The Great Escape! Introduction and Activity 1: Displacement and Buoyancy

Developed by Paul Mezick, ScienceTeacher, Daniel Hand High School, Madison CT
2014 Submarine Force Museum & Historic Ship *Nautilus* STEM-H Teacher Fellowship

Background:

The compressibility of gases is an important consideration for divers because of the effect it has on how long a diver can stay under the water, or how fast a diver can change depth. All gases, regardless of their chemical composition, exhibit similar behavior in response to variables such as temperature, pressure, and volume. The behavior of gases, when any one of the variables is manipulated, is called the ***Kinetic Molecular Theory of Gases***. For anyone who experiences significant time under water, these variables have effect on gases in your blood, body tissues, and the gases in your lungs. Divers have standard procedures and special equipment to assist in balancing the variables, but in emergency situations where a diver may have to ascend quickly, rapid changes in depth can result in a life threatening medical conditions. Submariners practice the skill of emergency escape from a sunken submarine.

Instructional Goals:

In this unit students will become familiarized with basic principles of **density, buoyancy, and pressure.** Students will explore the effect pressure has on solids, liquids, and gases. The focus will be placed on the relationship between volume and pressure when the temperature is held constant. Students will apply what they learn about the Kinetic Molecular Theory of Gases to function of the human lung. The culmination is for students to apply what they learned about density, buoyancy, and pressure to the physiological limitations for safely escaping from a submerged, stranded submarine. Students will generate an info-graphic that embodies each of the learning activities.

Prior Knowledge:

1. **CCSS.MATH.CONTENT.HSN.Q.A.1** Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.

2. **CCSS.MATH CONTENT.MP.4** Analyze and model mathematical relationships to draw conclusions.

Science Standards Connections:

1. **HS-PS2-2 Motion and Stability:** Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system.
2. **MS-PS1-4 Matter and its Interactions:** Develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed.
3. **HS-ETS1-3 Engineering Design:** Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.
4. **HS-ETS1-4 Engineering Design:** Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.

Introductory Video Activities:

1. Identify the Submarine Rescue Chamber in the photo from the Submarine Force Museum: http://www.ussnautilus.org/virtualTour/mainexhibit.shtml .

2. View the use of the rescue chamber in the video at http://www.youtube.com/watch?v=TuhWjHRAEPw, a 1953 U.S. Navy training film # MN-7418 of a submarine escape. "Submarine Escape : United States. Navy : Free Download & Streaming : Internet Archive." *Internet Archive*. N.p., n.d. Web. 23 July 2014.

3. The replacement for the rescue chamber, a "DSRV" or deep submergence recovery vehicle, is shown in the 14 minute video from 1973 at https://www.youtube.com/watch?v=oBZogh2PJTc "Deep Submergence Recovery System". The first of two DSRV's "Mystic" is shown below. The second is "Avalon" ; both DSRV's are inactivated and will soon be on display.

4. The current 21st Century U.S. Navy submarine escape procedures are included in Activity 4 of this lesson plan. A video demonstrates submarine school students practice escaping from a submarine at the U.S. Naval Submarine Base escape trainer at: http://www.theday.com/article/20100925/MEDIA0101/100929710 . "The Day - Escaping from a Submarine: A Trial Run | News from Southeastern Connecticut." *The Day*. N.p., n.d. Web. 22 July 2014.

Activity One: Displacement and Buoyancy

Objectives:

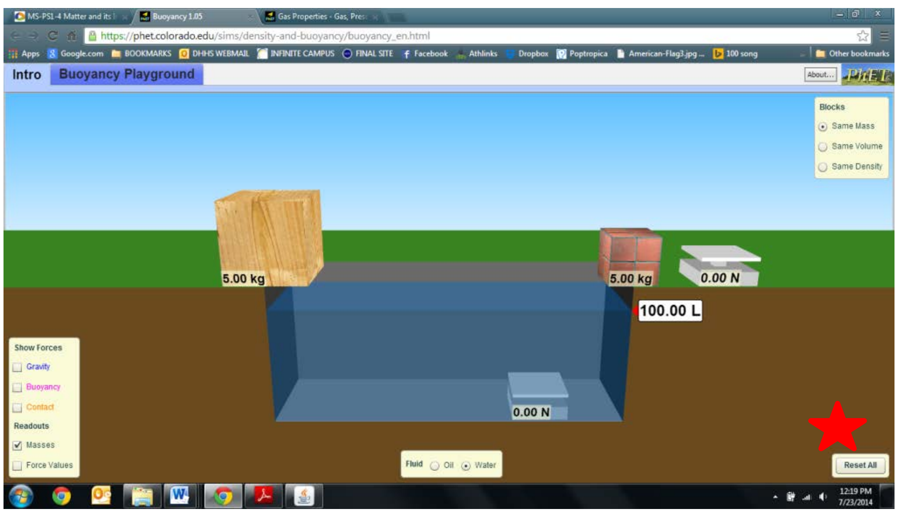
1. Familiarization with concept of displacement.
2. Investigate the conceptual relationship between buoyancy and density.

