Bermuda Deepwater Caves:
Dive of Discovery

Dancing with Robots

Image captions/credits on Page 2.

lesson plan

Focus

Force and motion

Grade Level

5-6 (Physical Science)

Focus Question

How can underwater robots move in precise directions?

Learning Objectives

- Students will describe the motion of an object in terms of position, direction, and speed.
- Students will compare and contrast six types of movement.
- Students will design a thruster system that could provide a remotely operated vehicle with forward/reverse, lateral, vertical, and rotational movements.

Materials

- Copies of *Underwater Robot Motion Inquiry Guide*; one for each student group
- Floral foam block, cardboard box, or other three-dimensional rectangular object that is light-weight and easily drilled or punctured to make holes, approximately 3-in x 2-in x 1-in (see *Underwater Robot Motion Inquiry Guide*, Part A); one for each student group
- Drinking straws; three for each student group
- Wood skewers, about 12-inches long; three for each student group
- Colored toothpicks; at least 8 for each student group
- Small cork, toothpaste cap, small wire nut, or similar object; one for each student group
- Hot glue gun with glue sticks (may be shared by several student groups)
- Scissors (may be shared by several student groups)
- Thin screwdriver or similar tool (may be shared by several student groups)
- Graph paper (if students will complete Learning Procedure Step 7)

Audio-Visual Materials

- (Optional) Interactive white board, computer projector or other equipment for showing images of underwater caves

Teaching Time

One or two 45-minute class periods

Seating Arrangement

Groups of two to four students

Maximum Number of Students

32

Key Words

Remotely operated vehicle (ROV)
Thruster
Motion

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.

Anchialine caves are partially or totally submerged caves that are located within a few kilometers inland from coastal areas. Anchialine (pronounced "AN-key-ah-lin") is a Greek term meaning "near the sea," and anchialine caves often contain freshwater and/or brackish water in addition to seawater. These caves may be formed in karst landscapes as well as in rock tubes produced by volcanic activity. Karst landscapes are areas where limestone is the major rock underlying the land surface, and often contain caves and sinkholes formed when acidic rainwater dissolves portions of the limestone rock. Water in anchialine caves tends to stratify according to salinity, with the heavier seawater below the level of fresh and brackish water. This stratification produces distinctive habitats occupied by a variety of species that are endemic to these environments (endemic means that these species are not found anywhere else). Some of these species are "living fossils" known as relict species, which means that they have survived while other related species have become extinct.

Animals that live only in anchialine habitats are called stygofauna or stygobites. Investigations of these species have revealed some puzzling relationships, including:

- Some stygobite species appear to have been in existence longer than the caves they inhabit, which implies that these species must have arrived in the caves from somewhere else; but how could this happen if these species are only found in caves?
- Some stygobite species are found in caves that are widely separated, such as certain crustacean species found in caves on opposite sides of the Atlantic Ocean and certain species in Australian anchialine caves that are also found in Atlantic and Caribbean caves.

Images from Page 1 top to bottom:
The peracarid crustacean order Mictacea is represented by only a single species, *Mictocaris halope*, from inland marine caves in Bermuda. Image courtesy Bermuda: Search for Deepwater Caves 2009.
http://oceanexplorer.noaa.gov/explorations/09bermuda/media/caves.html

Overhead view of Bermuda showing the island and the reef platform. Photo courtesy of Bermuda Zoological Society.
http://oceanexplorer.noaa.gov/explorations/09bermuda/media/bda.html

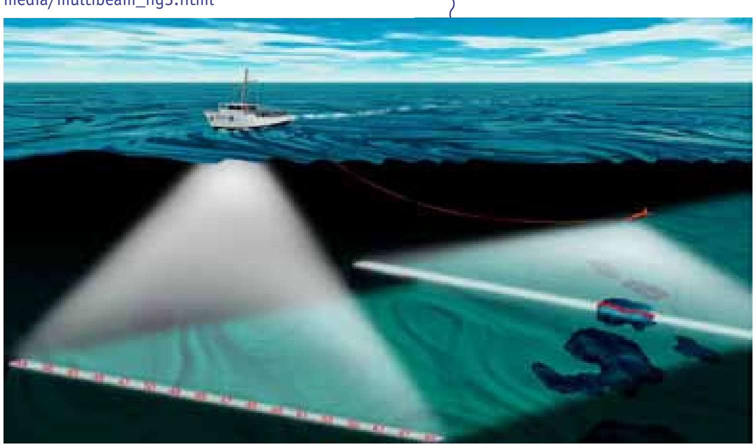
Divers swim between massive submerged stalagmites in Crystal Cave, Bermuda. Such stalactites and stalagmites were formed during glacial periods of lowered sea level when the caves were dry and air-filled. Image courtesy of Bermuda: Search for Deepwater Caves 2009.
http://oceanexplorer.noaa.gov/explorations/09bermuda/background/bermudaorigin/media/bermudaorigin_3.html

