The NOAA Ship *Okeanos Explorer*

NOAA Ship *Okeanos Explorer:* America's Ship for Ocean Exploration. Image credit: NOAA. For more information, see the following Web site: *http://oceanexplorer.noaa.gov/okeanos/welcome.html*

Come On Down!

(adapted from the 2002 Submarine Ring of Fire Expedition and the Lophelia II 2009: Deepwater Coral Expedition: Reefs, Rigs and Wrecks)

An essential component of the NOAA Office of Ocean Exploration and Research mission is to enhance understanding of science, technology, engineering, and mathematics used in exploring the ocean, and build interest in careers that support ocean-related work. To help fulfill this mission, the Okeanos Explorer *Education Materials Collection is being developed to encourage educators and students to become personally involved with the voyages and discoveries of the* Okeanos Explorer*—America's first Federal ship dedicated to Ocean Exploration. Leader's Guides for Classroom Explorers focus on three themes: "Why Do We Explore?" (reasons for ocean exploration), "How Do We Explore?" (exploration methods), and "What Do We Expect to Find?" (recent discoveries that give us clues about what we may find in Earth's largely unknown ocean). Each Leader's Guide provides background information, links to resources, and an overview of recommended lesson plans on the Ocean Explorer Web site (*http://oceanexplorer.noaa.gov*). An Initial Inquiry Lesson for each of the three themes leads student inquiries that provide an overview of key topics. A series of lessons for each theme guides student investigations that explore these topics in greater depth. In the future additional guides will be added to the Education Materials Collection to support the involvement of citizen scientists.*

This lesson guides student inquiry into the key topic of Ocean Exploration within the "Why Do We Explore?" theme. This lesson may be extended to include an optional inquiry into the concept of proxies using conductivity and salinity as an example.

Focus

Ocean Exploration

Grade Level

7-8 (Physical Science)

Focus Question

What are some physical science principles that affect the operation of deep-sea submersibles?

Learning Objectives

- Students will research the development and use of research vessels/vehicles used for deep-ocean exploration.
- Students will calculate the density of objects by determining the mass and volume.
- Students will construct a device that exhibits neutral buoyancy.

Materials

- Copies of *Underwater Robot Capability Survey*; one copy for each student group
- Copies of *Density and Buoyancy Inquiry Guide*; one copy for each student group
- 100 ml graduated cylinder; one for each student group
- Sink or large containers for waste water
- Faucet or large container of water with a spigot or siphon to allow controlled dispensing
- Small objects that will fit into the 100 ml graduated cylinders, such as washers or nuts, small pieces of wood, rocks, pieces of modeling clay, corks, etc.; each student group should have a collection of at least four objects including some that will sink and others that will float
- Triple beam balance; one balance may be shared by several groups
- Stiff wire approximately 3 inches long or a straightened paper clip; one for each student group

Audiovisual Materials

- Chalkboard, marker board, or overhead projector
- (Optional) Video or computer projection equipment to show images of submersibles

Teaching Time

Two 45-minute class periods

Seating Arrangement

Groups of two or four students

Maximum Number of Students

32

Key Words and Concepts

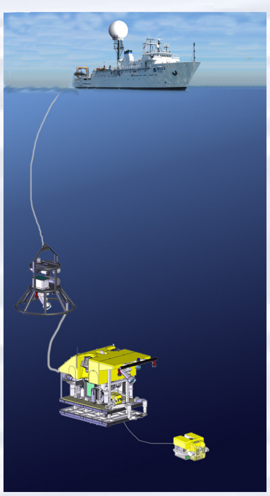
Density
Buoyancy
Submersible
Volume
Mass

Okeanos Explorer Vital Statistics:

Commissioned: August 13, 2008; Seattle, Washington
Length: 224 feet
Breadth: 43 feet
Draft: 15 feet
Displacement: 2,298.3 metric tons
Berthing: 46, including crew and mission support
Operations: Ship crewed by NOAA Commissioned Officer Corps and civilians through NOAA's Office of Marine and Aviation Operations (OMAO); Mission equipment operated by NOAA's Ocean Exploration and Research Program

For more information, visit http://oceanexplorer.noaa.gov/okeanos/welcome.html.

