## Designing for Buoyancy

<table>
<thead>
<tr>
<th>High School</th>
<th>Standard(s): HS-PS2-1; HS-ETS1-2, 1-3, 1-4; (Optional: CCSS-ELA.SL.4, SL.5, SL.6)</th>
<th>Topic: Forces and Energies</th>
<th>Developed by: ASNE with materials from the University of Colorado</th>
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**Overview:** Students will first engage with the PhET simulations using this webpage to explore buoyancy force and particularly target how density and volume are related to buoyancy force. Students will use this information to consider the forces in FLEET during the Maneuverability Test.

**Sample Lesson Flow**

1. Warm-up (3 min), watch three force videos (15 min), discuss those forces (15 min), diagram/explore forces in FLEET (10 min), exit slips (2 min)
2. Warm-up (5 min), watch three force videos (15 min), discuss those forces (30 min), watch student play FLEET to practice discussing forces (5 min), diagram/explore forces in FLEET (25 min), summary conversation (10 min)

**Prior Student Knowledge Required:**
- Exposure to ships in FLEET.

**Student Learning Objective:**
- Understand how density and volume affect buoyancy and the Archimedes' Principle.
- Connect current knowledge of forces with a deeper understanding of buoyancy force.

**Materials:**
- Computers that can play Flash-based simulations.
- Computers with FLEET installed.
- (Optional, Step XII & Challenge 3) Computers that play YouTube videos.
- (Optional, Step X) Materials for students to share solutions in an “Engineers Got Talent” show.

**LESSON PLAN – (5-E Model)**

### Engage

I. Students will be working completely on simulators today! (If that is not feasible, see Additional Resource A)

II. Ask students to open the lesson’s webpage or have it already opened when they come in:

   a. [http://www.navalengineers.org/Students/FLEET/For-Educators/High-School-Curriculum-Club/Week-5](http://www.navalengineers.org/Students/FLEET/For-Educators/High-School-Curriculum-Club/Week-5)

   b. Walk around to see if the simulator is working for everyone (if possible, you could do this before class).

III. Tell everyone that this week they will set a new best time in the Maneuverability Test. This requires building a ship that can start quickly and maintain speed through the waves and turns of the course.

IV. Students should work in pairs or small groups on these questions so that they can help each other navigate the simulation and check each other’s understanding.

### Explore & Explain

V. Tell students to answer each question in order.

   Students may experiment or play around the simulator for a few minutes, but make sure everyone is on task fairly soon.

VI. This outline walks through the questions online with supporting information for the instructor:

   1. There are two versions of this simulator the “Intro” version is simplified.

   If "Click to Run", does not work for you, ensure you have a version of Flash or download it here: [https://get.adobe.com/flashplayer/](https://get.adobe.com/flashplayer/)
a. The weight is given on each block in kilograms. Volume is trickier. Students will need to use displacement to measure the volume of the blocks in liters. The brick block immediately sinks and it is 2.5 liters (water was 100L with the brick block in the water it’s a total of 102.50 liters so the extra 2.5 liters is from the brick block). Students can click and hold the wooden block to similarly submerge it (even though it will float without additional force). The wooden block has a volume of 12.5 liters.

2. Students could make many drawings depending on the block they choose.
   a. The wood block has equal forces of buoyancy (up) and gravity (down).
      OR The brick block has a long gravity arrow (down) and forces of buoyancy and contact (up). The sum of the forces of buoyancy and contact will equal the force of gravity.
      OR If a student submerges the wood block, then the buoyancy force arrow (up) will be much longer than the gravity arrow (down). This shows that there is a net upward force so the block will quickly rise to the surface when released.

   b. The blocks will only stack like this if the brick block is on top of the wood block. The brick block has a downward force from gravity and an equal contact force from the wooden block that points upwards. The wooden block will have a downward contact force and a downward gravity force. The wooden block will also have an upward buoyancy force that is equal to the sum of the contact and gravity forces. NOTE: The simulator may cover up forces acting in the same direction so students should add/remove forces listed under “Show Forces” to ensure they understand all the forces acting on an object.

