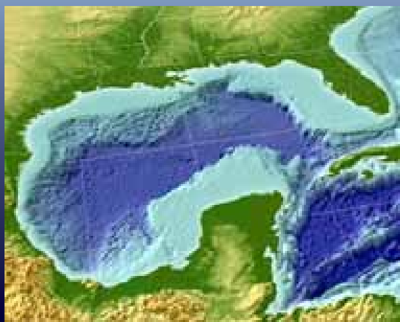


Lessons from the Deep:
Exploring the Gulf of Mexico's Deep-Sea Ecosystems
Education Materials Collection

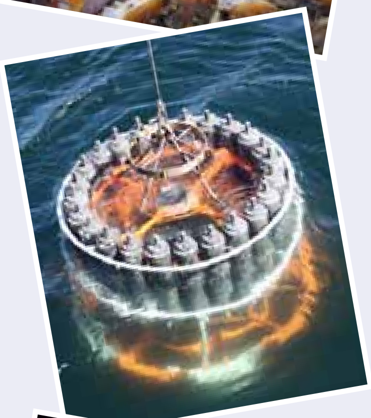


Image captions/credits on Page 2.

lesson plan

I, Robot, Can Do That!

(adapted from the Thunder Bay Sinkholes 2008 Expedition)

Focus
Underwater robotic vehicles for scientific exploration

Grade Level
(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 *Underwater Robot Capability Survey*, one for each student group

Audio/Visual Materials
- (Optional) Computers with internet access

Teaching Time
One or two 45-minute class periods, plus time for student research

Seating Arrangement
Seven groups of students

Maximum Number of Students

35

Key Words

ABE
ROPOS
Remotely Operated Vehicle
Hercules
Tiburon
RCV-150
Robot

Background Information

Following the Deepwater Horizon blowout, responders worked around the clock to control the flow of oil from the damaged wellhead. Many of these efforts depended upon remotely operated vehicles (ROVs), which are underwater robots that allowed responders to work on the mile-deep wellhead without the expense and risk involved in using manned submersibles. ROVs are linked by a group of cables to an operator who is usually aboard a surface ship. Most of these robots are equipped with one or more video cameras and lights, and may also carry other equipment such as collecting devices, cutters, water samplers, and measuring instruments to expand the vehicle's capabilities. In this lesson, students will investigate how underwater robots can be used in underwater explorations.

Learning Procedure

1. To prepare for this lesson: review the Ocean Explorer Web pages on underwater robotic vehicles, indexed at http://oceanexplorer.noaa.gov/technology/subs/subs.html.

2. Briefly discuss the role of underwater robots in responding to the Deepwater Horizon blowout event.

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

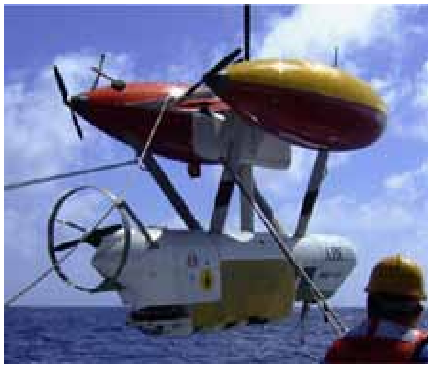
Images from Page 1 top to bottom:

A close-up mussel aggregation with *Chirodota heheva* sea cucumbers. Image courtesy of Expedition to the Deep Slope 2007.
http://oceanexplorer.noaa.gov/explorations/07mexico/logs/july3/media/cuke_600.html

A CTD rosette being recovered at the end of a cast. Note that the stoppers on the sample bottles are all closed. Image courtesy of INSPIRE: Chile Margin 2010.
http://oceanexplorer.noaa.gov/explorations/10chile/logs/summary/media/2summary.html

A methane hydrate mound on the seafloor; bubbles show that methane is continuously leaking out of features like this. If bottom waters warmed, this entire feature may be destabilized and leak methane at a higher rate.
http://oceanexplorer.noaa.gov/explorations/10chile/background/methane/media/methane4.html

Lophelia pertusa create habitat for a number of other species at a site in Green Canyon. Image courtesy of Chuck Fisher.
http://oceanexplorer.noaa.gov/explorations/08lophelia/logs/sept24/media/green_canyon_lophelia.html



The ABE autonomous underwater vehicle (free-swimming robot). ABE (full name: Autonomous Benthic Explorer) has been used on multiple expeditions to find new hydrothermal vents in the deep ocean all over the world, from New Zealand to South Africa and from Brazil to Ecuador. Photo courtesy of Christopher German.
http://oceanexplorer.noaa.gov/explorations/10chile/background/exploration/media/exploration1.html

Epitaph for ABE:
Under the wide and restless sea,
Lies my grave, now let me be;
Glad did I work and now I rest,
Now by deadlines no longer stressed.
And I lay me down with a will.