Procedure:

Getting Familiar

1. Visit the following URL for the Phet interactive applet. http://phet.colorado.edu/en/simulation/buoyancy
2. On the Intro screen, familiarize yourself with the applet by changing the blocks, and observing what happens when the various variable, mass, volume and densities are manipulated or held constant.
3. Check and uncheck the boxes under "Show Forces" to see where they act.

Note: Before beginning the lab activity ensure to select the "reset all" button, which will return your applet to the default settings.



http://phet.colorado.edu/en/simulation/buoyancy

Note: For teacher use or for independent learners to check their answers to the three sections:

Activity 1: Lab Set-up questions 5-9, Lab Procedure Part 1, and Lab Procedure Part 2,

see the red typed script following Lab Procedure Part 2 below.

Lab Setup:

1. Click over to the **Buoyancy Playground** and begin the lab.

2. There are various fluids and materials to manipulate within the buoyancy playground

3. The number of blocks selected should be set at two

4. **Block A** – select <u>wood</u> as the material and 4 kg for the mass. Verify the mass by placing the block on the scale located <u>outside of the water</u>.

Note: To convert from mass to weight use F=ma, (Newtons) = (mass) x 9.8

5. What did the applet set the default volume to for **Block A** when you selected 4 kg as the mass?

   ____

6. **Block B** – select <u>brick</u> as the material and 4 kg as the mass. Verify the weight by placing the block on the scale located <u>outside of the water.</u>

7. What did the applet set the default volume to for **Block B** when you selected 4 kg as the mass?

   ____

8. What is the volume of water in the pool?

   ____

9. Select the forces for **gravity** and **buoyancy**

Lab Procedure: Part 1

	Mass (kg)	Dry Weight (N)	Submerged weight (N)	Dry Volume (L)	Submerged Volume (L)	Density (kg/L)
BLOCK A "wood"	**4.0 kg**					
BLOCK B "brick"	**4.0 kg**					

Note: To convert from weight to mass use m=Fa, (mass) = (Newtons) / 9.8

1. Select **Block A**, and drag the object to the bottom of the water column.
2. Describe the change in the forces when you placed **Block A** at the bottom of the water column?

   ____

   ____

   ____

3. How did the volume of the water pool respond as **Block A** was placed at the bottom of the water column?

   ____

   ____

   ____

4. What is this change in volume called? What was the volume of **Block A**?

   ____

   ____

   ____

5. Does the value for **Block A** in question #4 represent the volume of the object? Explain your reasoning.

   ____

   ____

   ____

6. Place **Block A** on the scale submerged within the water column.
7. How would you describe the submerged weight of **Block A**?

   ____

   ____

   ____

8. Release **Block A**, and observe what happens.
9. How would you describe the relationship in the forces when you released **Block A**?

   ____

   ____

   ____

10. How did the volume of the water pool respond as **Block A** was released? Does the new volume represent the volume of the object?

____

____

____

11. Describe the relationship between the values for the weight and the value for the new volume.

____

____

____

12. Select **Block B**, and drag the object to the bottom of the water column.

13. Describe the change in the forces when you placed **Block B** at the bottom of the water column?

____

____

____

14. How did the displacement of the water column respond as **Block B** was placed at the bottom of the water pool? What was the value for the volume?

____

____

____

15. Place **Block A** on the scale submerged within the water column.

16. How would you describe the submerged weight of **Block B**?

____

____

____

17. Release **Block A**, and observe what happens.

18. How would you describe the relationship in the forces when you released **Block B**?

____

____

____

19. How did the volume of the water pool respond as **Block B** was released? Describe the relationship between the values for the weight and the value for the volume.

____

____

____

20. Based on your observations and responses to the previous questions, explain how is it possible to have two objects of the same mass where one object sinks and the other object floats? Use your observations from the Intro part of the lab to answer this question.

____

____

____

Lab Procedure: Part 2

1. View the following video about Archimedes' Principle http://www.youtube.com/watch?v=ijj58xD5fDI

"How Taking a Bath Led to Archimedes' Principle - Mark Salata." *YouTube*. YouTube, n.d. Web. 23 July 2014.

2. Identify the variables for the derived unit density. Write the equation for density.

   ____
   ____
   ____

3. Calculate the density of **Block A**

   ____

4. Calculate the density of **Block B**

   ____

5. Examine the applet. What is the fluid density for water in kg/L?

   ____

6. Examine the densities of **Block A** and **Block B**. What appears to be the relationship between density and the buoyancy (ability to float in a fluid) of an object? Explain your reasoning.

   ____
   ____
   ____

7. Using the keywords weight and displacement, explain why the depth at which **Block A** is submerged changes as you move the slider to represent different types of fluids?