Okeanos Explorer's Control Room is the exploration heart of the ship, serving a number of missions including processing of multibeam sonar for mapping, controlling video transmitted off the ship, and coordinating the interaction between those afloat and ashore. When ROVs are deployed, they are controlled here by a navigator, pilot and co-pilot. Images from various cameras on the ship, and on deployed ROVs, can be brought up on the large screens. Image credit: NOAA.



Okeanos Explorer's remotely-operated vehicle (ROV) system consists of a bell-shaped camera sled, a science-class ROV and a small xBot, all of which can operate as deep as 6000 meters. Image credit: NOAA.

Background Information

NOTE: Explanations and procedures in this lesson are written at a level appropriate to professional educators. In presenting and discussing this material with students, educators may need to adapt the language and instructional approach to styles that are best suited to specific student groups.

> "We know more about the dead seas of Mars than our own ocean."
>
> *– Jean Michel Cousteau*

In fact, our current estimation is that 95% of Earth's ocean is unexplored. At first, this may be hard to believe, particularly if we look at recent satellite maps of Earth's ocean floor. These maps seem to show seafloor features in considerable detail. But satellites can't see below the ocean's surface. The "images" of these features are estimates based on the height of the ocean's surface, which varies because the pull of gravity is affected by seafloor features. And if we consider the scale of these maps, it is easy to see how some things might be missed. To show our planet's entire ocean, a typical wall map has a scale of about 1 cm = 300 km. At that scale, the dot made by a 0.5 mm pencil represents an area of over 60 square miles! The fact is, most of the ocean floor has never been seen by human eyes.

On August 13, 2008, the NOAA Ship *Okeanos Explorer* was commissioned as "America's Ship for Ocean Exploration;" the only U.S. ship whose sole assignment is to systematically explore our largely unknown ocean for the purposes of discovery and the advancement of knowledge. To fulfill its mission, the *Okeanos Explorer* has specialized capabilities for finding new and unusual features in unexplored parts of Earth's ocean, and for gathering key information that will support more detailed investigations by subsequent expeditions. These capabilities include:

- Reconnaissance within a search area to locate unusual features or anomalies;
- Underwater robots (remotely operated vehicles, or ROVs) that can investigate anomalies as deep as 6,000 meters;
- Underwater mapping using multibeam sonar, capable of producing high-resolution maps of the seafloor to depths of 6,000 meters; and
- Advanced broadband satellite communication

For more about the *Okeanos Explorer*, visit http://oceanexplorer.noaa.gov/okeanos/welcome.html.

Some of the most exciting discoveries in modern ocean exploration have been made with the assistance of underwater robots. In this lesson, students will determine the density and buoyancy of various objects, and will use their knowledge of buoyancy principles to design an object that has neutral buoyancy in water; a characteristic that is often required for manned and unmanned submersibles.

Learning Procedure

1. To prepare for this lesson:
   a. If you have not previously done so, review introductory information on the NOAA Ship *Okeanos Explorer* at http://oceanexplorer.noaa.gov/okeanos/welcome.html. You may also want to consider having students complete some or all of the Initial Inquiry Lesson, *To Boldly Go…* (http://oceanexplorer.noaa.gov/okeanos/edu/leadersguide/media/09toboldlygo.pdf).
   b. Review the Ocean Explorer Web pages on underwater robotic vehicles, indexed at http://oceanexplorer.noaa.gov/technology/subs/subs.html.
   c. Review procedures described in the *Density and Buoyancy Inquiry Guide*, and prepare materials needed by student groups to complete this inquiry.
   d. If your students use Lego® robotics or Vernier® calculator-based laboratory materials, you may want to consider alternative procedures described on the *Using Electronic Force Sensors to Measure Buoyancy* information sheet.
   e. Depending upon available time, you may also want to have students complete the activity described in Step 5 of the lesson, *I, Robot, Can Do That!* (http://oceanexplorer.noaa.gov/explorations/05lostcity/background/edu/media/lostcity05_i_robot.pdf). In this activity, students identify which of the robots they have studied are best suited to a series of underwater missions.

