Neutral Buoyancy & Simulated Weightlessness

Lesson 1 of 3

Grade Level: 9 - 12
Subject: Physical Science, Biology
Prep Time: >30 minutes
Activity Duration: 50 minute period
Material Category: Common Household

National Education Standards

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<th>Science</th>
<th>Mathematics</th>
<th>Technology</th>
<th>Geography</th>
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Objective: Students examine how NASA biologists use water immersion experiments to simulate weightlessness and to investigate ways to counteract the effects of microgravity on astronauts.

Materials: (For each team of students)
- Scissors
- Metric ruler
- 2 standard-size metal paper clips
- 1 clear plastic drinking straw
- 4 oz. water with yellow food coloring (at room temperature)
- 1 calculator
- 2 clear 35-mm film containers
- 1 10 ml graduated cylinder or use a medicine dropper
- 1 plastic gallon milk bottle filled with clear room temperature water
- plastic tub (clear is best) large enough to suspend a drinking straw-at least 30 cm (12 inches) long by 15 cm (6 inches) wide by 15 cm (6 inches) deep or larger depending on the length of the straw.

Related Links:
Microgravity
Neutral Buoyancy & Simulated Weightlessness

Objective
Students examine how NASA biologists use water immersion experiments to simulate weightlessness and to investigate ways to counteract the effects of microgravity on the astronauts.

Pre-Lesson Instructions
1. Gather materials. Several weeks before the activity ask students to bring in clean, empty one gallon milk containers.

2. Prepare water and yellow food coloring the day before to allow water to come to room temperature. Store yellow water in the film containers and clear water in plastic one gallon milk containers. You should have one gallon of clear water and two film containers of yellow water for each team of students.

3. Make a photocopy of the lab for each lab group or student.

Background Instructions
1. Buoyancy. Introduce the concepts of water displacement and buoyancy, drawing on the students' experiences with swimming and taking a bath. (When you get into a bathtub the water level goes up because your body is displacing water. Your body is buoyed up with a force equal to the weight of the water you displace, a phenomenon known as Archimedes Principle.) Ask students why some objects float in water while others sink. In immersion experiments subjects are neutrally buoyant in water. These experiments can be used to simulate the fluid shifts that occur when astronauts are in a microgravity environment. Inform students that they will simulate weightlessness in the classroom by making a simple neutrally-buoyant model of a closed cardiovascular system.

2. Gravity and the cardiovascular system. NASA conducts experiments on humans and other animals, including giraffes and bats, to study the effects of gravity on the cardiovascular system. Investigating the physiology and cardiovascular systems of animals that are uniquely adapted to gravity may help scientists find ways to counteract some of the negative effects of microgravity (such as fluid shifts) on humans. Giraffes are valuable models when studying the cardiovascular system because they are very tall animals that must overcome large gravitational effects when pumping blood from the heart up to the head.
Giraffes, humans and other tall animals have high blood pressure at the heart level in order to maintain blood flow to the brain. When humans are in the microgravity environment of space, blood and other fluids move from the heart and lower body into the head because their vascular systems no longer have to overcome the force of gravity to pump blood to the brain. A similar thing may happen when giraffes lie down with their head at the same level as their heart. Blood moves from the tissues in the giraffe’s lower body up into the head. So much fluid can pool in the brain that the blood can no longer flow properly. This tendency to shift fluids may be one of the reasons that giraffes never let their heads rest at the same levels as their hearts, even when they’re lying down. This fluid shift also occurs when humans lie in bed for long periods of time.

Optional Materials for lecture/discussion:

- Slide or overhead of astronaut in microgravity
- Slide or overhead of astronaut in the KC-135
- Slide or overhead of astronaut in the WETF
- Slide or overhead of an astronaut on earth and an astronauts in a space vehicle in microgravity
- Slide or overhead of a bat hanging up side down
- Slide or overhead of a giraffe lying down and standing up

Source for astronaut slides: http://microgravity.msfc.nasa.gov/PPT/

Discussion/Wrap-up — Additional Information

Effects of gravity on blood circulation

NASA has done a great deal of research with unusual animals. Giraffes have been studied because they are the tallest living animal on the planet and their blood circulation is most affected by gravity. (Dinosaurs were taller and may have been more finely adapted to gravity than giraffes.) Humans and giraffes both stand upright. The effect of gravity causes upright animals to constrict the arteries in the lower body and expand the arteries above the heart. This allows blood to flow up to the head rather than pool in the lower body. In giraffes, the difference in arterial wall size from the upper to the lower body is greater than in any other animal because of their tremendous height. In the microgravity environment of space, this relative difference in artery size isn't necessary because gravity is no longer pulling blood into the lower body. Instead, the blood and other fluids shift upward in the body of animals in space and the cardiovascular system reacts by attempting to balance the relative sizes of blood vessels in the lower and upper body.

Ask students the following questions:
- If people lived and worked in space for very long periods of time, would their blood vessels equalize throughout their bodies?
- Would long term exposure to microgravity cause damaging elevation of intracranial pressure because of fluid build-up in the brain?

Scientists do not know the answers to these questions.

