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Thunder Bay Sinkholes 2008

I, Robot, Can Do That!
(adapted from the 2005 Lost City Expedition)

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 "Underwater Robot Capability Survey," one for each student group

Audiovisual Materials
❒ (Optional) Computers with internet access

Teaching Time
One 45-minute class period, 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
In June, 2001, the Ocean Explorer Thunder Bay ECHO Expedition was searching for shipwrecks in the deep waters of the Thunder Bay National Marine Sanctuary and Underwater Preserve in Lake Huron. But the explorers discovered more than shipwrecks: dozens of underwater sinkholes in the limestone bedrock, some of which were several hundred meters across and 20 meters deep. The following year, an expedition to survey the sinkholes found that some of them were releasing fluids that produced a visible cloudy layer above the lake bottom, and the lake floor near some of the sinkholes was covered by conspicuous green, purple, white, and brown mats.

Preliminary studies of the mats have found that where water is shallow (≤ 1.0 m) the mats are composed of green algae. In deeper (about 18 m) waters, mats are formed by filamentous purple cyanobacteria. Mats near the deepest (93 m) sinkholes are white or brown, but their composition is presently unknown. The appearance of mats near the deepest sinkholes is very similar to mats observed in the vicinity of cold seeps and hydrothermal vents in the deep ocean, which are often formed by chemosynthetic bacteria. These bacteria are able to obtain energy from inorganic chemicals, and are a food source for a variety of other organisms that inhabit cold seep and vent communities. Biological communities whose primary energy source comes from chemosynthesis are distinctly different from more familiar biological communities in shallow water and on land where photosynthetic organisms convert the energy of sunlight to food that can be used by other species. Hydrothermal vent and cold seep communities are home to many species of organisms that have not been found anywhere else on Earth, and the existence of chemosynthetic communities in the deep ocean is one of the major scientific discoveries of the last 100 years.

Scientists hypothesize that the source of the fluids venting from the Lake Huron sinkholes is the Silurian-Devonian aquifer beneath the lake's sediments. Aquifers are rocks and sediments that contain large amounts of water. Between 350 and 430 million years ago, during the Paleozoic era, shallow seas covered what is now the border between Canada and the United States between Minnesota and New York. Over thousands of years, sand, minerals, and sediments accumulated on the seafloor, and were gradually compressed to form sandstone, limestone and shale. About 1.8 million years ago, the Great Ice Age of the Pleistocene epoch began and continued until about 10,000 years ago. During this time, four major periods of glaciation occurred, separated by three interglacial periods. As the final glacial period came to a close, retreating glaciers along the U.S.-Canadian border revealed five huge lakes that we now know as the Laurentian Great Lakes. In the Great Lakes region, aquifers are found in deposits of sand and gravel left by glaciers, as well as in porous bedrocks (limestone and sandstone) that were formed much earlier in geologic time. Five major aquifers are recognized in this region: one near the land or lake floor surface (the surficial aquifer) and the others in deeper bedrock named for the geologic time periods when they were formed (the Cambrian-Ordovician, Silurian-Devonian, Mississippian, and Pennsylvanian aquifers). The bedrock that forms the Silurian-Devonian aquifer is primarily limestone and mineral formations from evaporating seawater. Both fresh and saline water are found in the Silurian-Devonian aquifer.

Sinkholes are common features where limestone is abundant, because limestone rocks are soluble in acid. Atmospheric carbon dioxide often dissolves in rainwater to form a weak acid (carbonic acid). Rainwater flowing over land surfaces may also pick up organic acids produced by decaying leaves and other once-living material. The resulting weak acid can slowly dissolve limestone rocks to form caves, springs, and sinkholes. Sinkholes on land are known recharge areas for the Silurian-Devonian aquifer (areas where water flows into the aquifer). But very little is known about the chemistry, geology, and biology of submerged sinkholes that may serve as vents for groundwater in the aquifer. Water samples collected near these sinkholes is very different from the surrounding lake, with much higher concentrations of sulfate, phosphorus, and particulate organic matter, as well as ten times more bacteria compared to nearby lake water. These observations suggest that submerged sinkholes may be biogeochemical "hot spots" inhabited by unusual and possibly unknown life forms. At the same time, water flow through submerged sinkholes depends upon recharge from land. This means that sinkhole ecosystems are likely to be very sensitive to changes in rainfall patterns that may accompany climate change, as well as human alterations of these landscapes surrounding recharge areas. These factors make understanding sensitive sinkhole ecosystems an urgent necessity.

Exploration of the deepest sinkhole ecosystems (93 m depth) would be very difficult without underwater robots called ROVs (which stands for "Remotely Operated Vehicle"). These are unoccupied robots linked by a group of cables to an operator who is usually aboard a surface ship. Most ROVs are equipped with one or more video cameras and lights, and may also carry other equipment such as a manipulator or cutting arm, water samplers, and measuring instruments to expand the vehicle's capabilities. The Thunder Bay Sinkholes 2008 Expedition will use an ROV called M-ROVER to carry sampling instruments, video and still cameras, an articulated arm for sampling and other tasks, and sonar imaging equipment. M-ROVER is capable of speeds up to 3-knots on the surface and 3/4 knot underwater, and is rated for a maximum depth of 450 meters. For more information about M-ROVER, visit http://www.engin.umich.edu/dept/name/facilities/oel/mrover.html. In this lesson, students will investigate how underwater robots can be used in underwater explorations.

