BACKGROUND

Motion toys are effective tools for helping children learn science and mathematics. Scientific and mathematical principles make these toys work. For example, wind-up toys convert stored potential energy in their springs into kinetic energy as the springs unwind. Gravity often plays an important role in the actions of toys, but how would the same toys function in an environment where the effects of gravity are not felt?

The Space Shuttle and the International Space Station provide such a setting so students can discover the answer to this question. A few sports activities and toys and a few hours of the crew members’ free time have brought the experience of free-fall and an understanding of gravity’s pull to students of all ages.

MICROGRAVITY: THAT FREEFALL FEELING

Many people misunderstand why astronauts appear to float in space. A common misconception is that there is no gravity in space. Another common idea is that the gravity from Earth and the Moon each pull on the astronauts from the opposite direction and cancel out. The real reason astronauts appear to float is that they are in a state of freefall around Earth.

On television, we see astronauts floating about in the Space Shuttle with no floor to stand on. They use Velcro to attach themselves and their equipment to walls to keep things from drifting out of reach. They eat carefully to keep their food under control.

Why does this floating sensation happen in orbit? Many people believe it is because the astronauts are so far from the Earth’s gravity pull, but this is NOT the reason. The same gravity force that keeps you in your chair also keeps the astronauts in orbit. If Earth’s gravity were turned off, orbiting astronauts would fly off into interplanetary space.

What is the most important difference between you in your chair and an astronaut floating in the shuttle? Compare your speeds. You are sitting still relative to the Earth’s surface. The astronaut is moving at the incredible speed of 8 km/sec (29,000 km/hour) and circles the Earth each 90 minutes. It is this speed that keeps the astronaut floating in orbit.
The shuttle is falling toward Earth just like you would be if your chair suddenly broke. But the shuttle is traveling so fast that the Earth curves away from it as it falls. If the shuttle were not continually falling toward Earth, its horizontal velocity would send it flying away from our planet. The astronauts are just falling around the Earth without ever reaching the ground (until they slow their speed down and come in for a landing).

So what does it feel like to fall? Imagine jumping off a high diving board. If you sat on a bathroom scale as you fell toward the water, what would the scale read? “Zero,” of course. You and the bathroom scale are falling at the same rate. Therefore you do not push on the scale and it reads “zero.” Riders cresting over roller coaster hills have the same weightless sensation.

This same effect happens in orbit. The shuttle, the astronauts, and all of their equipment are falling at the same rate around the Earth. So the astronauts and their food, tools, and toys all seem to float in the cabin. If an astronaut were to sit on a bathroom scale while in orbit, it would read “zero” just as it did for the falling diver.

The floating effect of Space Shuttles and astronauts in orbit has been called by many names such as freefall, weightlessness, zero-G (zero-gravity), or microgravity. Weightlessness and zero-G are incorrect terms that imply that gravity goes away in space. The term freefall best describes what causes the floating effect. Space scientists prefer to use the technical term microgravity because it includes the very small (micro) accelerations that are still experienced in orbit regardless of the objects falling.

**SCIENCE STANDARDS**

**Physical Science**
- Position and motion of objects
- Properties of objects and materials

**Unifying Concepts and Processes**
- Change, constancy, and measurement
- Evidence, models, exploration

**Science and Technology**
- Understanding about science and technology
- Abilities of technological design
Glossary

The following terms, scientific principles and mathematical equations are useful in describing the actions of toys on Earth and in space.

Acceleration: This is the rate of change in velocity.

Action Force: This is a force exerted on an object.

Air Resistance: This is the force of the air pushing against a moving object.

Angular Momentum: This is a property of spinning motion that must be conserved. Angular momentum is the product of an object’s mass, the radius of its circular path, and its velocity. The angular momentum of a spinning object is equal to its moment of inertia times its angular velocity. If the resultant external torque acting on a system is zero, the total angular momentum of the system is constant. The angular momentum is greater when the mass is farther from the rotation axis as in the spinning disk of a gyroscope. The direction of the angular momentum of a spinning object is along the axis of rotation in a direction defined by the right hand rule. When the curled fingers point in the direction of the rotation, the direction of the angular momentum is that of the outstretched thumb.

Centrifugal Force: This is the apparent outward force exerted by an object moving in a circle. In reality, the object is simply trying to move in a straight line.

Conservation of Angular Momentum: The torque of a spinning object is equal to the object's moment of inertia times its angular acceleration. The fact that a torque is required to change a spinning gyroscope’s angular velocity is called gyroscopic stability.

Force: This is a push or pull.

Freefall: This is the condition of an object falling in a gravity field.

Friction: This is a force which opposes sliding motion.

Gravity: The attraction of all objects to one another due to their mass.

