves around another in space like a satellite going around Earth. (*Desired answer: an orbit*) Ask students when you throw a ball or any object, what are you really seeing before the ball hits the ground? (*Desired answer: a piece of an orbit*)

3. Ask students to imagine that the ball could be thrown horizontally so hard that it would go around the Earth and return to you, what are you really seeing? (*Desired answer: The ball would fall around the Earth, it would be in orbit*) Ask students if the ball is still falling. (*Desired answer: yes, the ball is falling around the Earth*) Ask students to compare the ball to the Space Shuttle, if the ball is falling around the Earth, what is the Space Shuttle doing? (*Desired answer: it too is falling around the Earth*)

4. Ask students, if the Space Shuttle is falling around the Earth, are the astronauts in it falling or floating? Allow students to answer and support their opinions. Tell them that they will be conducting an experiment to learn more about just that.

Lesson Adaptation

Special Education: If students are having difficulty realizing that the ball will curve, direct them to investigate falling by lightly throwing small, soft objects, like pencil erasers. It may also be helpful to draw diagrams of students' observations on a chalkboard, whiteboard, or overhead.

Notes:

Activity: Astronauts - Floating or Falling?

In this activity, students will simulate the motion of an astronaut in space.

Student Materials (per pair of students)

- Stapler
- Red marker
- Roll of transparent tape
- Clear, 2 liter plastic bottle, completely dry inside
- Sheet of 8.5" x 11" yellow construction paper
- Approximately 50 cm of thin string or thread
- Scissors
- 12-inch ruler
- Student Worksheet 1

Preparation & Procedures

1. Place students into cooperative pairs. Students will need to work together to create and test their model, but can answer the questions together or independently.

2. Have students complete the gravity experiment by following the directions on Student Worksheet 1. Circulate around the room and assist students as needed.

Teaching Tip

Make sure the bottle and thread are dry, otherwise the astronaut may not fall when released.

Reflection & Discussion

Ask students to discuss the results of their experiment. Ask students why the model astronaut fell to the bottom of the "Space Shuttle" bottle when they held onto the bottle. (*Desired answer: gravity pulled the astronaut down while the student held the bottle*) Ask students why the astronaut appeared to float in the "Space Shuttle" bottle when they both were dropped at the same time. (*Desired answer: The bottle and the astronaut were both falling at the same rate. Therefore, the astronaut stayed at the same place within the bottle, making it appear as if it were floating*) Ask the students why we say "appears" to float, isn't it really floating? (*Desired answer: If the astronaut starts a few feet above the ground and ends up on the floor, it is definitely falling. However, it remains in the same spot in the bottle so it appears to float with respect to the bottle, but not with respect to the Earth.*)

Transfer of Knowledge

In order for students to apply what they have learned, have students explore feelings of weightlessness here on Earth. Have students describe the feeling they get when falling on a roller coaster, descending in an elevator, or driving over the crest of a hill. Have them write a couple of paragraphs about why they feel this way. If they were standing or sitting on a scale when this happened, what kind of change would they observe? A place for them to record their answer appears on Student Worksheet 1.

Extensions

Research why we put the International Space Station in orbit around the Earth. What can we learn by doing experiments in that environment that we can not learn here on Earth?

Placing the Activity Within the Lesson

In this activity, students learned that astronauts in orbit really are falling. Through the use of models, students concluded that astronauts appear to float because they are falling toward the Earth at the same rate as the Space Shuttle.

Curriculum Connections

Language Arts: Review the parts of a paragraph and paragraph composition.

Assessment Criteria for Activity

4 Points

- All observations are completed and recorded on the Data Table in Student Worksheet 1.
- Observations accurately described the results.
- Good use of adjectives to describe the observations.
- Writing is clear and understandable.
- *Transfer of Knowledge* question is answered and show a clear understanding of the main concepts.

3 Points

- Most observations are completed and recorded on the Data Table in Student Worksheet 1.
- Observations described the results.
- *Transfer of Knowledge* question is answered and shows a clear understanding of most of the main concepts.

2 Points

- Some observations completed and recorded on the Data Table in Student Worksheet 1.
- Observations attempt to describe the results.
- Writing is difficult to understand.
- *Transfer of Knowledge* question is answered and shows a clear understanding of some of the main concepts.

1 Point

- Few observations completed and recorded on the Data Table in Student Worksheet 1.
- Does not describe the results.
- *Transfer of Knowledge* question is answered, but does not show a clear understanding of the main concepts.

0 Points

- No observations are completed.
- Observations are off topic or unrelated.
- Writing is unreadable.

NOTES ON ACTIVITY:

Lesson Wrap-Up

Lesson Closure

Discuss with students how the microgravity environment of space might affect the bodies of the astronauts. Astronauts aboard the International Space Station might be living and working in space for up to six months. Have students brainstorm ways for astronauts to stay fit and healthy in space even in the absence of gravity.

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Activity: Astronauts – Floating or Falling?

