2005 Lost City Expedition

I, Robot, Can Do That!

Focus
Underwater Robotic Vehicles for Scientific Exploration

Grade Level
7-8 (Physical Science/Life Science)

Focus Question
How can underwater robots be used to assist scientific explorations?

Learning Objectives
Students will be able to describe and contrast at least three types of underwater robots used for scientific explorations.

Students will be able to discuss the advantages and disadvantages of using underwater robots in scientific explorations.

Given a specific exploration task, students will be able to identify robotic vehicles best suited to carry out this task.

Materials
❒ Copies of the "Undrwater Robot Capability Survey," one for each student group

Audio/Visual Materials
❒ (Optional) computers with internet access

Teaching Time
One 45-minute class period, plus time for student research

Seating Arrangement
Six groups of students

Maximum Number of Students
30

Key Words
ABE
ROPOS
Remotely Operated Vehicle
Hercules
Tiburon
RCV-150
Robot

Background Information
In 1977, scientists in the deep-diving submersible Alvin made the first visit to an oceanic spreading ridge near the Galapagos Islands, and made one of the most exciting discoveries in 20th century biology. In the middle of deep, cold ocean waters, they found hot springs and observed black smoke-like clouds billowing from chimneys of rock; and nearby were communities of animals that no one had ever seen before.

These hot springs came to be known as hydrothermal vents, and since that first discovery, more than 200 similar vent fields have been documented in the world's ocean. These systems are formed when seawater flowing through cracks in the seafloor crust enters magma-containing chambers beneath a spreading ridge. Intense heat from the molten rock causes a variety of chemical changes and many substances from the rocks become dissolved in the fluid. The heated fluid becomes less dense, rises upward, and emerges onto the sea floor to form a hydrothermal vent. When the heated fluid is cooled by cold water of the deep ocean, many of the dissolved materials precipitate, creating black clouds and chimneys of rock-like deposits. The hydrothermal fluid emerging from the vents is rich in sulfide, which is used as an energy source by chemosynthetic bacteria to produce essential organic substances. These autotrophic bacteria are the base of a diverse food web that includes large tubeworms (vestimentiferans), clams, mussels, limpets, polychaete worms, shrimp, and crabs.

In 2000, a different sort of vent field was serendipitously discovered on an underwater mountain called the Atlantis Massif near the Mid-Atlantic Ridge. This new field also had hot fluids venting from rocky chimneys. But these chimneys towered as much as 200 feet above the seafloor, much larger than chimneys found in other vent fields. In fact, the vent field was located 15 kilometers away from the spreading axis of the Mid-Atlantic Ridge and the chimneys looked so much like towers and spires of a fantastic city that the new vent field was named "Lost City." And the fluids emerging from the chimneys, as well as the surrounding biological communities, were unlike any other known hydrothermal system. Subsequent investigations have shown that the newly-discovered hydrothermal fields are not formed by seawater reacting with molten magma. Instead, these fields are formed when seawater reacts with solid mantle rocks. These rocks, called peridotites, are formed deep inside the Earth, but a unique type of faulting can bring them close to the seafloor. Cracks in the seafloor can allow seawater to percolate down to the up-lifted peridotites. When this happens, numerous chemical reactions occur between seawater and minerals in the rock (a process called serpentinization). These reactions produce a large amount of heat that causes the fluids to rise and eventually vent at the surface of the seafloor. Mixing between the heated fluids and cold surrounding seawater causes additional reactions that include precipitation of calcium carbonate (limestone), which forms the towering chimneys of Lost City. Because the reactions of seawater with peridotites are essential to these formations, the Lost City is called a "peridotite-hosted ecosystem."