Ostracods are small, bivalve crustaceans that can inhabit underwater caves. The ostracod genus *Spelaeoecia* is know only from marine caves and occurs in Bermuda, the Bahamas, Cuba, Jamaica and Yucatan (Mexico). Image courtesy of Bermuda: Search for Deepwater Caves 2009.
http://oceanexplorer.noaa.gov/explorations/09bermuda/background/plan/media/spelaeoecia.html

- Geographic distribution of some species suggests a possible connection with mid-ocean ridges, such as shrimps belonging to the genus *Procaris* that are only known from anchialine habitats in the Hawaiian Islands, Ascension Island in the South Atlantic, and Bermuda in the North Atlantic.
- Some anchialine species are most closely related to organisms that live in the very deep ocean.
- Some anchialine species are most closely related to organisms that live in deep-sea hydrothermal vent habitats.
- An unusually large proportion of anchialine cave species in Bermuda are endemic to these caves, suggesting that these habitats have been stable for a long period of time.

Most investigations of anchialine caves have been confined to relatively shallow depths; yet, the observations described above suggest that connections with deeper habitats may also be important to understanding the distribution of stygobite species. Bermuda is a group of mid-ocean islands composed of limestone lying on top of a volcanic seamount. Because these islands are karst landscapes, Bermuda has one of the highest concentrations of cave systems in the world. Typical Bermuda caves have inland entrances, interior cave pools, underwater passages, and tidal spring outlets to the ocean. Bermuda's underwater caves contain an exceptional variety of endemic species, most of which are crustaceans. Most of these organisms are relict species with distinctive morphological, physiological, and behavioral adaptations to the cave environment that suggest these species have been living in caves for many millions of years. Yet, all known anchialine caves in Bermuda were completely dry only 18,000 years ago when sea levels were at least 100 m lower than present because of water contained in glaciers. Such observations suggest the possibility of additional caves in deeper water that would have provided habitat for anchialine species when presently-known caves were dry.

Use of multibeam sonar to map the seafloor. Image courtesy of Jill Heinerth, Bermuda: Search for Deep Water Caves 2009.
http://oceanexplorer.noaa.gov/explorations/09bermuda/background/multibeam/media/multibeam_fig3.html



The primary goal of the Bermuda Deepwater Caves 2011: Dive of Discovery Expedition is to explore the uppermost 200 meters of the Bermuda seamount and adjacent seamounts to confirm the existence of underwater caves at depths between 60 and 200 meters. A related goal is to document underwater features that indicate sea level during the last Ice Age, which was much lower than at present.

During the Bermuda: Search for Deepwater Caves 2009 Expedition, high-resolution multibeam sonar was used to produce detailed maps that assisted with locating deep-water caves and sea level benchmarks. Sites of interest identified by the multibeam survey

Dr. Rikk Kvitek and graduate student Krystle Gomez prepare the ROV for deployment in the waters off the Bermuda Platform. Image Courtesy of Bermuda: Search for Deepwater Caves 2009 Exploration.
http://oceanexplorer.noaa.gov/explorations/09bermuda/logs/summary/media/bc_msp1_01.html

were examined and photographed using a remotely operated vehicle (ROV), an underwater robot. In particular, Expedition scientists were looking for signs of water movements around possible cave entrances, such as congregations of schooling fish, plumes of brackish water, sand ripples, or an unusual abundance of filter-feeding organisms such as sponges. During the Bermuda Deepwater Caves 2011: Dive of Discovery Expedition, technical divers will explore selected caves to collect biological specimens and place or recover instrument packages. For more information about results from the 2009 Expedition, see http://oceanexplorer.noaa.gov/explorations/09bermuda/logs/summary/summary.html.