Learning Procedure

1. To prepare for this lesson:
   - Review introductory essays for the Thunder Bay Sinkholes 2008 Expedition at http://oceanexplorer.noaa.gov/explorations/08thunderbay/welcome.html.
   - Review the Ocean Explorer Web pages on underwater robotic vehicles, indexed at http://oceanexplorer.noaa.gov/technology/subs/subs.html; and
   - Review information about M-ROVER at http://www.engin.umich.edu/dept/name/facilities/oel/mrover.html

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

2. Briefly introduce the Thunder Bay Sinkholes Expedition, highlighting the discovery of fluids emerging from sinkholes on the lake floor, and how an underwater robot will be used to explore sinkholes in deep water.

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

   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

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-illumi-

nated, 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

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

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 biol-

ogy 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-defini-

tion 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

Assessment

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

Extensions

1. Visit http://oceanexplorer.noaa.gov/explorations/08thunderbay/welcome.html to keep up to date with the latest Thunder Bay Sinkholes Expedition discoveries, and to find out what researchers are learning about these ecosystems.
2. Build your own underwater robot. See books by Harry Bohm under "Other Resources."

Multimedia Learning Objects

http://www.learningdemo.com/noaa/ Lesson 5 for interactive multimedia presentations and Learning Activities on Chemosynthesis and Hydrothermal Vent Life.

Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

Come on Down!

http://oceanexplorer.noaa.gov/explorations/deepeast01/background/education/media/come_down.pdf
(6 pages, 176k) (from the 2001 Deep East Expedition)

Focus: Ocean Exploration

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

Yo-Yos, Tow-Yos and pH, Oh My!

http://oceanexplorer.noaa.gov/explorations/02galapagos/background/education/media/gal_gr7_8_l2.pdf
(8 pages, 476k) (from the 2002 Galapagos Rift Expedition)

Focus: Galapagos Rift Expedition and Locating Hydrothermal Vents (Earth Science)
In this activity, students will learn how hydrothermal vents are formed and where they are located on the ocean floor, learn how scientists use CTDs to locate hydrothermal vents, and learn how to determine the pH of a water sample and how this variable can be used to detect hydrothermal vent activity.

Who Promised You a Rose Garden?

http://oceanexplorer.noaa.gov/explorations/02galapagos/background/education/media/gal_gr7_8_l3.pdf
(10 pages, 904k) (from the 2002 Galapagos Rift Expedition)

Focus: Biological communities associated with hydrothermal vents along the Galapagos Rift and mapping (Life Science)

Students will conduct independent research to discover what types of organisms can survive near hydrothermal vents, learn how organisms living along hydrothermal vents can survive in the absence of sunlight and photosynthesis, and use mapping skills to learn more about the Rose Garden at the Galapagos Rift.

Monsters of the Deep

http://oceanexplorer.noaa.gov/explorations/02mexico/background/edu/media/gom_monsters_gr78.pdf
(6 pages, 464k) (from the 2002 Gulf of Mexico Expedition)

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

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

One Tough Worm

http://oceanexplorer.noaa.gov/explorations/02mexico/background/edu/media/gom_toughworm.pdf
(8 pages, 476k) (from the 2002 Gulf of Mexico Expedition)

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

In this activity, students will be able to 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 will also be able to describe the problems posed by hydrogen sulfide for aerobic organisms, and explain three strategies for dealing with these problems.

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/08thunderbay/welcome.html – Follow the Thunder Bay Sinkholes 2008 Expedition daily as documentaries and discoveries are posted each day for your classroom use

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 focussing on the exploration, understanding, and protection of Earth as a whole system

http://oceanexplorer.noaa.gov/projects/thunderbay01/thunderbay01.html – Web site for the 2001 Ocean Explorer Expedition to survey "Shipwreck Alley" in Thunder Bay, Lake Huron

http://gvsu.edu/wri/envbio/biddanda/sinkhole.htm – 1 minute ROV video clip of conspicuous white benthic mats interspersed with the brownish mats characterizing the lake floor in the vicinity of the sinkhole, and a dark cloudy nepheloid-like plume layer prevailing just over the site of submarine groundwater seepage

ftp://ftp.glerl.noaa.gov/eos/El_Cajon_Boils_Short.wmv – Underwater video of El Cajon "boils"

ftp://ftp.glerl.noaa.gov/eos/Purple_Mats_40_sec.wmv – Underwater video of the purple benthic mats from the Middle Island Sinkhole

Biddanda, B. A., D. F. Coleman, T. H. Johengen, S. A. Ruberg, G. A. Meadows, H. W. VanSumeren, R. R. Rediske, and S. T. Kendall. 2006. Exploration of a submerged sinkhole ecosystem in Lake Michigan. Ecosystems 9:828-842. Available online at http://www.glerl.noaa.gov/pubs/fulltext/2006/20060020.pdf

Ruberg, S.A., D.F. Coleman, T.H. Johengen, G.A. Meadows, H.W. VanSumeren, G.A. LANG, and B.A. Biddanda. 2005. Groundwater plume mapping in a submerged sinkhole in Lake Huron. Marine Technology Society Journal 39(2):65-69. Available online at http://www.glerl.noaa.gov/pubs/fulltext/2005/20050038.pdf

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.

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

- 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

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 b. Sea level changes over time have expanded and contracted continental shelves, created and destroyed inland seas, and shaped the surface of land.

Essential Principle 5.

The ocean supports a great diversity of life and ecosystems.

Fundamental Concept b. Most life in the ocean exists as microbes. Microbes are the most important primary producers in the ocean. Not only are they the most abundant life form in the ocean, they have extremely fast growth rates and life cycles.

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 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 7.

The ocean is largely unexplored.

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 send your comments to:
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Student Handout

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