2. If you have not previously done so, introduce the NOAA Ship *Okeanos Explorer*, emphasizing that this is the first Federal vessel specifically dedicated to exploring Earth's largely unknown ocean. Lead a discussion of reasons that ocean exploration is important, and briefly review the major technological capabilities of the ship. Say that manned and unmanned submersibles are a key component of many ocean exploration expeditions, and tell students that their assignment is to investigate some of these robots. Assign one of the following robots to each student group, and provide each group with a copy of *Underwater Robot Capability Survey*:
   Autonomous Benthic Explorer (ABE)
   Hercules

Remotely Operated Platform for Ocean Science (ROPOS)
General Purpose Remotely Operated Vehicles (ROVs)
RCV-150
Tiburon

You may want to direct students to the Ocean Explorer Web pages on underwater robotic vehicles (see above). If students do not have access to the internet, provide copies of the relevant materials to each group.

3. Have each student group present a brief oral report of the capabilities of their assigned robot. The following points should be included:

Autonomous Benthic Explorer (ABE)
- Capable of operating to depths up to 5,000 meters
- Autonomous vehicle; no tether to support ship
- Tools: video cameras, conductivity and temperature sensors, depth recorder, magnetometer, sonar, wax core sampler, navigation system
- Developed to monitor underwater areas over a long period of time
- Follows instructions programmed prior to launch; data are not available until robot is recovered
- Operates independently during missions, but requires technicians and engineers for maintenance, as well as data managers to retrieve information stored in computer memory

Remotely Operated Platform for Ocean Science (ROPOS)
- Capable of operating to depths up to 5,000 meters
- 5,500 m of electrical-optical cable tether
- Tools: two digital video cameras; two manipulator arms that can be fitted with different sampling tools (stainless steel jaws, manipulator feedback sensors, rope cutters, snap hooks, core tubes); variable-speed suction sampler and rotating sampling tray; sonar; telemetry system
- Can also be outfitted with up to eight custom-designed tools such as a hot-fluid sampler, chemical scanner, tubeworm stainer, rock-coring drill, rock-cutting chainsaw, laser-illuminated, range gated camera, and downward-looking digital scanning sonar
- Wide variety of observation tools provides scientists with exceptional flexibility so they can quickly respond to new and unexpected discoveries
- A "typical" dive requires at least four people (and

sometimes more): the "Hot Seat" scientist, pilot, manipulator operator, and data/event logger

General Purpose Remotely Operated Vehicles (ROVs)

- Depth capability varies
- Operated by one or more persons aboard a surface vessel
- Linked to the ship by a group of cables that carry electrical signals back and forth between the operator and the vehicle
- Tools: most are equipped with at least a video camera and lights
- Additional equipment may include a still camera, a manipulator or cutting arm, water samplers, and instruments that measure water clarity, light penetration, and temperature.
- Also used for educational programs at aquaria and to link to scientific expeditions live via the internet.
- Range in size from that of a bread box to a small truck
- Often kept aboard vessels doing submersible operations for safety, and so the ROV can take the place of the submersible when it cannot be used because of weather or maintenance problems
- Can also be used to investigate questionable dive sites before a sub is deployed to reduce risk to the subs and their pilots

Hercules

- Capable of operating to depths of 4,000 meters
- Pilots operate *Hercules* via a long fiber-optic cable
- Designed primarily to study and recover artifacts from ancient shipwrecks
- Tools: High-Definition (HD) video camera; pair of still cameras to accurately measure the depth and area of the research site and to create "mosaics"; sensors for measuring pressure, water temperature, oxygen concentration, and salinity.
- Hydraulic thrusters—propellers in fixed ducts—control the ROV's movements.
- Yellow flotation package makes *Hercules* slightly buoyant in seawater
- Components that are not in pressure housings are immersed in mineral oil, which does not compress significantly under pressure
- Operates in tandem with tow sled "Argus"
- 30 meter (100 foot) tether connects *Hercules* to Argus
- Argus carries an HD video camera similar to the one on *Hercules*, as well as large lights that illuminate the area

around *Hercules*.

