FUTURE U.

Neutral Buoyancy

Objectives

Students wil be able to:

- **Explain** factors that contribute to positive and negative buoyancy.
- **Design** and **create** a boat prototype that exhibits neutral buoyancy.
- **Analyze** the results of several trials, each time **developing** a plan to optimize their prototype.

Overview

In this lesson, students will imagine they have been invited to join the Ocean Team at Boeing for an internship that focuses on unmanned undersea vehicles. In order to understand what this entails and to get a head start on their internship, students will explore the concept of buoyancy. Student groups will rotate through stations as they investigate negative and positive buoyancy with hands-on activities and calculations. They will even learn about some of the buoyancy adaptations in aquatic animals. They will then kick off their internship ready to design and construct a prototype that exhibits neutral buoyancy, and they will perform tests in order to optimize their designs.

This lesson focuses on:

Engineering Design Process

- Defining the Problem
- Designging Solutions
- Refine or Improve
- Communicating Results

21st Century Skills

- Communication
- Collaboration
- Critical thinking
- Creativity

Timing

Two 45–60-minute class periods

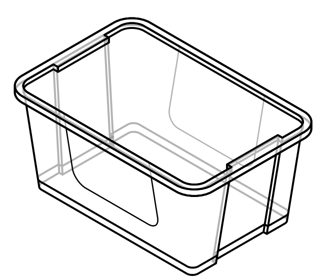
Materials

DAY 1

- Computer or device with the ability to project, one for the instructor
- Images to project: One, Two, and Three

- Buoyancy Capture Sheet, one per student
- Station 1 Materials: *
    - 4 sets of the following:
        - Station 1 Directions, 2 copies
        - Small container (food storage containers, empty hummus or cream cheese container, etc.), 1
        - Large container (at least four times larger than the small container), 1
        - Marbles, several*
        - Pitcher of water
        - Marker
        - Beaker with milliliter measurements
          *In advance, test how many marbles it will take to sink the small container. Then give students a few more than this amount.
    - Scale, at least one for the class to share (If this is not available, weigh one marble in advance and be ready to share this with students.)
- Station 2 Materials:
    - 4 sets of the following:
        - Container of water that is deep enough for an apple to float in (It should be able to hold at least four cups of water)
        - Apple
        - Small inflated balloon
        - Paper clip
        - 3 flat-bottomed caps/tops of different sizes (e.g. soda bottle, salad dressing, large yogurt container, peanut butter jar, etc.)
        - Pennies, about 50
- Station 3 Materials:
    - Article 1, enough for 1/3 of the class
    - Article 2, enough for 1/3 of the class
    - Article 3, enough for 1/3 of the class
        - The Real Story Behind Archimedes' Eureka! video, to project

DAY 2



- 72-quart clear plastic storage bin filled a little more than halfway with water
- Towel to place under the water container
- Design-Test-Optimize handout, for one-third of the class
- Boat prototype materials:
    - Empty 8-ounce bottle, for one-third of the class
    - Enough of the following for groups to share:

- Balloons
- Clothespins
- Duct tape
- Corks
- Small masses to give the boat weight: such as marbles, pebbles, coins, washers, etc.
- Sandwich bags
- Sponges
- Toothpicks
- Straws
- Scissors
- Any other available materials that students could use to create a neutrally-buoyant boat

Have you ever wondered…

What exactly is buoyancy?

When an object is placed in water, water is displaced or moved. (Think about what happens when someone gets into a bathtub.) The amount of water displaced depends on the object's density. Density is calculated based on an object's mass and volume. When something is dropped into water and it weighs more than the weight of the water that it displaces, it will sink. When something dropped in water weighs less than the weight of the water that it displaces, it floats.

This floating object is **buoyant:** If you push down on it, you will feel the water pushing back. Buoyancy is therefore the upward force from water that keeps things—or us—afloat! The buoyant force is equivalent to the weight of the water that the boat moves or displaces. An object with negative buoyancy will sink; an object with positive buoyancy will float; and an object with neutral buoyancy will hover!