Lesson Wrap-Up

Resources

Resources

Internet Resources & References

Student-Friendly Web Sites:

Living It Up in Space
  http://magma.nationalgeographic.com/ngexplorer/0110/articles/iss_0110.html

NASA: What Is Microgravity?
  http://www.nasa.gov/audience/forstudents/5-8/features/what-is-microgravity-58.html

NASA Human Space Flight
  http://spaceflight.nasa.gov/

Teacher-Oriented Web Sites:

Microgravity: Fall into Mathematics
  http://www.kidsdomain.com/down/mac/microgravity.html

Why Do Astronauts Float in Space?
  http://www.nasa.gov/audience/foreducators/topnav/materials/listbytype/Why_Do_Astronauts_Float.html

Journey through the Universe
  http://journeythroughtheuniverse.org/

Teacher Answer Key

Student Worksheet 1

4. The astronaut falls to the bottom of the "Space Shuttle" bottle because the student is holding the bottle up, so it does not fall. The astronaut is freely falling, or free-falling.

7. The astronaut stays at the level of the red line in the "Space Shuttle" bottle.

10. The astronaut feels weightless, even though he/she is falling, because the astronaut and the Space Shuttle are falling at the same rate.

Student Worksheet:
Astronauts - Floating or Falling?

Name ______________________________ Date __________

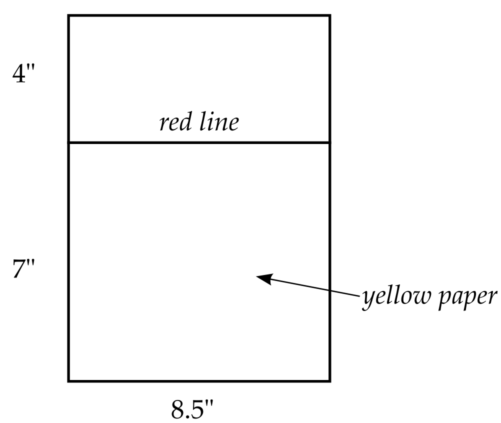
When astronauts are in space are they floating or falling?
Complete the following activity to find out!

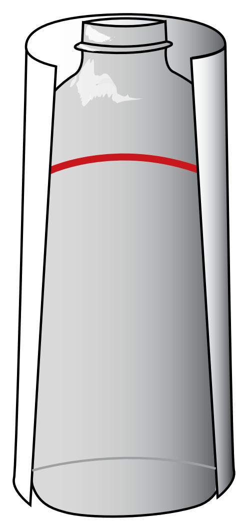
Student Materials (Per team)

- Sheet of yellow construction paper
- Red marker
- Transparent tape
- Scissors
- Clear, 2 liter plastic bottle (completely dry)
- Stapler
- Thread (50 cm)
- 12-inch ruler

Create a Model Astronaut and Space Shuttle

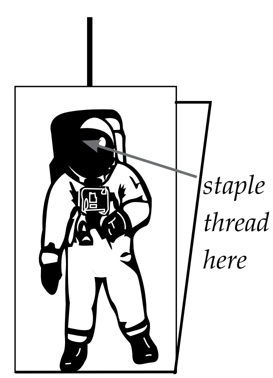
1. To create your model Space Shuttle, draw a thick red line four inches from the top of a piece of yellow paper. Tape the yellow paper lengthwise to the outside of a dry 2 liter bottle, so that the red line faces into the bottle. This area is now the back of the "Space Shuttle" bottle.



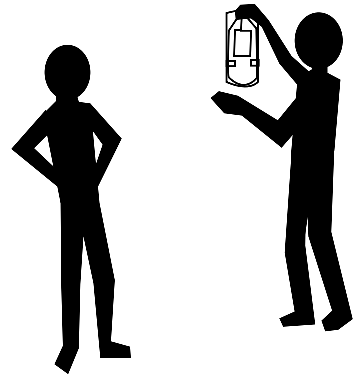


2. To create your model astronaut, cut out the rectangular picture of the astronaut located on the last page of the Student Worksheet. Fold the astronaut model in half, so that the astronaut has a front and a back, place the end of a 50 cm thread inside, and staple it together so that the string does not slip out. Do not cut the thread shorter!

3. Holding the thread, push the model astronaut into the bottle. Lower the model into the "Space Shuttle" bottle so that the astronaut's head is at the level of the red line in the bottle.



4. Keep holding the "Space Shuttle" bottle and release the thread that holds the astronaut. What happens to the astronaut in relation to the red line? Explain.
5. Pull the thread out of the bottle so that the astronaut's head is at the level of the red line once again. Hold onto the thread and bottle with your thumb and index finger. (See picture below.)



6. Ask your partner to stand across the room (about 20 feet away). Tell your partner to carefully watch the paper astronaut and the red line in the "Space Shuttle" bottle as you drop the bottle and thread (with astronaut) at the same time. Let go of the bottle and the thread at exactly the same time.

7. Where was the astronaut in relation to the red line in the "Space Shuttle" bottle during the fall?

8. Drop the "Space Shuttle" bottle and the paper astronaut four more times. Record your observations in the data table each time.

9. Exchange places with your partner and repeat steps 5-8 again.

10. Based on what you saw, explain why an astronaut feels weightless in space, even if he/she is falling.

Data Table

Drop	Observation
1	
2	
3	
4	
5	

Weightlessness on Earth

Describe the feeling you get when falling on a roller coaster, descending in an elevator, or driving over the crest of a hill. Write a couple of paragraphs about why you feel this way. If you were standing or sitting on a scale when this happened, what kind of change would you observe?