I. Exploring Buoyancy

How low can you go? This lab challenges your students to use their understanding of buoyancy, density and pressure to design and build ocean exploration devices.

Grade Levels: 4-8

Educational Outcomes:

1) Students will understand that a Buoyant Force is an upward force exerted by a fluid on a floating or submerged object.
2) Students will understand and demonstrate the difference between positive buoyancy, negative buoyancy and neutral buoyancy.
3) Students will understand and apply the key concepts of: buoyancy, density, and the balancing of forces to solve a design challenge.

Estimated Time: 1.5 hours

- Introductory Design Challenge: 20 min.
- Basic Science Discussion: 15 minutes
- Design Challenge:
    - Building – 40 minutes
    - Sharing – 10 minutes
    - Clean-up – 5 minutes

California Science Content Standards Connections:

Grade 8 Physical Science:
Forces

2b. **Students know when an object is subject to two or more forces at once, the result is the cumulative effect of all the forces.**

2c. **Students know when the forces on an object are balanced, the motion of the object does not change.**

2d. **Students know how to identify separately the two ro more forces that are acting on a single static object, including gravity**, elastic forces due to tension or compression in matter, and friction.

Density and Buoyancy

8. All objects experience a buoyant force when immersed in a fluid.

8a. **Students know density is mass per unit volume.**

8d. **Students know how to predict whether an object will float or sink.**

All grades - Investigation and Experimentation: Scientific progress is made by asking meaningful questions and conducting careful investigations. As a basis for understanding this concept and addressing the content in the other three strands, students should develop their own questions and perform investigations.

Gallery Connections: Explorations: Deep Frontier and Command the Depths (submersible ROVs), Diving into the Ocean exhibits, submarine floor activity.

II. Exploring Buoyancy: ADVANCED PREP AND SET-UP

Introductory Design Challenge:
Each team of two to three will have:

- 3 film canisters
- 1 plastic container filled w/ water
- Supplies from resource table

Student research station

- Galileo thermometer
- Lego Rescue Submarine
- Cartesian Diver (Squidy)
- Various objects displaying positive, negative & neutral buoyancy
- Key words with definitions

Science Discussion

- Lego™ Rescue Submarine
- 30 gallon fish tank or large plastic storage box
- Small airtight plastic container filled with marbles
- Larger airtight plastic container (~16 times larger than the small container
- Key words

Poster for wall:

- Archimedes Principle
- Boyle's Law

Design Challenge:
Each team of four to five will have:

- 1 half pint water bottle or film canister
- 1 large (66 qt.) plastic container of water with smaller plastic container inside to form a raised shelf.
- Supplies from resource table
- Objects for retrieval (We have used film canister lids with covered wire wrapped through a hole and twisted together).

General supplies available to everyone (from long table on side of room):

- Balloons
- Rubber bands
- Film canisters
- Tape
- Drinking straws
- Plastic aquarium tubing
- Glue guns/ glue
- Weights (beads, pennies, etc)
- Paper clips
- Duct tape
- Bubble wrap
- Pipe cleaners
- Syringes
- corks
- Styrofoam peanuts

Glue station:

It's advised to set up a hot glue station far away from any containers of water, so that students can use it as needed. Depending on the age of students, some instruction may be needed in how to properly use glue guns.

III. Exploring Buoyancy: LESSON PLAN

A. Introduction:

This class is about underwater exploration. We will be playing with the concepts of buoyancy, density, volume and pressure to enable us to explore a body of water at varying depths. In fact it will be your job to figure out how to use these concepts to dive and retrieve objects while being fully in control!

B. Mini Design Challenge: Float, Hover, Sink

Challenge:

Your first challenge is to design a set of simple devices that will house instruments to take water samples for the Water Quality Monitoring Project. You will need to collect samples at the surface, middle and bottom of the body of water in front of you. You will need to design 3 instruments, each varying in density so that one will float, one will hover and one will sink. (Hand out 3 film canisters per groups of 2 or 3, to be used with a pre-filled plastic container of water).