Another unusual animal studied by NASA Life Sciences Division is the bat. Bats spend much of their lives hanging upside down. This reverses the system that most animals have, with the result that bats have thinner blood vessels in the upper body and thicker blood vessels in the lower body. Biologists are interested in knowing how the
cardiovascular system of bats overcomes the gravity effect of fluid build-up in the head, seemingly without having problems of elevated intracranial pressure.

**Research Methods**

One way to study the effects of microgravity is to be submerged in a large tank of water. NASA calls one such tank a WETF (Weightless Environment Training Facility). Inside this tank people can experience neutral buoyancy and simulated weightlessness. The similarities of this watery environment to that of the space environment make the WETF a good place to do space travel experiments and training.

Another way NASA studies the effects of fluid shift in microgravity is by having subjects do long term (30 days and more) bed rest studies. The subjects lie in a bed with their heads tilted down at a 6 degree angle. This causes a fluid shift to the upper body, with a build-up of intracranial pressure. Changes that occur while at a 6-degree tilt help NASA life scientists understand what happens to astronauts during long-term space travel.

Another way to simulate a microgravity environment on Earth is to fly in NASA's KC-135. This airplane flies up to 35,000 feet then drops to 24,000 feet in a series of parabolic arcs. Each time the plane drops from 35,000 feet to 24,000 feet, the passengers in the plane experience microgravity, but only for about 20 to 30 seconds.

Lesson modified from an activity created by: Ranganath Weiner
http://stellar.arc.nasa.gov/stellar/Activities/Cardiovascular/Neutral%20buoyancy/neutral.html
Neutral Buoyancy & Simulated Weightlessness

Objective
Students examine how NASA biologists use water immersion experiments to simulate weightlessness and to investigate ways to counteract the effects of microgravity on the astronauts.

Prelab Questions
1. List as many ways as possible that the lack of gravity might affect a living organism in space.
2. Define and provide an example of Archimedes Principle.
3. Define the following terms: cardiovascular, density, displacement, gravity, microgravity, intracranial, neutral buoyancy, weight, and WETF.

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- 1 plastic gallon milk bottle filled with clear room temperature water
- plastic tub (clear is best) large enough to suspend a drinking straw—at least 30 cm (12 inches) long by 15 cm (6 inches) wide by 15 cm (6 inches) deep or larger depending on the length of the straw.

Procedure
1. Fill the plastic tub 2/3 full of water. Measure the distance from the bottom of the tub to the top of the water (in millimeters) and record the information on your data sheet.

2. Put paper clips perpendicular to the body of the straw 5 mm from each end (clipping the ends of the straw) to create an airtight chamber. Then put the empty sealed straw into the tub of water. The straw should float. Record initial observations.

3. Pull the straw from the tub and remove one paper clip. Open one of the film containers and pour a small amount of the yellow water into the graduated cylinder. (Alternatively,
use medicine droppers.) Record the amount of water. Have one team member hold the straw with the open end pointing up, while a second member pours the yellow water into the straw without spilling. Place the second paper clip back on the straw and put the straw back into the plastic tub. Measure the height of the straw from the BOTTOM of the tub and record the information on the data sheet.

4. Repeat step 3 with different measured amounts of yellow water until the straw stays suspended at the midpoint from the bottom of the tub to the top of the water in the tub. The straw is neutrally buoyant when it neither floats nor sinks in the water. Record each experiment attempt on the data sheet.

5. Calculate volumes and ratios. After neutral buoyancy is achieved, calculate the volume inside the straw, using cubic millimeters as the unit of measure. Measure the length and radius of the straw. To calculate the volume, use the formula:

\[
\text{Volume} = \pi r^2 L
\]

Where \( r = \) the radius of the straw and \( L = \) length of the straw.

6. Calculate the ratio of water to air, first subtract the volume of water from the total volume of the straw. This will give you the volume of air inside the straw. Compare the volume of air to the volume of water to get a ratio of air to water in the buoyant straw.
Neutral Buoyancy & Simulated Weightlessness Data Sheet

Name(s): __________________________

Before starting the experiment, predict the relationship between the amounts of water and air needed in the straw to make it neutrally buoyant.

% of water needed: ________  
% of air needed: __________

Depth of water in tub: _________ (Procedure Step 1)

What happened to the air-filled straw when it was placed in the tub? (Procedure Step 2)

Predict what change(s) would occur if a pump (like the human heart) was added to your model (a) on earth and (b) in the microgravity of space?

<table>
<thead>
<tr>
<th>No H₂O in straw</th>
<th>Predicted height from bottom of tub (mm)</th>
<th>Predicted yellow H₂O in tenths of ml of drops</th>
<th>Actual Height</th>
<th>Actual amount of H₂O</th>
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Calculate the percentage error for each trial: (Show work)
Trial #1       Trial #2       Trial #3       Trial #4

Percentage error = \frac{\text{actual} - \text{experimental}}{\text{actual}} \times 100

Conclusions

1. Have each team share their results. Then, as a class, calculate the average ratio of water to air.

2. Make graphs of the relationship between water addition and height of the straw in the tub. Mark the point of neutral buoyancy. (Attach your graph paper to your data sheet.)

3. What ratio of air and liquid is needed for this model to achieve neutral buoyancy?

4. Are there any more requirements for neutral buoyancy?

5. How does neutral buoyancy compare to microgravity conditions?

6. How are the effects of water immersion on a human similar to the effects of microgravity?