Underwater ROVs are linked to an operator aboard a surface ship by a group of cables. Most are equipped with one or more video cameras and lights, and may also carry other equipment such as a manipulator arm, water samplers, and measuring instruments to expand the vehicle's capabilities. In this activity, students will investigate principles of force and motion as they apply to underwater ROVs.

Learning Procedure

NOTE: This lesson is based upon two concepts that are included in many physical science curricula:

1) The motion of an object can be described by its position, direction of motion, and speed. That motion can be measured and represented on a graph.

2) If more than one force acts on an object, then the forces will reinforce or cancel one another, depending on their direction and magnitude. Unbalanced forces will cause changes in the speed or direction of an object's motion.

The primary emphasis of this lesson is on the relationship between the direction of applied force and and the resulting types of movement in an underwater robotic vehicle. Because many curricula emphasize graphing relationships between time, distance, and motion, Step 7 in the following procedure provides an optional activity that involves these relationships.

As is the case for all Ocean Explorer lessons, educators are encouraged to adapt the following procedure as necessary to best suit individual teaching styles, required content, and classroom needs.

1. To prepare for this lesson:
   (a) Review introductory essays for the Bermuda Deepwater Caves 2011: Dive of Discovery Expedition at http://oceanexplorer.noaa.gov/explorations/11bermuda/welcome.html.
   (b) Download the highlight video from the Bermuda: Search for Deepwater Caves 2009 expedition (http://oceanexplorer.noaa.

gov/explorations/09bermuda/media/movies/bermuda_trailer_video.html).

(c) Review the *Underwater Robot Motion Inquiry Guide* and *Underwater Robot Time-Distance Worksheet*.

(d) Gather materials for underwater robot motion models.


Entrance to one of Bermuda's caves. Image Courtesy of Bermuda: Search for Deepwater Caves 2009 Exploration.

2. Briefly introduce the Bermuda Deepwater Caves 2011: Dive of Discovery Expedition, and show some images of marine caves. Tell students that Bermuda has an unusually large number of species living in marine caves that are not found anywhere else, and that some are called "living fossils" because they have survived while other related species have become extinct. Explain that very little is known about deep water marine caves, and discuss why scientists might want to find and explore these caves. Briefly describe how anchialine caves may be formed.

   Tell students that high-resolution multibeam sonar was used in 2009 to produce detailed maps of the entire shelf edge around the Bermuda Platform in water depths greater than 150 m, and that sites selected from these maps were explored and photographed using an underwater robot called a remotely operated vehicle (ROV). Explain that a major activity during the 2011 Expedition is further exploration of some caves by human divers who will collect biological specimens and install instruments to measure currents, temperature, and chemical conditions (salinity, pH, dissolved oxygen and chlorophyll concentration) inside the caves.

3. Show students the highlight video from the Bermuda: Search for Deepwater Caves 2009 Expedition. Point out the ROV (bright green in the video clip) that was used to capture underwater imagery. Tell students that this type of ROV has a cable that connects the vehicle to an ROV pilot aboard a ship at the surface. The operator controls movement of the ROV so that it can capture the underwater images that scientists need to explore underwater caves. Tell students that they are about to investigate the kinds of movements that an underwater robot needs to capture this kind of video, and how those movements can be accomplished.

   Provide each student group with supplies listed under "Materials," and a copy of the *Underwater Robot Motion Inquiry Guide*. Be sure students understand how the finished model should appear, then have each group construct an Underwater Robot Motion Model as directed in Part A of the *Inquiry Guide*.

4. When students have completed their motion models, lead a discussion about the concepts of motion and position that can be illustrated with these models.

Prof. Tom Iliffe, diving with a Megalodon closed circuit rebreather, tows a plankton net through an underwater cave to collect small animals. Image courtesy of Jill Heinerth, Bermuda: Search for Deep Water Caves 2009.
http://oceanexplorer.noaa.gov/explorations/09bermuda/background/plan/media/plankton.html

If necessary, review the concept of the Cartesian coordinate system for two dimensions. Most students will have some familiarity with the system through experience with graphing, and possibly through using maps. Be sure students understand the meaning of "axis," and that the Cartesian coordinate system for two dimensions includes an "x" and a "y" axis. Extend this concept to three dimensions, and explain that the Cartesian coordinate system for three dimensions includes a third axis called the "z" axis. The key concept is that this coordinate system can be used to locate any position in the three-dimensional space surrounding the three axes. Tell students that in the three-dimensional system, the x- and y-axes are usually horizontal, while the z-axis is typically vertical. This may be confusing for students who are used to thinking of the y-axis as "up and down."