- Generally operates 24 hours a day while at sea, different teams called "watches" take turns operating the vehicle
- Six watch-standers on each watch:
  - Watch Leader makes sure that the scientific goals of the dive are being addressed.
  - Pilot operates *Hercules*, controlling its thrusters, manipulator arms, and other functions.
    Engineer controls the winch that moves Argus up and down, as well as Argus' thrusters and other functions, and assists the Pilot.
  - Navigator monitors the work being done and the relative positions of the vehicles and ship, and communicates with the ship's crew to coordinate ship movements.
  - Video and Data watch-standers record and document all the data that the vehicles send up from the deep.
- *Little Hercules* replaces *Hercules* for some missions; *Little Hercules* has no arms or tools, only gathers video images

Tiburon (ROV)

- Capable of operating to depths of 4,000 meters
- Controlled from a special control room on board its tender vessel, the R/V Western Flyer.
- Tether contains electrical wires and fiber-optic strands
- Electrical thrusters and manipulators, rather than hydraulic systems, allow vehicle to move quietly through the water, causing less disturbance to animals being observed
- Variable buoyancy system allows the vehicle to float motionless in the water without the constant use of the thrusters.
- Lower half of the vehicle is a modular toolsled, which can be exchanged with other toolsleds to carry out specific missions: benthic (or bottom) toolsled has an extra manipulator arm and extensive sample-carrying space for geological and biological samples; "midwater" toolsled used to explore the biology of open ocean creatures; rock coring toolsled has been used to take oriented rock cores from the sea floor.

RCV-150

- Capable of operating to depths of 914 m
- Tethered to support ship via a double armored electro-optical umbilical
- Tools: color video camera, 1500 watts of lighting, micro conductivity/temperature/depth sensor, sonar, manipulator with a six-inch cutoff wheel.

- Controlled by a single pilot from a control console located in the tracking room of the support ship
- Small size compared to a submersible allows ROV to have high maneuverability; can get close to the bottom and allow the cameras to peer under ledges and into nooks and crannies
- Much easier to launch and recover than a manned submersible so it can be used at night while the sub is being serviced
- Primary data collected is in the form of video
- Has been used to conduct surveys of bottomfish in Hawai'i
- In the event of a submersible emergency with one of the Pisces submersibles in water depths less than 3000 ft, the first action after notifying rescue assets would be to deploy the *RCV-150* to evaluate the nature of the emergency and if entangled, try to free the sub with the radial cutter.

4. Give each student group a copy of the *Density and Buoyancy Inquiry Guide* and a collection of objects whose density and buoyancy are to be determined. If necessary, explain how to use the balance, where students are to obtain water, and how they should dispose of wastewater. Now, on with the Inquiry!

5. Lead a discussion of students' results. In Part A of the *Inquiry Guide*, students should realize that they need to know mass and volume to find the density of an object. Since the volume of many substances changes in response to temperature, it is also true that the density of an object also depends upon temperature. But temperature changes usually have very small effects on density compared to the effects of changing mass and volume. Students should also observe that objects that float have lower densities than objects that sink.

   In Part B, students should realize that increasing the volume of an object will increase the volume and weight of fluid displaced when the object is immersed, and thus will increase the buoyant force acting on the object.

   Most science standards do not expect elementary students to distinguish between mass and weight, but middle school (Grades 6-8) students are expected to make this distinction. These concepts can be easily confused when dealing with density buoyancy, because when students use a balance to determine mass they are actually measuring weight (mass multiplied by the force of gravity). This works out because the balance is calibrated to take gravity into account, but under zero gravity conditions the balance would not give an accurate estimate of mass. So if we want to calculate the buoyant force acting on an object based on the weight of displaced fluid, we have to use units of weight such as pounds. If we want to use metric units of force (Newtons) we have to multiply the mass of the displaced fluid (in kg) by the acceleration of gravity (about 9.81 m/sec^2). Since these metric units, as well as the concepts of gravitational acceleration, are usually taught in higher grade levels, we do not have students calculate actual buoyant force in this lesson. But if students discuss buoyant force in terms of grams or kilograms, it is important to remind them that these are units of mass and that buoyancy involves units of weight.

These considerations are not a problem for the *Apply* portion of Part B, because the problem uses weight units (pounds). To calculate the minimum diameter for a 30-inch long cylinder that will displace enough water to generate a buoyant force of 900 lb:

(1) Calculate the volume required to displace 900 lb of water:

$$900 \text{ lb} \div 0.036127 \text{ lb/cubic inch} = 24{,}912 \text{ cubic inches}$$