Mass: This is the amount of matter an object contains.

Microgravity: An environment, produced by freefall, that alters the local effects of gravity and makes objects seem weightless.
Momentum is the product of an object’s mass times its velocity. Momentum is a conserved quantity within a closed system. \[ \text{Momentum} = \text{mass} \times \text{velocity} \]

**Newton’s Laws of Motion**

Sir Isaac Newton first formulated these three basic laws of motion:

**Newton’s First Law of Motion** An object continues in its initial state of rest or motion with uniform velocity unless acted on by an unbalanced external force. This is also called the Law of Inertia or the Inertia Principle.

**Newton’s Second Law of Motion** The acceleration of an object is inversely proportional to its mass and directly proportional to the resultant external force acting on it.

\[ \text{Force} = \text{mass} \times \text{acceleration} \]

**Newton’s Third Law of Motion** Forces always occur in pairs. If object A exerts a force on object B, an equal but opposite force is exerted by object B on object A. Application: objects move forward by pushing backward on a surface or on a fluid.

**Precession** This is the wobbling of a spinning object.

**Speed** This is the rate of change of an object’s position with time.

**Velocity** This is the speed and direction of an object’s motion.

**Weight** This is the magnitude of a gravitational pull.
TOYS IN SPACE...
To Infinity and BEYOND!

Name ____________________________

Space Quadrant/Hometown ____________________________

Disney·PIXAR
**Task Card: Kendama**

How does a kendama behave in microgravity?

1. How does a kendama behave in Earth’s gravity (1g)?

**Hypothesis**

What do you predict will happen in space?

2. Space Cadet _______________________

**Observation**

How did the kendama behave in space?

3. 

**Conclusion**

From your observation evaluate your hypothesis.

4. What are some other tricks you could use to make the ball stay?

Think About It!
Make your own kendama! Begin by listing materials you can find at school or at home to make your kendama. Write the steps you will follow to make the kendama. Working with a partner, make your kendama. See how many times you can catch the ball. Record your progress on one of the charts below.

**Materials:**

- 
- 
- 
- 
- 

**Steps in making the kendama:**

- 
- 
- 
- 
- 

www.nasa.gov
**TASK CARD: HOCKEY**

How does a hockey puck behave in microgravity?

Space Cadet _______________________

1. How does a hockey puck behave in Earth’s gravity (1g)?

**HYPOTHESIS**

What do you predict will happen in space?

2. 

**OBSERVATION**

How did the hockey puck behave in space?

3. 

**CONCLUSION**

From your observation evaluate your hypothesis.

Why do you think the vent helped keep the hockey puck in place?

4.
It can be dangerous to play hockey in microgravity. The hockey puck seems to go everywhere! Design some protective gear for the astronauts to wear when playing hockey in space.
**Task Card: Soccer**

How does a soccer ball behave in microgravity?

1. **Hypothesis**
   What do you predict will happen in space?

2. **Observation**
   How did the soccer ball behave in space?

3. **Think about it!**
   If you were an astronaut stationed on the ISS, what games would you play for entertainment?

4. **Conclusion**
   From your observation evaluate your hypothesis.

Space Cadet ____________________
Create a new ball game to be played in microgravity. Describe how it is played and the rules the players will follow. How will they keep score?

The roots of modern day soccer go back thousands of years to the kicking games that were played by Ancient Greeks, Romans, Chinese, Eskimos, Egyptians, and many more cultures.
Task Card: Lacrosse
How does a lacrosse ball and stick behave in microgravity?

Space Cadet ____________________________

1. How does a lacrosse ball and stick behave in Earth’s gravity (1g)?

HYPOTHESIS
What do you predict will happen in space?

OBSERVATION
How did the lacrosse ball and stick behave in space?

CONCLUSION
From your observation evaluate your hypothesis.

Could you play ping pong in space? Why?

Think About It!
LACROSSE
Baggataway or tewarathon was the name of the original game from which lacrosse evolved.

**FACTOID**

Describe how you would adapt the lacrosse ball or lacrosse sticks for use in microgravity.

Draw a picture of your new lacrosse ball and sticks.

How will your new ball and sticks make it easier to play lacrosse in space?
**HYPOTHESIS**
What do you predict will happen in space?

**OBSERVATION**
How did the car in the loop behave in space?

**CONCLUSION**
From your observation evaluate your hypothesis.

**THINK ABOUT IT!**
What do you think it would be like to drive a remote controlled car in space?
Design a new car and track for the astronauts to test in microgravity. Using the space below or a separate piece of paper, draw and describe your car and track design.

What would be better about your car and track than the loop and car the astronauts used?
**Task Card: Gravitron**

How does a gravitron behave in microgravity?