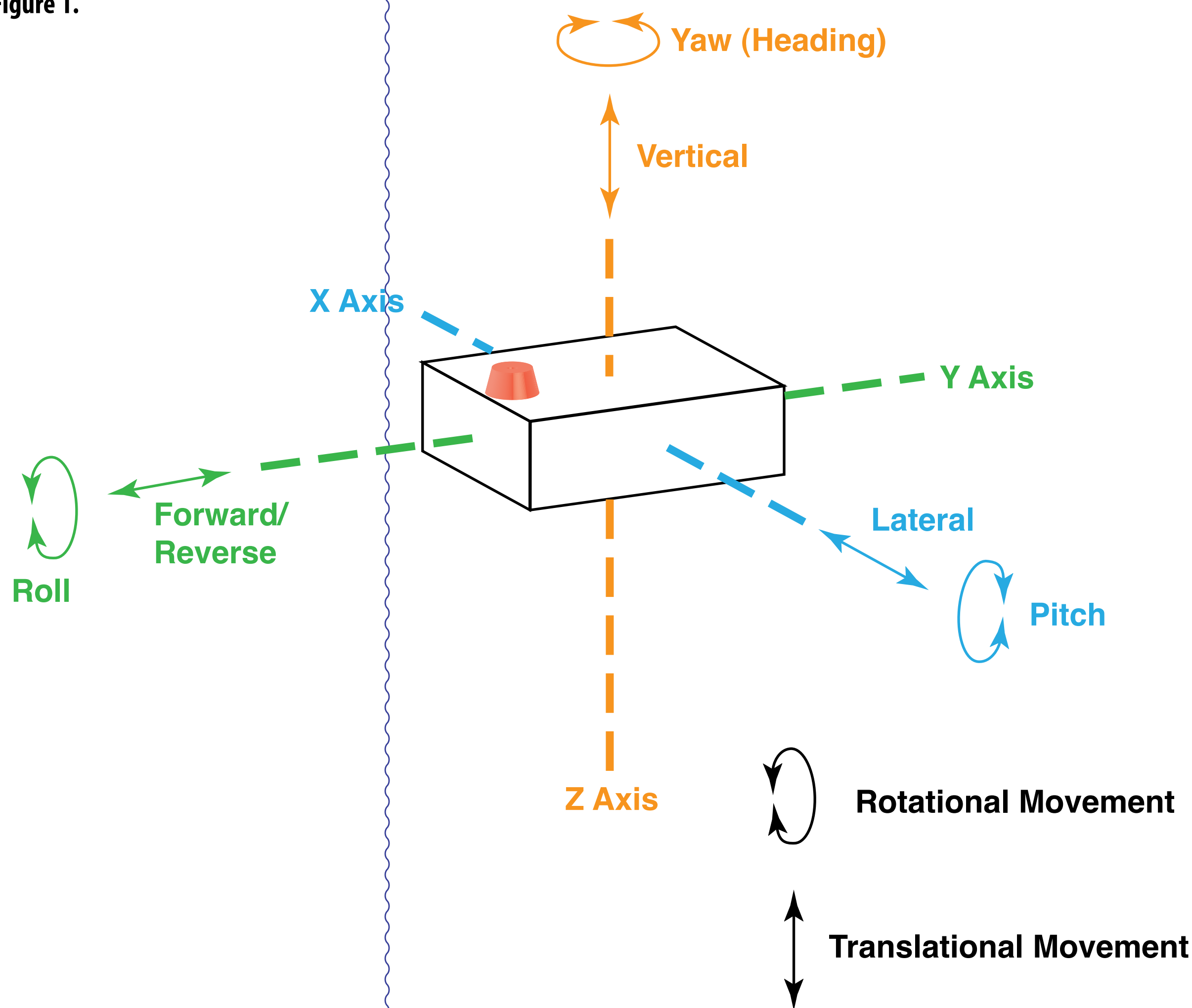
Point out that it is very important for a ROV pilot to know the exact position of the robot during a dive. Ask students how the position of an underwater object could be described. Students should identify some type of coordinate system with three axes as the basis for describing position. For many underwater ROV missions, geographic coordinates (latitude and longitude) are used for the horizontal (x and y) axes, and depth is used for the vertical (z) axis; but sometimes a customized grid system is used.