(2) Calculate the radius of a cylinder with this volume:

$$\text{(a) (pi) } r^2 \times L = 24{,}912 \text{ cubic inches}$$

$$\text{(pi) } r^2 \times 30 \text{ inches} = 24{,}912 \text{ cubic inches}$$

$$\text{(pi) } r^2 = 24{,}912 \text{ cubic inches} \div 30 \text{ inches } \varpi$$

$$\text{(pi) } r^2 = 830.4 \text{ square inches}$$

$$r^2 = 830.4 \text{ square inches} \div \text{(pi)}$$

$$r^2 = 264.5 \text{ square inches}$$

$$r = 16.26 \text{ inches}$$

(3) Calculate the diameter of the cylinder:

$$D = 2r = 2 \text{ (16.26 inches)} = 32.52 \text{ inches}$$

Discuss other factors that might influence this calculation. Temperature could have a relatively minor effect as discussed above. Pressure would be a much more serious consideration, since at depths of 400 m to 1500 m the pressure would be roughly 40 to 150 times greater than surface pressure. This presents serious design considerations, since there would be a large pressure difference between the inside and outside of the sphere if the sphere contained air at normal atmospheric pressure.

Salinity also affects buoyancy, and some of your students have probably found that it is easier to float in seawater than in freshwater. The reason, of course, is that the density of seawater is greater than freshwater (at the same temperature); so the weight of seawater displaced by an object will be greater than the weight of freshwater displaced by the same object, and the resulting buoyant force is greater in seawater.

The BRIDGE Connection

www.vims.edu/bridge/ – In the "Site Navigation" menu on the left, click "Ocean Science Topics," then "Human Activities," then "Technology" for links to resources about submersibles, ROVs, and other technologies used in underwater exploration.

The "Me" Connection

Have students write a brief essay describing how robots are (or may be) of personal benefit.

Connections to Other Subjects

English/Language Arts, Life Science, Mathematics

Assessment

Reports and discussions in Steps 3 and 4 provide opportunities for assessment.

Extensions

1. Follow events aboard the Okeanos Explorer at http://oceanexplorer.noaa.gov/okeanos/welcome.html.

2. Build your own underwater robot! See books by Harry Bohm under "Resources."

Multimedia Discovery Missions

http://oceanexplorer.noaa.gov/edu/learning/welcome.html
Click on the links to Lessons 3, 6, 11, and 12 for interactive multimedia presentations and Learning Activities on Deep-Sea Corals, Deep-Sea Benthos, Energy from the Oceans, and Food, Water, and Medicine from the Sea.

Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

Call to Arms
(PDF, 329 kb) (from the 2008 Deepwater Coral Expedition: Reefs, Rigs, and Wrecks)
http://oceanexplorer.noaa.gov/explorations/08lophelia/background/edu/media/calltoarms.pdf

Focus: Robotic Analogues for Human Structures (Physical Science/Life Science) (Grades 5-6)

Students will describe the types of motion found in the human arm, and describe four common robotic arm designs that mimic some or all of these functions.

I, Robot, Can Do That!
(340 kb, 11 pp) (from the Thunder Bay Sinkholes 2008 Expedition)
http://oceanexplorer.noaa.gov/explorations/08thunderbay/background/edu/media/robot.pdf

Focus: Underwater Robotic Vehicles for Scientific Exploration (Physical Science/Life Science) (Grades 7-8)

Students will be able to describe and contrast at least three types of underwater robots used for scientific explorations, discuss the advantages and disadvantages of using underwater robots in scientific explorations, and identify robotic vehicles best suited to carry out certain tasks.

The Robot Explorer
(PDF, 712 Kb) (from the 2009 Bermuda Caves Expedition)
http://oceanexplorer.noaa.gov/explorations/09bermuda/background/edu/media/09robot.pdf

Focus: Remotely operated vehicles for exploring anchialine caves (Physics/Earth Science/Technology) (Grades 9-12)

Students will discuss remotely operated vehicles and onboard systems used for exploring anchialine caves, and will explain the design and construction process for a simple robot explorer.

My Wet Robot
(7 pages, 260 kb) (from the PHAEDRA 2006 Expedition)
http://oceanexplorer.noaa.gov/explorations/06greece/background/edu/media/wet_robot.pdf

Focus: Underwater Robotic Vehicles (Physical Science) (Grades 9-12)

Students will be able to discuss the advantages and disadvantages of using underwater robots in scientific explorations, identify key design requirements for a robotic vehicle that is capable of carrying out specific exploration tasks, describe practical approaches to meet identified design requirements, and (optionally) construct a robotic vehicle capable of carrying out an assigned task.