Constraints:

- You can use any materials found at the resource table.
- Each group member must participate in solving the Design Challenge.
- You will need to use a different film canister for each challenge (floating, sinking and hovering).
- The hovering canister should be free to move around (i.e. not tethered or anchored).

DC Demonstration and Reflection:

Demonstration: Have students demonstrate their solutions for the class, at their tables. If students have not completed their solutions ask them *how the design would have worked.*

Reflection: Each group of students will explain their design strategy and how they were able to make their canisters float, hover and sink. Instructor should ask leading questions to get at the science behind the designs.

Teacher Notes:

Students should be encouraged to visit the research station as well as other student teams to assist them in their design strategies.

Students will use this initial challenge as a resource to inform their design in the 2nd challenge.

Classroom teachers can break up this lesson into 2-3 separate days (based on your teaching schedule). We suggest that students have one class period to design and demonstrate their devices (while reflecting on what they initially learned). Then another day to receive direct instruction about the content. Finally, a third period to redesign and demonstrate their vessels.

Teaching Points (Buoyancy content):

- The buoyant force is the net upward force exerted by a fluid on a submerged object.
- When an object floats, we say that it is positively buoyant.
- When an object sinks, we say that it is negatively buoyant.
- When an object hovers, we say that it is neutrally buoyant.
- When two or more forces act on an object, the result is the cumulative effect of those forces.
- Neutral buoyancy is a state in which the forces of gravity and buoyancy are in equilibrium or balanced, so the motion does not change.

Questions to encourage teaching points:

- What did you do to get the canisters to the correct locations?
- Can you tell me why 1 canister will float while another will sink?
- What forces are acting on the canister? (Gravity is pulling down and the buoyant force of the water is pushing up.)
- What can you say about these two forces when an object sinks? Floats? (Gravity is greater than the buoyant force on a sinking object but less than the buoyant force on a floating object)
- How did you get one canister to just hover? Was it difficult? (Hovering is the most difficult, because you need to balance the forces of gravity and the buoyant force. Most solutions require adding mass to get it to sink but then increasing the volume with a floatable material to get it to float.)

Key Words:

Archimedes Principle:
A body immersed in a fluid is buoyed up by a force equal to the weight of the displaced fluid.

Buoyancy:
The apparent loss of weight of an object submerged in a fluid.

Pressure:
The force exerted against an opposing body; expressed in units of force per unit of area.

Volume:
The amount of space occupied in three dimensions.

Mass:
The amount of matter that is contained by an object.

C. Buoyancy and Density (Demonstration & Discussion)

1. **Density Demonstration**

Show students a small (1-2 cup) plastic container filled with marbles. Discuss that it has a lot of stuff (mass) in a small shape (volume). Ask them to predict whether it will sink or float.

Empty the marbles into a larger container (16 times larger than the smaller container). Stress that this is the same amount of mass in a larger volume. Ask them to predict whether it will sink or float.

Teaching Points:

- Density is the amount of mass per unit volume.
- If you increase the mass but keep the volume the same, the density increases.
- If you increase the volume but keep the mass the same, the density decreases.

Questions to encourage teaching points:

- How does the submarine dive down? How does it become denser?
- How does the submarine surface?
- Why does this work?
- Does anyone know how a scuba diver is able to dive and surface?

2. **Submarine Demo**

Demonstrate for class the Lego™ Rescue submarine. Show how air is pulled out to allow it to dive and air is pumped back in to allow it to surface.

Teaching Points:

- When something is more dense than water, it is negatively buoyant. When it is less dense than water, it is positively buoyant. When it has the same density of water, it is neutrally buoyant.
- Density of water is greater than air.
- When the density of a submarine (or scuba diver) is greater than water it will sink, when it is less than water it will surface.

Questions to encourage teaching points:

- Can you think of real life applications for being positively buoyant (floating)? Negatively Buoyant (Sinking)? How about being neutrally buoyant (hovering)?
- Can you think of any things that might make use of all 3 forms of buoyancy?
- How does the submarine dive down? How does it become denser?
- How does the submarine surface?