Ask students whether information about x, y, and z coordinates is enough to understand exactly how an underwater robot is positioned in the water. If they say "Yes," ask whether the exact geographic coordinates of their present position (that is, where they are in the classroom) would tell someone exactly how they are positioned in the classroom. Students should realize that additional information is needed about their orientation (for example, the direction in which they are facing). Tell students that this information is called orientation, which is also known as attitude or angular position.

5. Now hold up one of the students' models, insert a long wooden skewer through one of the straws, and ask how the model may move. Students should understand that the rectangular object may slide along the skewer, or may rotate around the skewer. Tell students that the sliding movement is called a translation, and the rotating motion is called a rotation. So for each axis, we have the possibility of a translation in two directions, and a rotation in two directions.

   Demonstrate these motions for each axis, and name the motions as indicated in Figure 1. If the axis passing through the longest part of the rectangle is the y-axis, then:
   Translation along the x-axis results in lateral motion;
   Rotation around the x-axis results in pitch;
   Translation along the y-axis results in forward/reverse motion;

Figure 1.



Rotation around the y-axis results in roll;
Translation along the z-axis results in vertical motion; and
Rotation around the z-axis results in yaw (because this rotation determines the direction of forward motion along the y-axis, the term heading is often used instead of yaw).

Be sure students know that some descriptions of these motions switch the x- and y- axes. In the case of underwater ROVs, the important thing is to understand the six motions relative to the front, back, top, bottom, and sides of a vehicle. To avoid confusion when discussing these motions in aircraft, the term longitudinal axis is used for the axis that passes through the length of an aircraft from nose to tail; lateral axis is used for the axis that passes through the sides of the aircraft parallel to the wings; and vertical axis is used for the axis that passes through the top and bottom of the aircraft and is perpendicular to the other two axes.

Figure 2.

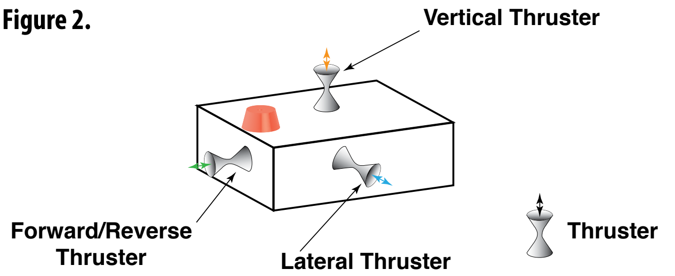


Figure 3.

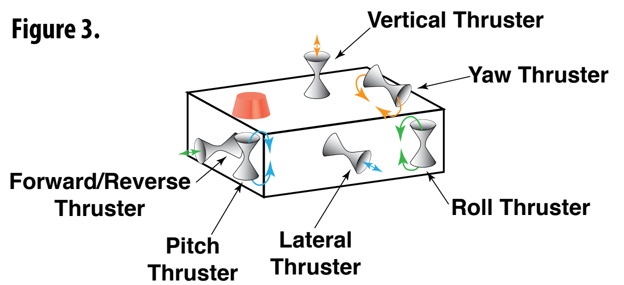


Figure 4.