The Roving Robotic Chemist
(14 pages, 440 kb) (from the PHAEDRA 2006 Expedition)
http://oceanexplorer.noaa.gov/explorations/06greece/background/edu/media/robot_chemist.pdf

Focus: Mass Spectrometry (Chemistry) (Grades 9-12)

Students will be able to explain the basic principles underlying mass spectrometry, discuss the advantages of in-situ mass spectrometry, explain the concept of dynamic re-tasking as it applies to an autonomous underwater vehicle, and develop and justify a sampling strategy that could be incorporated into a program to guide an AUV searching for chemical clues to specific geologic features.

Where's My 'Bot?
(17 pages, 492kb) (from the Bonaire 2008: Exploring Coral Reef Sustainability with New Technologies Expedition)
http://oceanexplorer.noaa.gov/explorations/08bonaire/background/edu/media/wheresbot.pdf

Focus: Marine Navigation (Earth Science/Mathematics) (Grades 9-12)

Students will estimate geographic position based on speed and direction of travel, and integrate these calculations with GPS data to estimate the set and drift of currents.

The Robot Archaeologist
(PDF, 17 pages, 518k) (from the AUVfest 2008 Expedition)
http://oceanexplorer.noaa.gov/explorations/08auvfest/background/edu/media/robot.pdf

Focus: Marine Archaeology/Marine Navigation (Earth Science/Mathematics) (Grades 9-12)

Students will design an archaeological survey strategy for an autonomous underwater vehicle (AUV); calculate expected position of the AUV based on speed and direction of travel; and calculate course correction required to compensate for the set and drift of currents.

Other Resources

The Web links below are provided for informational purposes only. Links outside of Ocean Explorer have been checked at the time of this page's publication, but the linking sites may become outdated or non-operational over time.

http://oceanexplorer.noaa.gov – Web site for NOAA's Ocean Exploration Program

http://celebrating200years.noaa.gov/edufun/book/welcome.html#book – A free printable book for home and school use introduced in 2004 to celebrate the 200th anniversary of NOAA; nearly 200 pages of lessons focusing on the exploration, understanding, and protection of Earth as a whole system

Bohm, H. and V. Jensen. 1998. Build Your Own Programmable Lego Submersible: Project: Sea Angel AUV (Autonomous Underwater Vehicle). Westcoast Words. 39 pages.

Bohm, H. 1997. Build your own underwater robot and other wet projects. Westcoast Words. 148 pages.

http://cosee-central-gom.org/ – Web site for The Center for Ocean Sciences Education Excellence: Central Gulf of Mexico (COSEE-CGOM)

National Science Education Standards

Content Standard A: Science As Inquiry

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard B: Physical Science
- Properties and changes of properties in matter

Content Standard D: Earth and Space Science
- Structure of the Earth system

Content Standard E: Science and Technology
- Abilities of technological design

Content Standard F: Science in Personal and Social Perspectives
- Populations, resources, and environments
- Science and technology in society

Content Standard G: History and Nature of Science
- Science as a human endeavor

Ocean Literacy Essential Principles and Fundamental Concepts

Essential Principle 6.

The ocean and humans are inextricably interconnected.

Fundamental Concept b. From the ocean we get foods, medicines, and mineral and energy resources. In addition, it provides jobs, supports our nation's economy, serves as a highway for transportation of goods and people, and plays a role in national security.

Fundamental Concept e. Humans affect the ocean in a variety of ways. Laws, regulations and resource management affect what is taken out and put into the ocean. Human development and activity leads to pollution (such as point source, non-point source, and noise pollution) and physical modifications (such as changes to beaches, shores and rivers). In addition, humans have removed most of the large vertebrates from the ocean.

Fundamental Concept g. Everyone is responsible for caring for the ocean. The ocean sustains life on Earth and humans must live in ways that sustain the ocean. Individual and collective actions are needed to effectively manage ocean resources for all.

Essential Principle 7.

The ocean is largely unexplored.

Fundamental Concept a. The ocean is the last and largest unexplored place on Earth—less than 5% of it has been explored. This is the great frontier for the next generation's explorers and researchers, where they will find great opportunities for inquiry and investigation.

Fundamental Concept b. Understanding the ocean is more than a matter of curiosity. Exploration, inquiry and study are required to better understand ocean systems and processes.