**Space Cadet**

1. How does a gravitron behave in Earth’s gravity (1g)?

2. What do you predict will happen in space?

**Observation**

How did the gravitron behave in space?

**Conclusion**

From your observation, evaluate your hypothesis.

**Think About It!**

What else spins in space?
If you were an astronaut, what toy would you like to take into space?

Gyroscopes can be dated as far back as Ancient Greece, China, and Rome as spinning tops used for amusement.

How would you test your toy in microgravity?

Compare how you think your toy would react in space verses how it behaves in Earth’s gravity (1g).
** TASK CARD: JUMP ROPE **
How does a jump rope behave in microgravity?

Space Cadet ____________________________

1. How does a jump rope behave in Earth’s gravity (1g)?

2. What do you predict will happen in space?

3. How did the jump rope behave in space?

4. Did the astronauts really jump?

** CONCLUSION **
From your observation evaluate your hypothesis.

** HYPOTHESIS **
What do you predict will happen in space?
Describe a jump rope strategy that could be used in microgravity so that two people could jump rope at the same time.
How does a density wand behave in Earth’s gravity (1g)?

What do you predict will happen in space?

How did the density wand behave in space?

From your observation evaluate your hypothesis.

What would you do if the contents of the density wand leaked out while you were in space?
Using the following materials, make your own density wand:

- A clear container (empty water bottle, baby food jar, etc.)
- Water
- 5–10 objects that will not dissolve in water (marbles, glitter, small plastic beads or toys, buttons, paper clips, plastic confetti, etc.)

Follow these steps to make your density wand:

1. Put all of the objects you have collected into the container.
2. Fill the container with water, leaving a small amount of air space.
3. Put the top securely on the container.
4. Follow the instructions on the next page.
What will happen when you move the container? Write your hypothesis. Watch the objects in the container, record your observations, and write your conclusion.

<table>
<thead>
<tr>
<th>HYPOTHESIS</th>
<th>OBSERVATIONS</th>
<th>CONCLUSION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Move the container around. (How did you move it? Did you shake it? Spin it? Did you move it in another way?) How did the objects behave when the container was moved?</td>
<td></td>
</tr>
</tbody>
</table>

Draw a picture of your density wand.
**Task Card: Yo-Yo**

**How does a yo-yo behave in microgravity?**

Space Cadet ____________________________

1. How does a yo-yo behave in Earth’s gravity (1g)?

2. **Hypothesis**
   What do you predict will happen in space?

3. **Observation**
   How did the yo-yo behave in space?

4. **Conclusion**
   From your observation evaluate your hypothesis.

If you were an astronaut what yo-yo test would you like to try?

**Toys in Space**
Design your own yo-yo for Buzz Lightyear to use in space.

**FACTOID**

**YO-YO**
The yo-yo is one of the oldest known toys. Versions of the now popular toy have been unearthed in Ancient Greece and drawings discovered on the walls of Egyptian temples.
How does a top behave in microgravity?

Space Cadet ____________________________

1. How does a top behave in Earth's gravity (1g)?

HYPOTHESIS
What do you predict will happen in space?

OBSERVATION
How did the top behave in space?

CONCLUSION
From your observation evaluate your hypothesis.

THINK ABOUT IT!
If you were an astronaut, how would you keep the top spinning on a flat surface?
TOP

Ancient Greeks and Romans constructed tops out of boxwood, terra-cotta, and bone. In Asia, tops were made from conch shells, nuts, gourds, bamboo, stone, and other natural materials.

SPACE CADET CHALLENGE

COIN SPIN

You will need the following materials:

- A coin or any other object that is shaped like a disc
- Tape
- Paper clips

Steps:

1. Practice spinning the disc by holding it on its top with one finger and flicking the edge of the disc with your other hand.
2. Observe how the disc moves. How long does it stay upright and spinning?
3. Now tape a paper clip to one side of the disc.
4. Before spinning the disc, write a hypothesis stating what you think will happen when you spin the disc.
5. Spin the disc in the same way you did in Step 1.
6. Observe how the disc moves.
7. From your observations, evaluate your hypothesis. Did anything surprise you?
Task Card:
Basketball
How does a basketball behave in microgravity?

Space Cadet ________________________________

1. How does a basketball behave in Earth’s gravity (1g)?

Hypothesis
What do you predict will happen in space?

Observation
How did the basketball behave in space?

Conclusion
From your observation evaluate your hypothesis.

Think About It!
What changes or improvements would you make in the way that basketball is being played now?
Your hard work and scientific thinking have earned you a promotion.

Congratulations

Space Ranger

BUZZ LIGHTYEAR

Space Ranger of Star Command

Teacher

NASA