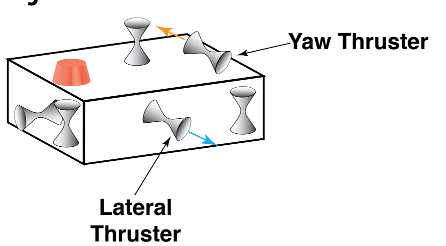
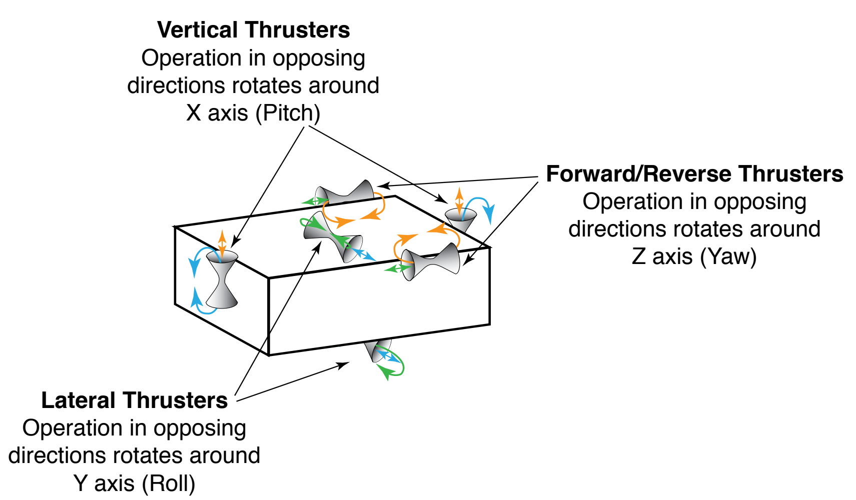


Figure 5.



6. Have students complete Part B of the *Underwater Robot Motion Inquiry Guide*, then have each group present their results. If three thrusters are located so that the force of each thruster is directed exactly along a single axis, then these three thrusters will provide lateral, forward/reverse, and vertical motion along the x-, y-, and z-axes, respectively (Figure 2). Adding an additional thruster somewhere along each axis (but not at the middle of the axis) whose force is perpendicular to the axis, will cause rotational motion (Figure 3). If these thrusters are operated one at a time, though, they will also cause translational motion. To have only one rotational motion, two thrusters must be operated simultaneously so that the translational movements are cancelled out (Figure 4). The thruster arrangement shown in Figure 5 would be a better choice for an ROV that needed to have all six motions, since two thrusters could be operated in the same direction to obtain more power for translational motions, and could be operated with opposite rotations to spin the vehicle around a perpendicular axis.

Operating more than one thruster at a time gives skilled ROV pilots a way to achieve complex motions with their robot. This technique also makes use of a basic force/motion concept:

If more than one force acts on an object, then the forces will reinforce or cancel one another, depending on their direction and magnitude. Unbalanced forces will cause changes in the speed or direction of an object's motion.

Another way to increase pilot control is to mount thrusters at an angle to the translational axes rather than parallel to these axes; this is called vectoring. When vectored thrusters are operated in pairs, it is easier to achieve precise control of rotational motion combined with translational motion.

The LBV (little benthic vehicle) robot used for the Bermuda: Search for Deepwater Caves 2009 Expedition only has four thrusters because it does not need all six motions. Two thrusters are provided for forward/reverse motion, since this motion needs the most power, and is the most common motion during underwater missions. The same two thrusters can provide rotational motion around the z-axis (yaw or heading) for steering. Vertical motion is important for diving and surfacing the vehicle, as well as for fine-tuning the vehicle's direction of motion, but a single thruster is adequate for these needs. Similarly, a single thruster is adequate for lateral motion. These motions are sufficient to obtain video imagery needed by the Expedition. Pitch and roll motions are less useful, except to control unwanted pitch and roll. In many cases, ROVs have floatation and ballast weights that limit pitch and roll of the robot.

7. (Optional) Provide each student group with a copy of the *Underwater Robot Time-Distance Worksheet*. When students have completed the worksheet, review their results:
   - ROV #1 has a speed of about 400 feet per minute, or about 4 knots
   - ROV #2 (graphed in Figure 1 on the Worksheet) has a speed of about 300 feet per minute, or about 3 knots; so ROV #1 is faster.

The BRIDGE Connection

www.vims.edu/bridge/ - In the "Site Navigation" menu on the left, scroll over "Ocean Science Topics," then "Human Activities," then click "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 at least three ways in which they make personal use of the two force/motion concepts identified at the beginning of the Learning Procedure.

Connections to Other Subjects

Mathematics, Earth Science

Assessment

Written reports and class discussions provide opportunities for assessment.

Extensions

1. Visit http://oceanexplorer.noaa.gov/explorations/11bermuda/welcome.html for more about the Bermuda Deepwater Caves 2011: Dive of Discovery Expedition.
2. Build your own underwater robot! See "ROV's in a Bucket" and books by Harry Bohm under "Resources."
3. For additional activities with ROVs, see *I, Robot, Can Do That!* (http://oceanexplorer.noaa.gov/edu/guide/media/gomdse14irobot78.pdf).