How do submarines move between positive, neutral, and negative buoyancy?

Unlike a ship, which is designed to have positive buoyancy, a submarine is designed to control its buoyancy so it can alternate between positive, neutral, and negative buoyancy depending on where it needs to go. A submarine contains special tanks called ballast tanks on both sides of its body. These tanks can be filled with water or air depending on its buoyancy goals. When a submarine wants to achieve positive buoyancy and float, it fills its ballast tanks with air. This makes the boat's overall density less than that of the water. When the submarine wants to sink, air is released from the tanks and replaced by water until the submarine's density is greater than the water around it. The submarine also keeps a supply of compressed air available for when it needs to rise again. When this compressed air enters the tanks, water is pushed out and the submarine rises, first shifting to neutral buoyancy and then restoring positive buoyancy.[1]

Make Connections

How does this connect to students?

Water is essential to life. It covers more than two-thirds of the Earth's surface, comprises nearly two-thirds of our own bodies, and is needed by living things in order to survive. It's therefore important to have an understanding of water and its many properties.

The property of buoyancy connects to many activities—including swimming, scuba-diving, and boating. It plays an important role in staying safe in water situations (Think: life jackets!), and it is necessary for understanding nature, from maritime animals to the pollution that affects their living environment. The concept of buoyancy is far-reaching and will help students better comprehend the world around them.

How does this connect to careers?

Marine Archeologists: Like archeologists on land, marine archeologists investigate human history through the study of artifacts. However, these types of archeologists explore underwater and—as they do so—they must be constantly aware of their buoyancy because a miscalculation could disturb sediment or destroy an artifact![2]

Naval Architect: Naval architects create the designs for water vessels. Based on the desired qualities and the constraints presented, they use software to create new ship designs, evaluate designs for feasibility, and/or modify and optimize existing vessels and systems.

Safety Engineer: While these engineers can work in a variety of settings, some safety engineers design, test, and optimize the buoyancy of ships both before and after cargo has been added onboard.

How does this connect to our world?

Not only does water cover the majority of Earth's surface, but it plays an integral role in the world's economy. Over 90% of the world's trade is carried by sea, and this kind of transport is the most cost-effective way to move goods and materials around the world. Shipping provides an important source of income for both developing and developed countries.[3]

An understanding of buoyancy is also important as the world strives to clean up marine pollution, including the ocean's garbage patches. Engineers and scientists studying this problem must not only consider the buoyancy of the ocean's trash, but also the advantages that a buoyant clean up tool could provide.[4]

Sources

[1] How Submarines Work. HowStuffWorks. science.howstuffworks.com/transport/engines-equipment/submarine1.htm.

[2] Scuba Careers: Becoming an Underwater Archeologist. PADI. blog.padi.com/2018/05/29/scuba-careers-becoming-an-underwater-archeologist/

[3] "IMO (International Maritime Organization)." United Nations. https://business.un.org/en/entities/13.

[4] "Passive Cleanup System." The Ocean Clean Up. theoceancleanup.com/oceans/.

Blueprint for Discovery

Instructor Prep: This lesson requires a variety of materials. Before each class session begins, take time to organize the materials that will be needed. If one session has more than one station or activity, separate these materials in advance.