This be the verse you grave for me;
"Here lies ABE where it longed to be;
Home is the sailor, home to the sea,
Here it rests, now let it be."
~ Al Bradley (after Robert Louis Stevenson)

IFE's ROV Hercules on the deck of the NOAA Ship *Ronald H. Brown*.
http://oceanexplorer.noaa.gov/technology/subs/hercules/media/hercules_ondeck.html

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
- NOTE: ABE was lost during the INSPIRE: Chile Margin 2010 Expedition; see http://oceanexplorer.noaa.gov/explorations/10chile/logs/mar7a/mar7a.html

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

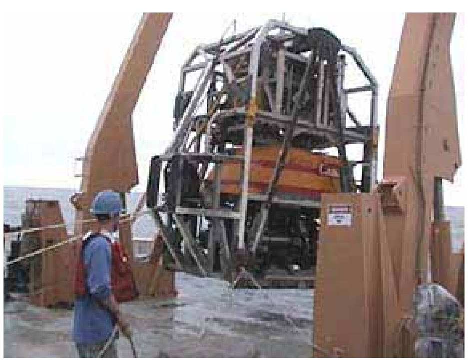
- Six watch-standers on each watch: Watch Leader makes sure that the scientific goals of the dive are being addressed; Pilot operates Hercules, controlling its thrusters, manipulator arms, and other functions; Engineer controls the winch that moves Argus up and down, as well as Argus' thrusters and other 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

M-ROVER

- Capable of operating to depths of 450 meters
- Tethered; a single Engineer/Operator accompanies the vehicle on every mission
- Tools: video and still cameras; three-function articulated arm with elbow, wrist, and jaw movements for sampling and other tasks; sonar imaging equipment; and up to 100 lb of additional equipment
- Propelled by four horizontal thrusters and two vertical thrusters
- Capable of speeds up to 3-knots on the surface and 3/4 knot underwater
- Can hover motionless in light to moderate currents
- Autopilot provides automatic depth control, automatic altitude control, and magnetic course and vehicle orientation
- Can be operated from many different platforms, including research vessels, docks and piers, and from shore; principal platform is the University of Michigan's Research Vessel *Laurentian*

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



ROPOS being deployed for deep water operations inside its steel cage.
http://oceanexplorer.noaa.gov/technology/subs/ropos/media/roposfirstdive.html

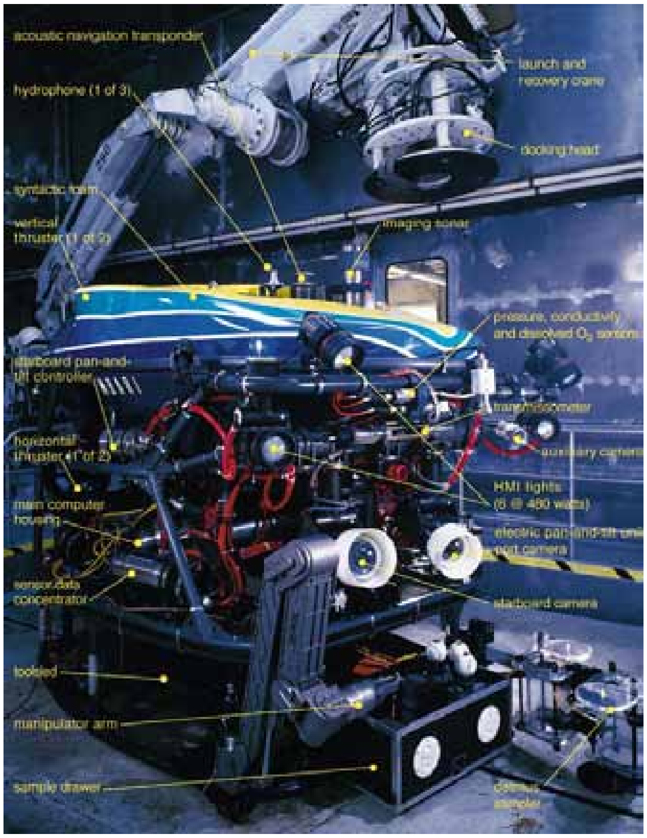
- A "typical" dive requires at least four people (and sometimes more): the "Hot Seat" scientist, pilot, manipulator operator, and data/event logger