Teacher Notes:

This lesson can easily be extended, by having students actually calculate the density of objects. Guide them to "discover" the formula for finding density, by first guiding them through the demonstration and discussion on what density is. Then once they understand that density is the amount of stuff (mass) in a particular shape (volume), ask them how they might calculate the density of water and guide them to the equation: density = mass/volume. Given water that has a mass of 100 grams in a container with volume of 100 milliliters. They can then calculate that the density of water is 1 g/ml.

Teacher Notes:

A **submarine** surfaces by pumping compressed air into the ballast tanks. The water that is in the ballast tanks is then forced out to make room for the air until the submarine's density is less than the water outside the submarine. The submarine dives by pumping the air out and filling the ballast tanks with water.

Scuba divers use lead weights to descend and add compressed air to their BC (Buoyancy Compensator) vests to ascend and to control their buoyancy (although not too much air is added because air expands as the diver ascends).

Information about fish swim bladders can also be presented here.

See "CONTENT NOTES" at the end of the lesson for information on **animal buoyancy**.

- Does a submarine change its mass or volume to change its density? (It changes its mass. The shape or volume doesn't change).
- Does anyone know how a scuba diver is able to dive and surface?

D. Design Challenge: Buoyancy Controlled!

Challenge/Scenario: Your second challenge is to design and create a vessel that can become negatively buoyant to retrieve an object located at the bottom, then become positively buoyant to bring the object back to the surface.

Constraints:

- Your vessel must retrieve the object provided by the teacher.
- Your vessel must maintain buoyancy control (no uncontrollable sinking or floating).
- You must control the vessel from outside the tank.
- You can only use the materials allowed.
- You can visit the research station at any time to get ideas for your design.
- Each group member must participate in the design, construction, and operation of the vessel.
- You will be allowed to test your vessel as you work.

E. Demonstration and Reflection:

Demonstration: Have students demonstrate their device for the class, at their tables. If students have not completed their device ask them *how the device would have worked.*

Reflection: Each group of students will explain their design strategy and how their vessel controls buoyancy in relation to density, mass, volume etc. Instructor should ask leading questions and point out facets of the student's designs.

Questions to elicit student thinking & understanding:

- How is your vessel's buoyancy controlled?

Teacher Notes:

An optional variation on this challenge is to give groups water with different characteristics to see how the density of water can change. First do a demonstration with students where you add salt to a small, clear container of water and watch what happens to a hovering film canister. Each group could then be given either: the Arctic Ocean (cold saltwater*), the Sea of Cortez (warm saltwater*), Lake Vasona (room-temperature freshwater), or Lake Tahoe (cold freshwater). Groups who finish early, could test and possibly revise their vessel to operate in the Great Salt Lake (really salty, room-temperature water.)

The **density of fresh water** is 62.4 pounds per cubic foot (28.3 kg/ 0.03 m3). **Seawater**, however, is denser: 64 pounds per cubic foot (29 kg/0.03 m3). As seawater is more dense, it exerts a greater buoyant force.

Oceanic salinity levels are typically around 3%. The Great Salt Lake is approximately 10% salinity (depending on the time of year).

Please note:
*To determine accurate oceanic salinity levels, use a salinity measure, purchased from a local aquarium shop. As you add salt to water containers simulating the Artic Ocean and Sea of Cortez, measure the salinity levels until it reaches the correct oceanic range.

Crushed ice should be added to the Lake Tahoe and Arctic Ocean water containers.

- How does your vessel increase its density in order to dive and retrieve objects?
- How does your vessel decrease its density to become more positively buoyant?
- If you had more time, is there anything that you would have done differently with your design?

F. Clean up: Reduce! Re-use! Recycle!

Only throw away items that cannot be re-used. All items should be returned to the appropriate place.

G. Post activity:

- Play with buoyancy in the air. Use a helium filled balloon and devise a way to make it "hover" or become neutrally buoyant (without being tethered) at a specific height (such as 4ft). Think about how buoyancy in air is similar/different to water.