Multimedia Discovery Missions

http://oceanexplorer.noaa.gov/edu/learning/welcome.html
Click on the link to Lesson 15 for interactive multimedia presentations and Learning Activities on Seamounts.

Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

I, Robot, Can Do That!
(Grades 7-8) (9 pages, 357k) (from the 2005 Lost City Expedition)
http://oceanexplorer.noaa.gov/explorations/05lostcity/background/edu/media/lostcity05_i_robot.pdf

Focus: Underwater robotic vehicles for scientific exploration (Physical Science/Life Science)

Students 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.

Entering the Twilight Zone
(Grades 5-6) (8 pages, 352k) (from Expedition to the Deep Slope 2007)
http://oceanexplorer.noaa.gov/explorations/07mexico/background/edu/media/zone.pdf

Focus: Deep-sea habitats (Life Science)

Students describe major features of cold seep communities, list at least five organisms typical of these communities and will infer probable trophic relationships within and between major deep-sea habitats. Students also describe the process of chemosynthesis in general terms, contrast chemosynthesis and photosynthesis, describe major deep-sea habitats and list at least three organisms typical of each habitat.

What's That?
(Grades 5-6) (7 pages, 356k) (from the The Lost City 2005 Expedition)
http://oceanexplorer.noaa.gov/explorations/05lostcity/background/edu/media/lostcity05_whatsthat.pdf

Focus: Investigating Lost City hydrothermal field ecosystems by remotely operated vehicles (Life Science/Physical Science)

Students describe a sampling strategy for investigating an unknown area, and will be able to explain why this strategy is appropriate for such an investigation; identify and discuss some of the limitations faced by scientists investigating unexplored areas of the deep ocean, and discuss how an autonomous underwater vehicle such as the

Autonomous Benthic Explorer (ABE) can contribute to discoveries such as the Lost City Hydrothermal Field.

Ship of the Line
(Grades 5-6) (9 pages, 293k)(from AUVfest 2008)
http://oceanexplorer.noaa.gov/explorations/08auvfest/background/edu/media/shipline.pdf

Focus: Maritime history (Physical Science/Social Science)

Students describe general characteristics and technologies used in 18th century naval ships; draw inferences about daily life aboard these ships; and explain at least three ways in which simple machines were used on these vessels.

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/explorations/11bermuda/welcome.html – Web site for the Bermuda Deepwater Caves 2011: Dive of Discovery Expedition

http://oceanexplorer.noaa.gov/explorations/09bermuda/welcome.html – Web site for the Bermuda: Search for Deepwater Caves 2009 Expedition

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

http://www.marinetech.org/ – Web site for the Marine Advanced Technology Education (MATE) Center, with information on making ROVs and ROV competitions

http://monitor.noaa.gov/publications/education/rov_manual.pdf – "ROV's in a Bucket;" directions for a simple underwater ROV that can be built by grade-school children using off-the-shelf and off-the-Internet parts; by Doug Levin, Krista Trono, and Christine Arrasate, NOAA Chesapeake Bay Office

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://www.tamug.edu/cavebiology/index2.html – Web site, Anchialine Caves and Cave Fauna of the World

http://www.goodearthgraphics.com/virtcave/index.html – Virtual Cave Web site

Iliffe, T. M. and L. S. Kornicker. 2009. Worldwide diving discoveries of living fossil animals from the depths of anchialine and marine caves. Smithsonian Contributions to Marine Sciences 38:269-280; available online at http://www.tamug.edu/cavebiology/reprints/Reprint-195.pdf

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
- Motions and forces
- Transfer of energy

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

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 2.
The ocean and life in the ocean shape the features of the Earth.
Fundamental Concept c. Erosion—the wearing away of rock, soil and other biotic and abiotic earth materials—occurs in coastal areas as wind, waves, and currents in rivers and the ocean move sediments.
Fundamental Concept e. Tectonic activity, sea level changes, and force of waves influence the physical structure and landforms of the coast.

