Dive the Cartesian Way

Ted Allen, Science Teacher, Ledyard Middle School, Ledyard CT
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Submarine Force Library and Museum Association Fellow

Background:
Submarines are ships capable of being submerged. The history of submarines and their operation have largely revolved around being able to alter the density of the vessel so that it may dive below the surface, maintain a depth, and return to the surface as needed. The way modern submarines accomplish this task is to bring in and remove water from tanks in the submarine called ballast tanks. Submarines through the history of our submarine force and other navies across the world have accomplished this task in a variety of ways but the simple truth is that by changing densities submarines alter the weight of the ship allowing it to accomplish these tasks.

Instructional Goal: This lesson encourages students to research and read about the way submarines change and maintain depth in the ocean. Students will then model how the taking in of water (ballast) and release of it from a submarine allows the change of buoyancy to rise (positive buoyancy), dive (negative buoyancy), and maintain depth (neutral buoyancy). Students will also make measurements of volume and graph these results and report on their results in a written format.

Science Standard links:
- MS-PS2-2 Motion and Stability: Forces and Interactions (Next Generation Science Standards)
- CCSS.ELA-Literacy.RST.6-8.9 (Common Core State Standards for Literacy in Science and Technical Subjects)

Preliminary Knowledge:
1. Students should be familiar with balanced and unbalanced forces.
2. Students should be familiar with Archimedes Principle and buoyancy.
3. Students need awareness of physical properties of water and air, i.e. Air may be compressed, and water is non-compressible.

Introductory Activities:
1. http://www.youtube.com/watch?v=JrU0bYq7KPQ&list=PLFD9B22F33A5FBDCB Watch Video on U.S. Navy YouTube Channel
2. Read about buoyancy at http://www.onr.navy.mil/focus/blowballast/sub/work3.htm
3. To learn more science, read all seven pages on how submarines work from the Office of Naval Research at http://www.onr.navy.mil/focus/blowballast/sub/work1.htm
4. To learn more about the history of the U.S. Submarine Force visit www.ussnautilus.org and take a virtual tour.

Activity One: Forces

Objective:
1. Model and discuss the two competing forces involved in the vertical motion of a submerged object.
2. Identify which of these forces are natural constants and which can be controlled.

Materials:
- Markers
- Paper

Procedures:
1. Construct a graphic model showing the relationship between the buoyant force and gravity.
2. As a class discuss how the forces would have to be altered to have a submerged submarine rise? How would they have to be altered to make the submarine dive (sink farther)?
3. (Extension) For a surfaced submarine, before it dives, discuss the relationship between the buoyant force and the force of gravity?

Questions:
1. For a submerged submarine, of the two forces, which can be controlled and which is a constant for us?
2. How is the density of a submarine controlled?
3. Describe the relationship between the force of gravity on a submarine, and the submarines weight?

Answers:
1. The force of buoyancy is constant, but the density and weight can be changed by adding or removing water from the submarine, while at a given depth.
2. Density (and weight) are controlled by adding or removing water from submarine ballast tanks, changing the force of gravity relative to the force of buoyancy. The force of buoyancy is equal to the weight of the fluid displaced by the submarine's hull.
3. Weight equals the force of gravity, they are the same thing.

   NOTE: If the density of an object exceeds the density of water, the object will sink.

Activity Two: Cartesian Diver

Objective:

1. Construct a Cartesian Diver to model changing the buoyant force by altering the density of the diver.
2. Make measurements and graph the volume of water required to maintain positive buoyancy, neutral buoyancy, and negative buoyancy.

Materials: (per group)

- Graduated glass medicine dropper with rubber bulb (preferred) or others as available
- Wax pencil if needed to mark graduations on medicine dropper
- Ruler (metric)
- Clear plastic two liter soda bottle with cap
- Pencils
- Graph paper

Procedure:

1. Rinse out two-liter bottle and remove label.
2. Find the mass of the empty medicine dropper. Record.
3. If needed, mark off graduations at each cm on medicine dropper.
4. Fill two-liter bottle all the way to the opening.
5. Squeeze bulb to fill medicine dropper approximately halfway, place in water “bulb up” to ensure it floats with only 10% of the dropper above the surface with a vertical alignment.
6. Place dropper in bottle and reseal with cap. (Have as small an air bubble as possible in the top of the bottle.
7. Record the amount of water in the medicine dropper while floating, record in lab notebook.
8. Practice raising and lowering the Cartesian Diver by squeezing the side of the two-liter bottle.
9. What happens to the volume of water in the medicine dropper as you squeeze the bottle? Record answer.
10. Practice submerging and raising the diver slowly, and attempt to have it float in the middle of the bottle.
11. Once you have these mastered, measure the volume of water in the diver for floating at the top, slowly sinking, neutrally buoyant, sinking fast, and sitting on the bottom. Graph these using a bar graph on graph paper.

Questions:

1. What factor is changing in the diver as you squeeze the sides of the two-liter bottle?
2. Assuming each graduation on the diver shows 1 cm^3 what is the difference of volume of water in the diver on the surface, as neutrally buoyant, and resting on the bottom?
3. Since one cm^3 of water has a mass of 1 gram, what is the mass of the dropper at these three locations? What is the percent of change of mass at neutral buoyancy and at the bottom from floating on the surface?
   a. Formula is (***original value – new value)/original value***
4. Where on your graph is the volume difference most pronounced? Why do you think this is?
5. How does this model the way a submarine submerges and raises? What are some ways it could be improved?
6. What is Archimedes' Principle/

Reference: **http://www.history.navy.mil/branches/teach/fieldtrip-dive.htm**

Answers:

1. The amount of water in the diver increases when you squeeze and decreases when you release the pressure on the sides.
2. Answers will vary depending on the individual diver, temperature of the water, mass of the dropper and a host of other variables.
3. Answers will vary depending on the individual diver, temperature of the water, mass of the dropper and a host of other variables.
4. Answers will vary, but will usually be: at the surface will show the greater difference in most cases.
5. It models the way a submarine goes up and down by showing the taking in of water to increase density, which overcomes the buoyant force and lowers the sub; while releasing water lowers the density and leads to the sub rising. Ways to improve the lesson will vary widely.
6. **Archimedes' principle** is the law of buoyancy. It states that "any body partially or completely submerged in a fluid is buoyed up by a force equal to the weight of the fluid displaced by the body." The weight of an object acts downward (the force of gravity), and the buoyant force provided by the displaced fluid acts upward.