DAY 1

1. Begin class by toggling between Images One, Two, and Three, and challenge students to brainstorm and share: Why do some objects sink while others float? What are some of the main differences between the three images? Do you think these differences impact whether an object sinks or floats?
2. Then focus on Image Two, and explain that students are about to imagine that they have been invited to join Boeing's Ocean Team for a new internship program. Point to the image on the screen and explain that their internship will focus on Boeing's unmanned undersea vessels. In order to get ahead and do well in the internship, students will explore the concept of buoyancy before their internship begins.
3. Write the word "buoyancy" on the board and invite students to brainstorm words or phrases that come to mind when they think of this word. Before moving on, ensure students understand that buoyancy refers to the ability of an object to float when it is submerged in water. Even more specifically, it is the upward force that water exerts on this submerged object.
4. Tell students that their internship will eventually challenge them to construct a model of a boat that is neutrally buoyant. However, before they do this and maybe before they even understand what this term means, they will rotate through stations investigating different concepts related to buoyancy. Complete the following to prepare students for these stations:
    - Divide the class into groups of three.
    - Distribute one Buoyancy Capture Sheet to each student.
    - Show students where they can find each of the three stations.
    - Explain that the station's directions are included at each station. It will be each group's responsibility to read and follow the directions carefully. Students will visit a total of three stations and will stay at each station for about 10 minutes.
    - Assign the groups evenly among the three stations. Explain that even if stations have more than one group at them, students should work with their group only.
    - Then instruct students to quietly move to their assigned station and begin.
5. Keep an eye on the clock and on students' progress. After every 10–12 minutes, instruct groups to rotate clockwise to the next station, for a total of three stations.
6. When all three stations are complete, bring the class back together. Ask students to share what they have learned about buoyancy from each of the stations, beginning with Station 1. Guide students in recapping the following:
    - **Station 1:**
        - Key Takeaway: When your boat became heavier than the weight of the water that could fit inside it, it sunk!
        - Here's why: When you place an object in water, the water surrounding the object is displaced (or moved). When you filled your boat to the top with water and weighed it, this was the most water that your boat would be able to displace without sinking.

- **Station 2:**
  Investigation 1:
  - Key Takeaway: Density matters.
  - Here's why: Density can be calculated by dividing the mass of an object by its volume. Something that is solid and compact (like the paperclip) has a higher density than something that is light and large (like the apple or balloon). The paperclip has a higher density than water, which is why the paper clip sunk while the apple and balloon stayed afloat.

  Investigation 2:
  - Key Takeaway: The bottom surface area of an object (i.e. the surface that is against the water) also matters.
  - Here's why: Buoyancy is water's upward force, so when this surface area is larger, it has more area for the buoyant force to push upon. In addition, if we apply what was learned in Station 1, a larger cap displaces more water than a smaller cap—so it is able to take on more weight before it sinks.
- **Station 3:** Answers may vary, but invite students to share what they learned.

7. Conclude class with a viewing of The real story behind Archimedes' Eureka! to summarize the discussion and explain that we can thank Archimedes for the understanding of buoyancy that we have today. As students watch, encourage them to use the fourth square of their Buoyancy Capture Sheet to record at least one new fact that they learn about buoyancy.
8. Discuss the notes that the students jotted. Then instruct the class to store their capture sheet in a safe place and explain they will use these notes as they design their boat prototypes next session!

DAY 2

Instructor Note: Before this session begins, fill up the water container and place it on top of the towel in an area of the classroom with enough room around it for students to gather. Then display the rest of the prototype materials in another easily accessible part of the classroom.

1. Begin by welcoming students to the first day of their Ocean Team internship at Boeing. Instruct them to take out their Buoyancy Capture Sheet, and thank them for the work they completed to prepare for this internship! Explain that their first challenge as interns will be to use their background knowledge about positive buoyancy and negative buoyancy to create a boat prototype (or model) that is neutrally buoyant.
2. Ask: Considering what you know about positive and negative buoyancy, what do you think it means to be neutrally buoyant? Ensure students understand that something that is neutrally buoyant doesn't sink to the bottom or float above the water. Instead, it hovers in the water between the surface and floor. A submarine is an example of a water vessel that can be neutrally buoyant.
3. Instruct students to return to the groups they were in the day before and explain they will work in these teams to create a neutrally-buoyant boat prototype. Then prepare them for designing their prototypes by completing the following:
   - Distribute an empty bottle to each group. Explain that this must be used as the base for their prototype.
   - Show students where to find the other prototype materials, and briefly review what is available.

- Pass out one Design-Test-Optimize handout to each group. Review the instructions provided under each of the headers, and explain that groups should use the water container to take turns testing their protypes. During each trial, teams should consider their results and what they have learned about buoyancy to optimize (or improve upon) their design.
- Deduct 10–15 minutes from the end of the class session and explain that teams will have this amount of time to design, build, and complete all three trials. The class will then come back together and discuss what they learned.