Essential Principle 5.
The ocean supports a great diversity of life and ecosystems.
Fundamental Concept e. The ocean is three-dimensional, offering vast living space and diverse habitats from the surface through the water column to the seafloor. Most of the living space on Earth is in the ocean.
Fundamental Concept f. Ocean habitats are defined by environmental factors. Due to interactions of abiotic factors such as salinity, temperature, oxygen, pH, light, nutrients, pressure, substrate and circulation, ocean life is not evenly distributed temporally or spatially, i.e., it is "patchy". Some regions of the ocean support more diverse and abundant life than anywhere on Earth, while much of the ocean is considered a desert.
Fundamental Concept h. Tides, waves and predation cause vertical zonation patterns along the shore, influencing the distribution and diversity of organisms.

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 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

In addition to consultation with expedition scientists, the development of lesson plans and other education products is guided by comments and suggestions from educators and others who use these materials. Please send questions and comments about these materials to: oceanexeducation@noaa.gov.

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Credit

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Underwater Robot Motion Inquiry Guide

Part A: Make an Underwater Robot Motion Model

This model will help you visualize the basic motions of underwater robots.

Here's what you should have to make your model:

- ❑ 1 - Three-dimensional rectangular object, approximately 3-in x 2-in x 1-in
- ❑ 3 - Drinking straws
- ❑ 3 - Wood skewers, about 12-inches long
- ❑ 8 - Colored toothpicks
- ❑ 1 - Small cork, toothpaste cap, small wire nut, or similar object
- ❑ Hot glue gun with glue sticks
- ❑ Scissors
- ❑ Thin screwdriver or similar tool

1. Cut straws to make three pieces about 4-inches long.

2. Using a thin screwdriver or similar tool, make holes in the rectangular object as shown in the illustration below. Holes should be large enough to provide a snug fit for straws.

3. Insert one straw into each of these holes, and secure in place with some hot glue.

4. Attach a small cork, toothpaste cap, or similar object to one end of the rectangular object. This will represent a video camera carried aboard an underwater robot.

Your Underwater Robot Motion Model is finished!

Part B: How to Make a Robot Dance

Motion for underwater remotely operated vehicles comes from motors called thrusters that have propellers. Usually, these motors can be made to rotate both clockwise and counterclockwise, so they can provide thrust in two directions.

Your challenge is to decide where to put thrusters so your robot can have the following motions:

- Lateral motion
- Pitch
- Forward/reverse motion
- Roll
- Vertical motion
- Yaw (which is the same as Heading)

Place a skewer through the straws to help visualize where to place the thrusters to produce various motions. When you've decided where to place a thruster, glue a toothpick onto your model so that the ends of the toothpick point in the direction of thrust (assume that you are using reversible motors that can provide thrust in two opposite directions).

Extra Challenge Question:

The Bermuda: Search for Deepwater Caves 2009 Expedition used a Seabotix LBV200 remotely operated vehicle shown in the photograph below to obtain video imagery of the areas that were being explored. This robot uses four thrusters. What kind of motion do you think the robot can achieve with four thrusters?

The SeaBotix LBV (little benthic vehicle) is a remotely operated vehicle (ROV) that researchers will use to explore potential underwater caves. Its small size (just 21 inches in length) makes it an ideal tool for exploring small underwater spaces. Image courtesy of Bermuda: Search for Deep Water Caves 2009 Exploration.
http://oceanexplorer.noaa.gov/explorations/09bermuda/logs/hires/0925_lvb_hires.jpg

Underwater Robot Time-Distance Worksheet

One of the questions that ocean explorers ask when they are choosing an underwater robot is, "How fast will it move?" Speed is defined as distance covered divided by time needed to cover that distance.

Table 1
Distance/Time Test for ROV #1

Time (minutes)	Distance (feet)
10	4052
20	8107
30	11905
40	15953
50	20108
60	24008
70	28203
80	31858
90	36012

1. Table 1 shows the results of speed tests for an underwater remotely operated vehicle (ROV). Use these data to plot a graph that shows distance on the y-axis and time on the x-axis. What is the speed of this ROV?
2. Worksheet Figure 1 shows a distance-time graph for ROV #2. What is the speed of ROV#2 as graphed in Worksheet Figure 1?
3. Which ROV is faster?
4. Speed of water vehicles is often measured in knots. One knot is equal to one nautical mile per hour. One nautical mile is about 6,000 feet. What is the speed in knots of ROV #1?
5. What is the speed in knots of ROV #2?

Worksheet Figure 1