IV. Exploring Buoyancy: CONTENT NOTES

Animal Buoyancy Adaptations

Fish

Most fishes (but not all) have air bladders, which we will call gas bladders here. The primary function of the gas bladder is to allow the fish to achieve neutral buoyancy; that is, to keep from sinking. To achieve neutral buoyancy--that is, to be able to stay at any depth it wants--a fish has to be able to take gas into the bladder and let gas out of it, just like you might blow up a balloon or let it deflate.

There are two major different types of gas bladders in fishes: physostomous, in "primitive," and physoclistous, in "derived" fishes.

Fish with physostomous air bladders take gas into their bladders using their mouths: they rise to the surface and swallow air. To let out air, they just burp it out. Examples of this kind of fish are catfish, trout and salmon, sturgeon, minnows, suckers, and eels.

Physoclistous gas bladders, however, do not open to the mouth, so the fish has to let gas in and out of the bladder using a very complex little patch of blood vessels that absorb or let go of gases from the blood. Fishes with these bladders include bass, perch, mosquitofish, and sunfish.

Since physoclistous fishes cannot just burp the gas out of their bladders, they cannot change depths quickly. This is why many fishes, when taken quickly from deep habitats to the surface, will eventually die: they cannot deflate their bladders quickly enough. A good example of this is the rockfish. Many rockfish are caught by nets but fishermen do not want them because of young age, small size, or because they were not looking for rockfish: these fish, even when released, will likely die.

Whether a fish floats or sinks depends on two forces. The fish is pushed upwards by a force equal to the weight of water it displaces. This is the force, which causes buoyancy. The second force is gravity, which pulls the fish downwards. If the buoyancy force is greater than the force of gravity, the fish rises. If the buoyancy force is less, the fish sinks. If the forces are equal, the fish remains at the same level.

http://www.questacon.edu.au/html/sink_or_swim.html (Check out sink or swim animation.)

Sharks
A shark is more like an airplane. It doesn't have a swim bladder, so it uses its forward movement to control vertical position. The tail is like the shark's propeller -- the shark swings it back and forth to move forward. In an airplane, this forward movement pushes air around the wings. In a shark, this forward movement pushes water around the fins. In both cases, this movement of matter creates lift -- the fluid is different, but the principle is exactly the same. Sharks also attain greater buoyancy through the concentration of low-density oils in their greatly enlarged livers.

Sea Snakes
Sea snakes have adapted their bodies to marine life. Their tails are flattened for swimming. They have glands in their mouths that remove and excrete salt from the seawater that they happen to swallow. Their nostrils close when they submerge and they have special scales that shield their mouths. A sea snake has one lung that extends the length of its body and it's used like a reserved air sac and for buoyancy control. Sea snakes can also absorb oxygen from the water through their skin and stay submerged for about two hours if necessary.

Marine Mammals
Weddell seals can store more than four times as much oxygen as humans can. Human scuba divers get in trouble if they resurface too quickly since water pressure causes nitrogen to enter the blood stream. As they rise through the water the nitrogen can expand into bubbles that lead to a painful and even lethal condition known as decompression illness.

For marine mammals, the trick lies in storing oxygen in myoglobin, an iron-rich oxygen-binding protein, rather than in the lungs' air sacs. By storing oxygen in the protein, the animals allow water pressure to almost completely collapse their lungs. Once their lungs are collapsed their buoyancy decreases and they start to sink effortlessly.

Penguins
Penguins display two strategies for controlling buoyancy. First, they have solid dense bones to overcome buoyancy. Second, Emperor Penguins have stones in their stomach equal to 5% to 8% of their body weight. Apparently they pick them up diving to the bottom to act as buoyancy compensation. When they have long distances to travel, to their rookery, they regurgitate some of the stones to lighten their load.