3. This is the tab with more variables.

4. Students will need to design materials for questions 5C and 5D.

5. You may want to pull the class at this point to make a data collection tool that everyone will use. Connect this tool to your engineering design process. This step is creating the tests necessary to evaluate designs and record relevant data. For example,

<table>
<thead>
<tr>
<th>Tests</th>
<th>Mass</th>
<th>Volume</th>
<th>Density</th>
<th>Sink?/Float?</th>
<th>Density of Liquid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material A</td>
<td>—</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Material B</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Material C</td>
<td></td>
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</table>

a. This is a dense question so it may be worth explaining again to groups that are stuck. The answer is that the difference is 0. Because gravity is the same and the total mass is the same, the force of gravity is the same (98 Newtons) for both situations.

b. Placing a wooden block under an aluminum block will make it float if the volume of the wooden block is at least five times greater. Students could also use a Styrofoam block that has a volume that is at least 3.3 times greater. The overarching principle is that the sum of the masses divided by the sum of the volumes must be less than 1.0. This relationship shows that the combined density of the two blocks must be less than the density of water.

c. Styrofoam with the smallest volume (1L, 0.15 kg) will have the least surface area contact because its “draft” (the amount of the material submerged in water) is the least. Making the block as small as possible decreases the surface area as well.

d. One possible solution is an ice block with any volume. (The density of water is 1.00 kg/L so any material with a density between 0.91 kg/L and 0.99 kg/L is acceptable.

e. One possible solution is a 7.05 kg block with a 5L volume and density 1.41 kg/L. (The density of honey is 1.42 kg/L so any material with a density between 1.35 kg/L and
1.42 kg/L is acceptable.

f. This answer will not be different than the answer for #2a but students will have more options for the types of materials.

Elaborate

6. These are thought experiments so let students talk with each other to process these ideas.
   a. The ship floats so it must be less than 1.00 kg/L. Better estimates will be between 0.4 and 0.7 kg/L because it’s not mostly submerged in water like an ice block (density 0.92 kg/L) and it’s not nearly levitating on top of the water like Styrofoam (density 0.15 kg/L).
   b. Some of the lighter materials will need to be under the water. A ship displaces water with air, so the air/steel combined density is less than 1.00 kg/L.
   c. As you researched in Week 2, there needs to be some weight at the bottom, but as you now know that weight cannot exceed an important ratio. Even though steel is much heavier than water, it is used a lot because having a weight at the bottom of the hull is stabilizing. This is one reason we discuss the keel so much.

VII. Move students into FLEET.

VIII. Let students explore the Maneuverability Test with this newfound knowledge. The primary questions on their minds should be:
   a. What is the ideal weight for the ship?
   b. How should the weight be distributed (consider all three dimensions) for maximum speed and agility?

Evaluate

IX. (Optional) If you have time for the extension challenges, consider having different groups work on different challenges so that they can share their results.

X. (Optional) Given that these challenges are designed to require a bit of engineering magic, you could preface this work by setting up an “Engineers Got Talent” show. Ideally, students could project their solution so that all can see it, but if that is not possible require them to draw two or three pictures showing the solution alongside design data (e.g., materials, density) and testing data (e.g., graphs).

The three challenges push you to create some interesting solutions. Some may call them magic, but we know that these solutions show that you have engineering talent. We will have a quick episode of “Engineers Got Talent” at the end of class so that you can show off your solutions to these challenges. I will work with you so that different groups work on different challenges.