   ____
   ____
   ____

Answers to Activity 1:

Lab Set-up questions 5-9,

Lab Procedure Part 1, and

Lab Procedure Part 2,

see the red typed script below:

Note: To convert from mass to weight use F=ma, (Newtons) = (mass) x 9.8

5. What did the applet set the default volume to for **Block A** when you selected 4 kg as the mass?

   ____

   10 L
6. **Block B** – select brick as the material and 4 kg as the mass. Verify the weight by placing the block on the scale located outside of the water.

7. What did the applet set the default volume to for **Block B** when you selected 4 kg as the mass?

   ____

   2 L
8. What is the volume of water in the pool?

   ____

   100.00 L
9. Select the forces for **gravity** and **buoyancy**

Lab Procedure: Part 1

	Mass (kg)	Dry Weight (N)	Submerged weight (N)	Dry Volume (L)	Submerged Volume (L)	Density (kg/L)
BLOCK A "wood"	**4.0 kg**	**39.2 N**	**0 N**	**10 L**	**4.0 L**	**0.4 kg/L**
BLOCK B "brick"	**4.0 kg**	**39.2 N**	**19.6 N**	**2 L**	**2.0 L**	**2.0 kg/L**

Note: To convert from weight to mass use m=Fa, (mass) = (Newtons) / 9.8

1. Select **Block A**, and drag the object to the bottom of the water column.

2. Describe the change in the forces when you placed **Block A** at the bottom of the water column?

   ____

   ____

   Gravity remains the same, but buoyancy increases with depth
3. How did the volume of the water pool respond as **Block A** was placed at the bottom of the water column?

   ____

   ____

   The volume of the water increased
4. What is this change in volume called? What was the volume of **Block A**?

   ____

   ____

   Displacement. The volume of Block A was 10 L
5. Does the value for **Block A** in question #4 represent the volume of the object? Explain your reasoning.

   ____

   ____

   Yes it did. The volume of the entire object was displaced
6. Place **Block A** on the scale submerged within the water column.

7. How would you describe the submerged weight of **Block A**?

The object appears to have no weight when completely submerged

8. Release **Block A**, and observe what happens.

9. How would you describe the relationship in the forces when you released **Block A**?

The force of gravity is balanced with the buoyant force

10. How did the volume of the water pool respond as **Block A** was released? Does the new volume represent the volume of the object?

The volume of water in the pool was reduced because not all of the object was displaced. The new volume represents only that portion of the object that is displaced

11. Describe the relationship between the values for the weight and the value for the new volume.

The volume of the water displaced is equal to the weight of the object

12. Select **Block B**, and drag the object to the bottom of the water column.

13. Describe the change in the forces when you placed **Block B** at the bottom of the water column?

Gravity remains unchanged, but the buoyancy increases with depth

14. How did the displacement of the water column respond as **Block B** was placed at the bottom of the water pool? What was the value for the volume?

The volume of the water increased. The volume of Block B was 2.0 L

15. Place **Block A** on the scale submerged within the water column.

16. How would you describe the submerged weight of **Block B**?

The submerged weight of Block B was 19.6 N –or- 2 kg

17. Release **Block A**, and observe what happens.

18. How would you describe the relationship in the forces when you released **Block B**?

The buoyant force was less than the force of gravity

19. How did the volume of the water pool respond as **Block B** was released? Describe the relationship between the values for the weight and the value for the volume.

The volume of water in the pool did not change. The object remained submerged, and therefore the entire object was displaced.

20. Based on your observations and responses to the previous questions, explain how is it possible to have two objects of the same mass where one object sinks and the other object floats? Use your observations from the Intro part of the lab to answer this question.

In order for an object to float it must displace a volume of water that is equal to its weight. The wood block sank until it displaced a volume of water equal to weight of the object. The brick was unable to displace a volume of water, even when completely submerged, to equal its weight.

Lab Procedure: Part 2

1. View the following video about Archimedes' Principle http://www.youtube.com/watch?v=ijj58xD5fDI

"How Taking a Bath Led to Archimedes' Principle - Mark Salata." *YouTube*. YouTube, n.d. Web. 23 July 2014.

2. Identify the variables for the derived unit density. Write the equation for density.

Mass and Volume are the derived units. D = M / V

3. Calculate the density of **Block A**

0.4 kg/L

4. Calculate the density of **Block B**

2.0 kg/L

5. Examine the applet. What is the fluid density for water in kg/L?

1.00 kg/L

6. Examine the densities of **Block A** and **Block B**. What appears to be the relationship between density and the buoyancy (ability to float in a fluid) of an object? Explain your reasoning.

Objects that float (positive buoyancy) have a density that is less than the fluid they are immersed in

7. Using the keywords weight and displacement, explain why the depth at which **Block A** is submerged changes as you move the slider to represent different types of fluids?

Adjusting the density of the fluid changes the amount of fluid that the object must displace to equal the weight of the object. Objects must displace more in fluids with lower densities, and displace less in fluids with higher densities.