4. Encourage students to begin. As students are working, rotate around the classroom and answer questions as needed. Provide a reminder when there are 15, 10, and 5 minutes left to work.
5. When there are 10–15 minutes left in the session, bring the class back together with their prototypes in hand. Debrief by discussing the following questions:
    - What challenges arose when you tried to make your neutrally-buoyant protype?
        - If time allows, invite one group who does not yet have a neutrally-buoyant prototype to demonstrate what happens when they place their prototype in water. Then encourage the class to provide constructive feedback and suggestions.
    - What strategies helped you create a neutrally-buoyant prototype? Why did these strategies work?
        - If time allows, invite one group who successfully designed a neutrally-buoyant prototype to demonstrate how their prototype works.
6. Conclude the session by congratulating students on a successful start to their internship. Explain that if students enjoy exploring buoyancy and/or the engineering design process, there are many STEM careers available—from safety engineers who ensure that real boats can stay afloat to marine archeologists who use their knowledge of buoyancy as they scuba dive and explore the oceans!

Extend

Students can further investigate the concept of buoyancy in relation to density—but this time explore what happens when it's the liquid's density that changes. Students can create an experiment in which they alter the density of water by adding varying amounts of substances like sugar, baking soda, salt, and/or food coloring. They can then use an egg (or their boat prototype) to see if this object maintains the same buoyancy in each of the different water solutions.

National Standards

Next Generation Science Standards

Engineering Design:

- MS-ETS1-1: Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.
- MS-ETS1-3: Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.
- MS-LS4-4. Construct an explanation based on evidence that describes how genetic variations of traits in a population increase some individuals' probability of surviving and reproducing in a specific environment.

Motion and Stability: Forces and Interactions:

- MS-PS2-2: Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.

Common Core English Language Arts Standards

Reading:

- R.1: Read closely to determine what the text says explicitly and to make logical inferences from it; cite specific textual evidence when writing or speaking to support conclusions drawn from the text.
- R.7: Integrate and evaluate content presented in diverse media and formats, including visually and quantitatively, as well as in words.

Speaking & Listening:

- SL.1: Prepare for and participate effectively in a range of conversations and collaborations with diverse partners, building on others' ideas and expressing their own clearly and persuasively.

Buoyancy Capture Sheet

Station 1	Station 2
What will make an object have negative buoyancy and sink?	What are two factors that can contribute to an object's positive buoyancy? 1. 2.

Station 3	Video Viewing
How does buoyancy help animals survive? What did you learn that could be helpful as you begin to think about designing a boat?	Listen for at least one new fact about buoyancy:

Station 1: Sinking, Sinking, Sunk

Directions: While making a boat sink may not seem difficult, do you know exactly what it takes to submerge it underwater? Find out by following these step-by-step directions.

Materials Needed:

- Smaller container, 1
- Larger container, 1
- Marbles, several
- Pitcher of water
- Marker
- Beaker

1. **Volume** is the amount of space that something takes up. Imagine that your small container is your boat. Measure the volume of this boat by filling it with water. Once it is filled to the top, carefully pour the water into the beaker.

   What is your boat's volume? _______ milliliters

2. Now calculate the weight of the water that your boat could hold.

   One milliliter of water = 1 gram. Therefore, your boat can hold _____ grams of water.

3. Fill the larger container halfway with water. Use the marker to draw a small line inside the container, as close to the water as you can. Then place your empty boat (i.e. your small container) in the water.

   Observe: What happens to the water?

4. Place marbles carefully in your boat, one at a time.

   Discuss: As you add more and more weight, what happens to the boat? What is happening to the water surrounding the boat?

5. As soon as your boat fully sinks, remove it from the container, and dump out any water. Then place the container, still filled with marbles, on the scale and record its weight:

   Boat's "sinking" weight: ____ grams.

6. Discuss: What connections can you make? What does it take to make a boat sink? Why do you think this is the case?

7. Record what you have learned in the Station 1 square of your Buoyancy Capture Sheet.

Station 2: Staying Afloat

Directions: Buoyancy is the force of a liquid pushing up on an object. Complete the two investigations below, followed by the group discussion, to see what conclusions you can make about the force of buoyancy.