Fundamental Concept c. Over the last 40 years, use of ocean resources has increased significantly, therefore the future sustainability of ocean resources depends on our understanding of those resources and their potential and limitations.

Fundamental Concept d. New technologies, sensors and tools are expanding our ability to explore the ocean. Ocean scientists are relying more and more on satellites, drifters, buoys, subsea observatories and unmanned submersibles.

Fundamental Concept f. Ocean exploration is truly interdisciplinary. It requires close collaboration among biologists, chemists, climatologists, computer programmers, engineers, geologists, meteorologists, and physicists, and new ways of thinking.

Send Us Your Feedback

We value your feedback on this lesson, including how you use it in your formal/informal education setting.
Please send your comments to: oceanexeducation@noaa.gov

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Density and Buoyancy Inquiry Guide

A. Density

Background

Density is a physical property of matter that is related to an object's mass (how "heavy" it is) and volume (the object's physical size). You know that a handful of styrofoam weighs much less than a handful of rocks. This is because the density of the styrofoam is less than the density of the rocks. Density is usually defined as "mass per unit volume," and the density of an object or substance is stated in "grams per cubic centimeter."

Inquire

Your task is to measure the density of objects in the collection provided by your teacher. What two properties of each object do you need to know to find the object's density?

Measure the mass of each object using a balance as directed by your teacher. Record these measurements on the data sheet.

Now measure the volume of each object. The easiest way to do this is to immerse the object in water in a graduated cylinder and measure the increase in water volume. Put water into a graduated cylinder so the cylinder is about half full. Record the volume of the water on the data sheet in the "Volume Without Object" column. Drop the object into the cylinder and record the new volume on the data sheet in the "Volume With Object" column. If the object floats, you will need to push it down with a piece of stiff wire until the object is completely submerged. Subtract "Volume Without Object" from "Volume With Object" and record the result in the "Object Volume" column.

Calculate the density of each object by dividing the mass by the volume, and record the results on the data sheet in the "Density" column. Hint: One milliliter is the same as one cubic centimeter.

Record the buoyancy of the object in the last column.

What do you notice about the density of objects that sink compared to objects that float?

B. Buoyancy

Background

Read the following explanation of Archimedes' Principle:

> The idea of buoyancy was summed up by a Greek mathematician named Archimedes: any object, wholly or partly immersed in a fluid, is buoyed up by a force equal to the weight of the fluid displaced by the object. Today, this definition is called Archimedes' Principle.

Density and Buoyancy Inquiry Guide - 2

Archimedes is considered one of the three greatest mathematicians of all time (the other two are Newton and Gauss). Archimedes was born in 287 B.C., in Syracuse, Greece. He was a master at mathematics and spent most of his time thinking about new problems to solve.

Many of these problems came from Hiero, the king of Syracuse. Archimedes came up with his famous principle while trying to solve this problem: The king ordered a gold crown and gave the goldsmith the exact amount of metal to make it. When Hiero received it, the crown had the correct weight but the king suspected that some silver had been substituted for the gold. He did not know how to prove it, so he asked Archimedes for help.

One day while thinking this over, Archimedes went for a bath and water overflowed the tub. He recognized that there was a relationship between the amount of water that overflowed the tub and the amount of his body that was submerged. This observation gave him the means to solve the problem. He was so excited that he ran naked through the streets of Syracuse shouting "I have found it!". The goldsmith was brought to justice and Archimedes never took another bath...(just kidding!).

(from *Discover Your World with NOAA: An Activity Book*; http://celebrating200years.noaa.gov/edufun/ book/welcome.html)

Inquire

If the volume of an object increases but the mass of the object does not change, how does this affect the buoyant force acting on the object when it is immersed in a fluid?

Apply

Underwater robots usually are designed to be able to achieve neutral buoyancy (they do not sink or float, but stay suspended in the middle of the water) while they are performing various tasks. One way to adjust buoyancy is to pump water in or out of floatation cylinders that are attached to the frame of the robot. This changes the volume of air that is contained inside the cylinders, and therefore changes their buoyancy.

Suppose you have an underwater robot that weighs 900 pounds in the water without any extra floatation. What is the minimum diameter of a cylinder that is 30 inches long that will provide enough floatation to make the robot neutrally buoyant?