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

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 off 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



A detailed image of the sensors and sampling tools on the ROV Tiburon. Image courtesy of MBARI.
http://oceanexplorer.noaa.gov/technology/subs/tiburon/media/tiburon02.html

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.

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 deepsea ecosystems, we want to survey the Atlantis Massif (an underwater mountain near the Mid-Atlantic Ridge, depth 630 m) for hydrothermal 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 1,100 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 (Statistics)

Assessment

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

Extensions

1. See the "Resources" section of *Lessons from the Deep: Exploring the Gulf of Mexico's Deep-sea Ecosystem Education Materials Collection Educators Guide* for additional information, activities, and media resources about deepwater ecosystems in the Gulf of Mexico.
2. Build your own underwater robot! See *ROV's in a Bucket* and books by Harry Bohm under Resources.

Multimedia Discovery Missions

http://www.learningdemo.com/noaa/ Click on the links to Lessons 3, 5, 6 for interactive multimedia presentations and Learning Activities on Deep-Sea Corals, Chemosynthesis and Hydrothermal Vent Life, and Deep-Sea Benthos.

Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

Monsters of the Deep (6 pages, 464 KB)

http://oceanexplorer.noaa.gov/explorations/07mexico/background/edu/media/monsters.pdf

Focus - Predator-prey relationships between cold-seep communities and the surrounding deep-sea environment (Life Science)

Students describe major features of cold-seep communities, list at least five organisms typical of these communities, and infer probable trophic relationships among organisms typical of cold-seep communities and the surrounding deep-sea environment. Students also describe the process of chemosynthesis in general terms, contrast chemosynthesis and photosynthesis, and describe at least five deep-sea predator organisms.

One Tough Worm (8 pages, 476 KB)

http://oceanexplorer.noaa.gov/explorations/07mexico/background/edu/media/worm.pdf

Focus - Physiological adaptations to toxic and hypoxic environments (Life Science)

Students explain the process of chemosynthesis, explain the relevance of chemosynthesis to biological communities in the vicinity of cold seeps, and describe three physiological adaptations that enhance an organism's ability to extract *oxygen from its environment. Students also describe the problems posed by hydrogen sulfide for aerobic organisms, and explain three strategies for dealing with these problems.*

Design a Reef! (5 pages, 408k)
http://oceanexplorer.noaa.gov/explorations/03mex/background/edu/media/mexdh_aquarium.pdf

Focus - Niches in coral reef ecosystems (Life Science)

In this activity, students will compare and contrast coral reefs in shallow water and deep water, describe the major functions that organisms must perform in a coral reef ecosystem, and explain how these functions might be provided in a miniature coral reef ecosystem. Students will also be able to explain the importance of three physical factors in coral reef ecosystems and infer the fundamental source of energy in a deep-water coral reef.

Let's Go to the Video Tape! (7 pages, 552 KB)
http://oceanexplorer.noaa.gov/explorations/07twilightzone/background/edu/media/videotape.pdf

Focus - Characteristics of biological communities on deep-water reef habitats (Life Science)

In this activity, students will recognize and identify some of the fauna groups found in deep-sea coral reef communities, infer possible reasons for observed distribution of groups of animals in deep-sea coral reef communities, and discuss the meaning of "biological diversity." Students will compare and contrast the concepts of "variety" and "relative abundance" as they relate to biological diversity, and given abundance and distribution data of species, will be able to calculate an appropriate numeric indicator that describes the biological diversity of a community.

Forests of the Deep Ocean (12 pages, 300 KB)
http://oceanexplorer.noaa.gov/explorations/08lophelia/background/edu/media/forests.pdf

Focus - Morphology and ecological function in habitat-forming deep-sea corals (Life Science)

In this activity, students will be able to describe at least three ways in which habitat-forming deep-sea corals benefit other species in deep-sea ecosystems, explain at least three ways in which the physical form of habitat-forming deep-sea corals contributes to their ecological function, and explain how habitat-forming deep-sea corals and their associated ecosystems may be important to humans. Students will also be able to describe and discuss conservation issues related to habitat-forming deep-sea corals.