Glossary and Concepts:

- Archimedes principle: The relationship between buoyancy and displaced fluid: An immersed object is buoyed up by a force equal to the weight of the fluid it displaces.
- Boyle's Law: At a constant temperature, the volume of a given quantity of gas is inversely proportional to the pressure upon the gas.
- Buoyancy: The apparent loss of weight of an object submerged in a fluid.
- Buoyant force: The net upward force exerted by a fluid on a submerged object.
- Density: A property of a substance, equal to the mass divided by the volume; commonly thought of as the lightness or heaviness of a substance.
- Displaced: Term applied to fluid that is moved out of the way when an object is placed in the fluid. A completely submerged object displaces a volume of fluid equal to its own volume.
- Equilibrium: A state of balance, e.g. the state of a body on which no net force acts.
- Fluid: Anything that flows; any liquid or gas.
- Force: Any influence that tends to accelerate an object; a push or a pull; force = mass x acceleration (F = ma: Newton's 2nd law), measured in Newton's (N).
- Gravity: A pulling force exerted by any mass upon another; the Earth's gravitational force exerts an acceleration (g) of 9.8 m/s2.
- Mass: A measure of the quantity of matter in a body; a measure of the inertia of an object; the amount of stuff in an object.
- Neutrally buoyant: A state in which the forces of gravity and buoyancy are in equilibrium or balanced.
- Pressure: The force per unit of surface area; exerted perpendicular to the surface; measured in Pascals.
- Principle of flotation: A floating object displaces a quantity of fluid of weight equal to its own weight.
- Volume: The amount of space occupied in three dimensions.
- Weight: The force on a body due to the gravitational attraction of another body (usually, the Earth).

Resources:

- *Boats, Ships, Submarines, and other Floating Machines* by Ian Graham. Kingfisher Books, New York, NY, 1993.
- *Conceptual Physics: a High School Physics Program* by Paul G. Hewitt. Addison-Wesley Publishing Co., Inc., Menlo Park, CA, 1997.
- *Experiments with Balloons* by Robert Gardner and David Webster. Enslow Publishers, Inc., Springfield NJ, 1995.
- Aquarius website: http://www.uncwil.edu/nurc/aquarius/lessons.htm
- AskERIC educational website: http://askeric.org/
- The Gateway to Educational Materials website: http://thegateway.org/
- How Stuff Works: http://www.howstuffworks.com
- How Things Work: http://howthingswork.virigina.edu
- Roberts, Robert S., (1982), "Teaching an Old Diver New tricks," The Science Teacher, Vol. 49 No. 7, pp. 25-27,October.
- Carusella, Brian, (1998) "Cartesian Diver", freeweb.pdq.net/headstrong/cart.htm

Literature Connections

The Magic School Bus Ups and Downs : A Book About Floating and Sinking (Magic School Bus) by Jane B. Mason, et al (February 1997)

Tell Me How Ships Float (Whiz Kids) by Shirley Willis (March 2000)

Ogs Learn to Float (Reading for Beginners Series) by Felicity Everett, Graham Round (Illustrator) (March 1996)

How Do Big Ships Float? by Isaac Asimov (December 1992)

Tom Swift and His Submarine Boat by Victor Appleton (July 2000)

Little Orange Submarine by Ken Wilson-Max (June 2001)

Life on a Submarine (High Interest Duties: On Duty) by Gregory Payan, Alexander Guelke (September 2000)

Monsters Don't Scuba Dive by Debbie Dadey, et al (May 1995)

Imagine You Are a Scuba Diver (Action Sports Library) by Carolyn J. Crooke (December 2001)

Dive to the Deep Ocean: Voyages of Exploration and Discovery (Turnstone Ocean Explorer Book) by Deborah Kovacs (March 1999

The Discovery of the Titanic by Robert D. Ballard, et al (October 1995)

The History of Underwater Exploration by Robert F. Marx (December 1990)

Water and Light: A Diver's Journey to a Coral Reef (Southwestern Writers Collection Series) by Stephen Harrigan (May 1999)

A Pictorial History of Oceanographic Submersibles, by James B. Sweeney

Ships and Other Seacraft (Rand McNally Factbooks) by Brian Williams

Water Baby: The Story of Alvin by Victoria A. Kaharl