In contrast to the abundant biological communities of hydrothermal vents formed by volcanic activity, the Lost City Hydrothermal Field (LCHF) initially appeared to be devoid of living organisms. But when scientists took a closer look at the surface of the chimneys (they actually vacuumed the surface), they found large numbers of tiny shrimps and crabs. Because most of these animals are less than one centimeter in size, transparent or translucent, and tend to hide in small crevices, they were easily overlooked when the LCHF was first discovered. While the total biomass around the LCHF vents appears to be less than at other hydrothermal vents, scientists believe there is just as much diversity (variety of different species). Like previously discovered vent communities, the LCHF ecosystem is based on microorganisms that are able to use chemicals in the vent fluids as an energy source for producing complex organic compounds that are used as food by other species (chemosynthesis). But again, the LCHF differs in that the fluids emerging from the chimneys has very little of the hydrogen sulfide and metals that are typical in hydrothermal fluids of other vent. Instead, LCHF vent fluids contain high concentrations of methane and hydrogen, and these chemicals appear to provide the energy source for chemosynthetic microbes.

The scientists who discovered Lost City weren't actually looking for it; they were studying a large underwater mountain known as the Atlantis Massif using a robotic vehicle known as the Autonomous Benthic Explorer (ABE) that is designed to conduct underwater surveys without a pilot or tether to a ship or submersible. In this lesson, students will investigate how ABE and other underwater robots can be used in underwater explorations.

Learning Procedure

1. To prepare for this lesson:
   (a) Visit the Lost City expedition's Web pages (http://oceanexplorer.noaa.gov/explorations/05lostcity/welcome.html; http://www.lostcity.washington.edu/; and http://www.immersionpresents.org) for an overview of the expedition and background essays; and

   (b) Review the Ocean Explorer Web pages on underwater robotic vehicles, indexed at http://oceanexplorer.noaa.gov/technology/subs/subs.html.

   (c) If students do not have access to the internet, make copies of relevant materials on underwater robotic vehicles from the Web site referenced above.

2. Briefly review the concepts of plate tectonics and the discovery of Lost City hydrothermal vents in 2000, including a short description of how an underwater robot contributed to the discovery. You may want to show video clips from some of the sites referenced in Step 1 to supplement this discussion.

3. Tell students that their assignment is to investigate underwater robots that can be used to perform various tasks that support scientific exploration of the deep ocean. 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.

4. 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 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 seafloor.

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 human-occupied 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

5. Tell students that you are going to describe a series of missions for which an underwater robot is needed. After they hear each mission description, each group should decide whether their robot is capable of the mission, and then discuss which of the candidate robots is best suited for the job.

   Read each of the following mission descriptions:

   (a) We are planning an expedition to study an unexplored area of the Arctic Ocean with a maximum depth of 3,000 meters. We are particularly interested in geological formations, and want to collect rock cores and samples of biological organisms that may be living on these formations.
   [ROPOS and Tiburon can be fitted with a rock-coring drill and biological sampling equipment.]

   (b) As part of the ongoing study of the Lost City, we want to survey other parts of the Atlantis Massif for similar vent communities. This will require a robot that can travel back and forth across the mountain, maintaining a distance of about 5 meters from the bottom, with continuous depth recordings and video images taken every 10 meters.
   [Several robots have the capability to do this work, but ABE is best suited for this type of survey since it can operate independently while humans do other work.]

   (c) We are studying fish communities around deep water coral reefs off the coast of Florida (depth 500 – 700 m). We need video records of fish species in a variety of habitats, particularly under coral ledges near the bottom.
   [RCV-150 and some General Purpose ROVs could do this work. RCV-150 has been used

specifically for fish surveys, and its small size allows it to work close to the bottom and record images under ledges.]

(d) We are developing an educational program for our city aquarium, and want to show some of the capabilities of underwater robots. What kind of robot would be most practical for this purpose?
[A small General Purpose Remotely Operated Vehicle would be most cost effective.]

(e) Our expedition is studying the linkages between pelagic (mid-water) and benthic (bottom) communities associated with a hydrothermal vent in the Gulf of Mexico (depth is approximately 2,500 meters). We want to collect biological samples from both areas, as well as geological samples (including rock cores) from the benthic areas.
[ROPOS and Tiburon are capable of collecting the benthic and rock core samples. Tiburon also has a dedicated toolsled specifically for studying midwater organisms.]