Materials needed:

- Container of water
- Apple
- 3 caps of different sizes
- Paper clip
- Small inflated balloon
- Pennies, about 50

Investigation #1:

1. Line up the apple, small balloon, and paper clip according to estimated weight, and record them in the first column of the chart below.
2. Complete the second column's hypothesis with your group.
3. Test your hypothesis and record your results in the third column.
4. Discuss: Other than weight, what are some other differences among these three objects? How might this affect their buoyancy?

   Tip: Think about how compact (or dense) each object is!

Objects (lightest to heaviest)	Hypothesize: Will each object float or sink? Circle one.		Results	
	Float	Sink	Float	Sink
	Float	Sink	Float	Sink
	Float	Sink	Float	Sink

Investigation #2:

1. Place the three caps in the container of water, so the rims of the caps are facing upward.
2. Place pennies in all of the caps, one at a time, until two of the three caps have sunk.
3. Then consider: What connections can you make between the surface area of the top of each cap and its buoyancy?

Discuss: What have you learned about water's buoyant force that could help you design a buoyant boat? Discuss this as a group and then summarize your response in the Station 2 square on your Buoyancy Capture Sheet.

Station 3: Animal Buoyancy

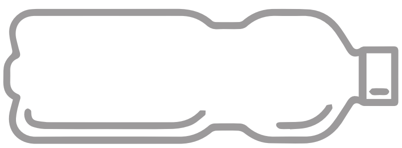
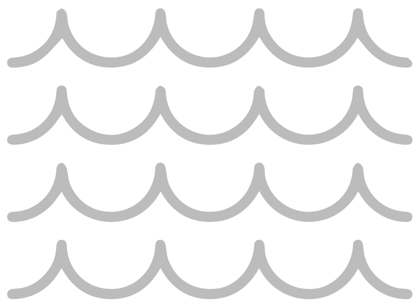
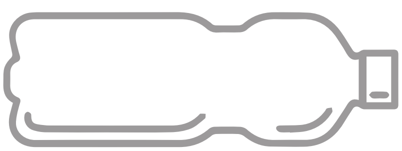
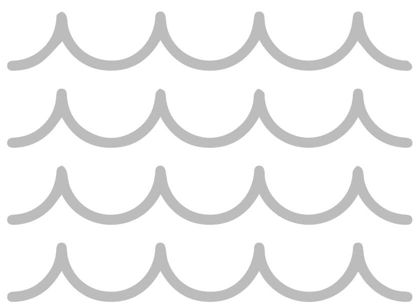
Directions: Animals knew how to dive, sink, and move in water long before humans started building boats! Discover what animal adaptations can teach you about buoyancy by following the step-by-step directions below.

Materials Needed:

- Article 1: Hippos Can't Swim, So How Do They Move Through the Water?
- Article 2: Diving, Rolling, and Floating, Alligator Style
- Article 3: How Do Fish Rise and Sink in the Water?

1. Each group member should select a different article to read. Every article explores how animals can be naturally buoyant.
2. As you read, annotate for *how* the animal(s) floats and/or sinks, as well as why the animal(s) developed this *adaptation*.
3. When you are done reading, use your annotations to answer the questions in the Station 3 square of your Buoyancy Capture Sheet.
4. When everyone in your group is done reading and annotating, share the takeaways that you each recorded and jot anything else you learn from your peers that may be helpful as you begin to design your boat!

Design—Test—Optimize handout

Design Sketch your design idea in the space below. Then add arrows to describe the different forces that will be acting upon the boat. In other words, what will help your boat sink? What will help your boat float?	**Test** Sketch: What happened during the trial? If the forces acted differently than you anticipated, add arrows to explain what happened.	**Optimize** Discuss & Jot: What could your team change to make your boat more neutrally buoyant? Once you have jotted your idea, move down to the next row and design it!
Trial 1 		
Trial 2 		
Trial 3