XI. (Optional) Here are some possible solutions to the challenges:
   a. The word “bounce” indicates that the upward force will eventually be greater than the downward force. This is possible in the simulator by using the largest block and dropping it from the greatest height. This allows the gravity to have its greatest effect. The force of gravity creates a large velocity. The upward buoyancy force decreases this downward velocity, but not before the block touches the scale in the water.
   b. This requires a second block on top of the wooden block that ensures the combined density is around 1.01 kg/L.
   c. Pause the video after the problem is presented. The solution is the second 2/3 of the video. Note that the idea of using an extreme case is a very valuable tool. While the answer is not
clear with a normal size rock, a rock with a HUGE density will obviously sink the boat but
displace very little water.

XII.  **(Optional)** Play this YouTube clip from TED-Ed ([https://www.youtube.com/watch?v=ijj58xD5fDl](https://www.youtube.com/watch?v=ijj58xD5fDl)) about Archimedes Principle. The closing question is: How did Archimedes use density and volume
to judge whether the crown was made of gold? 🎥

### Additional Resources

A. If you are unable to use the simulators, consider one of the “Extra” lessons at
www.fleetengineering.org or ask students to draw free-body diagrams that describe the situations in
FLEET and in the challenges. You will need to first explain that water has a density of 1 kg/L and any
material with a lesser density will float while anything with a greater density will sink.

B. This version of TED-Ed focuses more on the naval engineering applications of Archimedes Principle. It’s
a great 4-minute video: [https://www.youtube.com/watch?v=0v86Yk14rf8](https://www.youtube.com/watch?v=0v86Yk14rf8)

C. The next two pages are the student-facing questions. You may want to print it for easy use as you walk
around.
Print out of online questions for Week 5 simulation

**Things to Explore**

1. Use the Intro version of the simulator for the two questions below. You can click and hold a block to move them, you can even hold them underwater if you want.
   
   A. What is the volume and weight of the brick block? How much force does gravity pull on the block?
   
   B. What is the volume and weight of the wood block? How much force does gravity pull on the block?

2. Use the bottom left checkboxes to turn on the force diagram arrows and add the force values too.
   
   A. Diagram the forces that are shown when one block is in the water.
   
   B. Diagram the forces on each block when you stack two blocks on top of each other in the water.

3. Click the tab in the upper left for "Buoyancy Playground." This will give you access to more variables to manipulate.

4. Click the "Two" button under Blocks so that you can experiment with two blocks. (If you want to design your own material, click "My Block" in the upper left corner.)

5. Create a data table that records the density, the displacement, the force of gravity, and any other variables you determine are relevant to answer the questions below.

**Questions & Design Challenges:**

A. What is the difference in the force of gravity on one 10-kg brick block and on two stacked 5-kg brick blocks?

B. What are **two** ways that you can make the cube of aluminum float?

C. Design a material that has the least surface area contact with the water.

D. Design a material that just barely floats in water.

E. Design a material that just barely floats in honey.

F. Draw a force diagram with one wet block and one dry block. One block will be floating in water, the dry block will be stacked on top of the first block. Be sure to document all the forces.

**Connecting to FLEET**

6. Now talk about density and buoyancy forces in relation to FLEET.

   A. What do you think the density of your ship is?

   B. How would you arrange the materials in your boat to have the greatest buoyancy?

   C. How would you arrange the materials in your boat to have buoyancy and stability?

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**Student-facing website:** [http://www.navalengineers.org/Students/FLEET/For-Educators/High-School-Curriculum-Club/Week-5](http://www.navalengineers.org/Students/FLEET/For-Educators/High-School-Curriculum-Club/Week-5)
Print out of online questions for Week 5 simulation

**Extra time?**

**Challenge 1:** Make the wooden block hit the "scale" that measures forces in the water then bounce off it.

**Challenge 2:** Make the wooden block rest on the "scale" that measures forces in the water but exert less than 1N of force.

**Challenge 3:** Watch the first minute of [this video from the Physics girl](http://www.navalengineers.org/Students/FLEET/For-Educators/High-School-Curriculum-Club/Week-5), then use this simulation to think through the possible solutions.