Your Expedition of Discovery (17 pages, 764 KB)
http://oceanexplorer.noaa.gov/explorations/09lophelia/background/edu/media/09yourexped.pdf

Focus - Global Positioning Systems (Physical Science/Earth Science)

In this activity, students will explain how global positioning satellites are used to determine the location of points on Earth's surface, and will identify at least three practical uses for the Global Positioning System (GPS). Students will also explain how the geographic position of objects may be described by latitude and longitude, and given latitude and longitude coordinates will use GPS technology to find the corresponding location.

Other Links and 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/ – Ocean Explorer Web site

http://www.piersystem.com/go/site/2931/ – Main Unified Command Deepwater Horizon response site

http://response.restoration.noaa.gov/deepwaterhorizon – NOAA Web site on Deepwater Horizon Oil Spill Response

http://docs.lib.noaa.gov/noaa_documents/NESDIS/NODC/LISD/Central_Library/current_references/current_references_2010_2.pdf – Resources on Oil Spills, Response, and Restoration: a Selected Bibliography; document from NOAA Central Library to aid those seeking information concerning the Deepwater Horizon oil spill disaster in the Gulf of Mexico and information on previous spills and associated remedial actions; includes media products (web, video, printed and online documents) selected from resources available via the online NOAA Library and Information Network Catalog (NOAALINC)

http://www.gulfallianceeducation.org/ – Extensive list of publications and other resources from the Gulf of Mexico Alliance; click "Gulf States Information & Contacts for BP Oil Spill" to download the Word document

http://rucool.marine.rutgers.edu/deepwater/ – Deepwater Horizon Oil Spill Portal from the Integrated Ocean Observing System at Rutgers University

http://www.darrp.noaa.gov/southeast/deepwater_horizon/ index.html – Information about damage assessments being conducted by NOAA's Damage Assessment Remediation and Restoration Program

http://response.restoration.noaa.gov/ – Click "Students and Teachers" in the column on the left for information, fact sheets, and activities about oil emergencies, habitats, and other ocean issues

Fisher, C., H. Roberts, E. Cordes, and B. Bernard. 2007. Cold seeps and associated communities of the Gulf of Mexico. *Oceanography* 20:118-129; available online at http://www.tos.org/oceanography/issues/issue_archive/20_4.html

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.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

National Science Education Standards

Content Standard A: Science As Inquiry

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

Content Standard E: Science and Technology

- Personal and community health

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

Ocean Literacy Essential Principles and Fundamental Concepts

Essential Principle 1.
The Earth has one big ocean with many features.

Fundamental Concept h. Although the ocean is large, it is finite and resources are limited.

Essential Principle 3.
The ocean is a major influence on weather and climate.

Fundamental Concept f. The ocean has had, and will continue to have, a significant influence on climate change by absorbing, storing, and moving heat, carbon and water.

Essential Principle 5.
The ocean supports a great diversity of life and ecosystems.

Fundamental Concept c. Some major groups are found exclusively in the ocean. The diversity of major groups of organisms is much greater in the ocean than on land.
Fundamental Concept d. Ocean biology provides many unique examples of life cycles, adaptations and important relationships among organisms (such as symbiosis, predator-prey dynamics and energy transfer) that do not occur on land.
Fundamental Concept g. There are deep ocean ecosystems that are independent of energy from sunlight and photosynthetic organisms. Hydrothermal vents, submarine hot springs, and methane cold seeps rely only on chemical energy and chemosynthetic organisms to support life.

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 g. Everyone is responsible for caring for the ocean. The ocean sustains life on Earth and humans must live in ways that sustainthe 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 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.
Please e-mail your comments to: oceanexeducation@noaa.gov

For More Information

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Acknowledgements

This lesson was developed by Mel Goodwin, PhD, Marine Biologist and Science Writer. Design/layout by Coastal Images Graphic Design, Mount Pleasant, SC. If reproducing this lesson, please cite NOAA as the source, and provide the following URL: 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

Tools

Special Capabilities or Advantages

Other Details