(f) We are exploring the wreck of a Spanish galleon that lies in a deep canyon 3,000 meters below the surface. We need a complete, detailed photographic survey of the area around the ship, and also want to be able to recover artifacts that may be discovered.
[Hercules was designed specifically for the study of ancient shipwrecks and recovery of artifacts, and is capable of high-definition photographic surveys.]

(g) A Pisces submersible has become tangled in the rigging of a sunken freighter in 1,500 feet of water. We need a robot to survey the situation and cut the rigging to free the sub.
[All of the robots could respond to this emergency – if they were in the immediate area, and had the necessary cutting attachments available. RCV-150 is specifically designed to support Pisces operations, and would most likely be carried as part of emergency response equipment on support vessels.]

(h) We are exploring a series of underwater caves, approximately 300 meters deep. The entrances to some of these caves is only about 300 cm square. We need video images of the interior of these caves to plan further explorations.
[General Purpose Remotely Operated Vehicles can be as small as a bread box, and could provide the video images needed for this work.]

(i) Our research team is studying an unexplored chain of underwater volcanoes. We want to sample geological formations as well as biological communities, but won't know exactly what types of samples will be needed until we can see the area. Depths in our study area will be between 1,500 and 4,500 meters.
[ROPOS can be fitted with a wide variety of observation tools that could give these scientists the flexibility they need to respond to new and unexpected discoveries]

(j) Our scientific team needs to monitor the water temperature around a newly erupting underwater volcano, two miles below the surface of the ocean. We need samples taken every hour for a month.
[ABE is the only robot in the group capable of autonomous operations and long-term monitoring.]

(k) We are studying the organisms associated with a deepwater habitat (1,000 – 2,000 meters depth), and want a complete photographic record of the study area (approximately 10,000 square meters. We also need to collect samples of unknown organisms for identification.
[ROPOS, Hercules, Tiburon, and some

General Purpose ROVs could do this work. This is an opportunity to discuss the advantages and disadvantages of the different systems. You may want to ask what additional details about the mission would help in making the best choice.]

6. Briefly discuss the disadvantages of underwater robots compared to submersibles. The major drawback is that the human presence is lost, and this makes visual surveys and evaluations more difficult. Tethered robots also are constrained to some extent by their cabled connection to the support ship.

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

Evaluation

Reports and discussions in Steps 4 and 5 provide opportunities for assessment.

Extensions

1. Have students visit http://oceanexplorer.noaa.gov/explorations/05lostcity/welcome.html to keep up to date with the latest Lost City Expedition discoveries.

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

Resources

http://oceanexplorer.noaa.gov/explorations/05lostcity/welcome.html – Web site for the 2005 Lost City expedition.

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.oceanexplorer.noaa.gov/explorations/02fire/logs/magicmountain/welcome.html – Virtual tour of Magic Mountain, a hydrothermal vent site located on Explorer Ridge in the NE Pacific Ocean, about 150 miles west of Vancouver Island, British Columbia, Canada.

http://www.bio.psu.edu/hotvents – Virtual tour of hydrothermal vent communities

http://seawifs.gsfc.nasa.gov/OCEAN_PLANET/HTML.ps_vents.html – Links to many other Web sites with information about hydrothermal vents

National Science Education Standards

Content Standard A: Science As Inquiry
- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard E: Science and Technology
- Abilities of technological design
- Understandings about science and technology

Content Standard F: Science in Personal and Social Perspectives
- Science and technology in society

Content Standard G: History and Nature of Science
- Nature of science

For More Information

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http://oceanexplorer.noaa.gov

Underwater Robot Capability Survey

Name of Robotic Vehicle ____________________

Maximum Operating Depth ____________________

Tethered or Autonomous ____________________

Minimum Number of Crew Required for Operation

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Tools

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Special Capabilities or Advantages

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Other Details

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