Hints:

(a) The formula for the volume of a cylinder is (pi) r^2 x L, where r is the radius of the cylinder and L is the length of the cylinder.

(b) One cubic inch of water weighs approximately 0.036127 lbs.

Underwater Robot Capability Survey

Name of Robotic Vehicle

Maximum Operating Depth

Tethered or Autonomous

Minimum Number of Crew Required for Operation

Tools

Special Capabilities or Advantages

Other Details

Density and Buoyancy Inquiry Data Sheet

Object	Mass (g)	Volume Without Object (ml)	Volume With Object (ml)	Object Volume (ml)	Density (g/cm3)	Buoyancy S = sinks F = Floats N = Neutral

Using Electronic Force Sensors to Measure Buoyancy

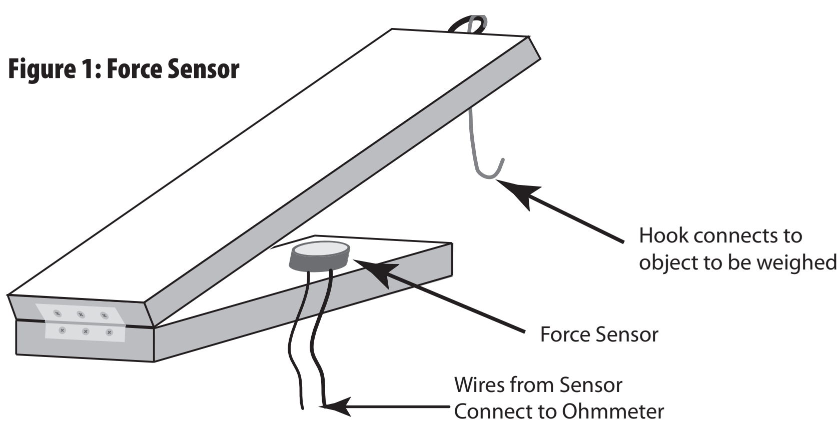
Electronic force sensors can be adapted to measure buoyancy. Incorporating this approach to measurements in Part A of the Inquiry provides additional opportunities for hands-on student problem-solving, as well as experience with using calculators or computers for data logging and analysis.

Vernier Software and Technology (http://www.vernier.com) offers a dual-range sensor that can be used as a replacement for a hand-held spring scale, and attaches to graphing calculators as well as interfaces that allow sensor readings to be stored and analyzed by personal computers. The sensor may be mounted on a ring stand and used to measure the weight of objects attached to a hook built into the sensor. If these objects are immersed in a container of water, the change in weight provides a measure of buoyancy.

Adapters are available to allow the Lego Mindstorms® RCX and NXT microcontroller bricks to accept Vernier and other third-party sensors that can provide data to personal computers via RoboLab® software (http://www.lego.com/eng/education/mindstorms/home.asp?pagename=input). Since many middle schools participate in First Lego League competitions, students may already be familiar with procedures for acquiring data using these microcontrollers and software.

Less expensive force sensors are also available. FlexiForce® sensors, for example, are very thin printed circuits that can be used to measure force between two surfaces. Since these sensors are essentially variable resistors whose resistance decreases as force is applied, the change in resistance can be read with an inexpensive ohmmeter. By calibrating the sensor with objects whose weight is known, a graph can be constructed that converts sensor resistance into units of force (see http://www.tekscan.com/pdfs/FlexiforceUserManual.pdf for details). To use this type of sensor for buoyancy measurements, it is necessary to devise a way for the object being tested to apply pressure to the sensor. One solution is illustrated in Figure 1, but students will probably create many others as well.

Figure 1: Force Sensor



Using Electronic Force Sensors to Measure Buoyancy - 2

A variety of Web pages provide directions for constructing simple force sensors from very inexpensive materials (e.g., http://www.instructables.com/id/How-to-Make-Bi-Directional-Flex-Sensors/). Many of these also are devices whose resistance changes as they are subjected to pressure or flexing, and are based on plastic or cloth materials that include substances that make these materials conductive to electricity. The plastic bags used in the electronics industry to ship static-sensitive components are one example, and are readily available at little or no cost. Offering students the option of constructing their own sensors provides additional opportunities for creativity and problem-solving.

Note: Mention of proprietary names does not imply endorsement by NOAA.