Bermuda: Search for Deep Water Caves 2009

# Call to Arms

(Adapted from the 2008 Deepwater Coral Expedition: Reefs, Rigs and Wrecks)

Image captions/credits on Page 2.

lesson plan

## Focus

Robotic analogues for human structures

## Grade Level

5-6 (Life Science /Physical Science)

## Focus Question

How can scientists build robotic arms that are capable of movements similar to the human arm?

## Learning Objectives

- Students will be able to describe the types of motion found in the human arm.
- Students will design and construct a model of a mechanical arm that mimics some or all of the motion capabilities of the human arm.
- Students will be able to describe combinations of simple machines that are used in their mechanical arm models.
- Students will be able to define mechanical advantage, and discuss the importance of mechanical advantage in robotic arm designs.
- Students will be able to describe four common robotic arm designs that mimic motion capabilities of the human arm.

## Materials

- Copies of *Robotic Arm Inquiry Worksheet,* one for each student group

Materials for students' arm models:

- Cardboard tubes
- Pencils or dowels (to serve as axles)
- Hole punch (to make holes in cardboard tubes for axles)
- Rubber bands (various sizes to make drive belts, to hold parts together, and to make "nuts" that will keep the axles in place on the cardboard tubes)
- Pieces of styrofoam
- Modeling clay
- Tape
- String
- Cardboard and/or small cardboard boxes to form bases for arm models

## Audio-Visual Materials

- ❑ None

## Teaching Time

Two or three 45-minute class periods

## Seating Arrangement

Groups of 3-4 students

## Maximum Number of Students

32

## Key Words

Anchialine cave
Bermuda
ROV
Robotic arm
Simple machines

## 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 in 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. Volcanic caves are formed when the surface of flowing volcanic lava cools and hardens, while molten lava continue to flow underneath. If the molten lava continues to flow away from the hardened surface, a hollow tube will be formed that becomes a lava tube cave.

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 locations. (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.

**Images from Page 1 top to bottom:**
Water in inland tidal cave pools in Bermuda is brackish at the surface, but reaches fully marine salinity by a depth of several meters. Image credit: NOAA, Bermuda: Search for Deep Water Caves 2009.
http://oceanexplorer.noaa.gov/explorations/09bermuda/background/bermudaorigin/media/bermudaorigin_5.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 credit: NOAA, Bermuda: Search for Deep Water 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 credit: Tom Iliffe, NOAA, Bermuda: Search for Deep Water Caves 2009.
http://oceanexplorer.noaa.gov/explorations/09bermuda/background/plan/media/spelaeoecia.html

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

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 crustacean species found in caves on opposite sides of the Atlantic Ocean and species in Australian anchialine caves that are also found Atlantic and Caribbean caves.
- Geographic distribution of some species suggests a possible connection with mid-ocean ridges. For example, shrimps belonging to the genus *Procaris* 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 they are karst landscapes, the islands of Bermuda have 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.

To help find undiscovered caves, the Bermuda: Search for Deep Water Caves 2009 expedition will use an underwater robot called a remotely operated vehicle (ROV). Underwater ROVs are linked to an operator aboard a surface ship by a group of cables. Most are equipped with one


Remotely operated vehicles (ROVs) are essentially robots that are operated by a person aboard a surface vessel. Image credit: NOAA.
http://oceanexplorer.noaa.gov/technology/subs/rov/media/rov_2guys_mc.html


Lights and video cameras equip ROVs, enabling the operator to navigate below the ocean's surface. The S2 Phantom ROV, shown above, can move horizontally, vertically, or laterally. Image credit: NOAA.
http://oceanexplorer.noaa.gov/technology/subs/rov/media/ROVunderwater.html

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. Many of the tasks performed by an ROV require a robotic arm that is capable of some of the movements of a human arm.

In this activity, students will investigate ways that these movements can be replicated with mechanical systems.

## Learning Procedure

1. To prepare for this lesson:
   (a) Review introductory essays for the Bermuda: Search for Deep Water Caves 2009 expedition at http://oceanexplorer.noaa.gov/explorations/09bermuda/welcome.html. You may also want to visit http://oceanexplorer.noaa.gov/technology/subs/rov/rov.html for images and discussions of various types of ROVs used in ocean exploration. If you want to explain multibeam sonar, you may also want to review information and images at http://oceanexplorer.noaa.gov/technology/tools/sonar/sonar.html.
   (b) Review the *Robotic Arm Inquiry Worksheet*, and prepare materials for students' arm models.
   (c) Download a few images of anchialine caves from http://www.tamug.edu/cavebiology/index2.html.

2. Briefly introduce the Bermuda: Search for Deep Water Caves 2009 expedition, emphasizing that very little is known about deep water anchialine caves. Describe the overall geology of Bermuda (a limestone cap on top of a volcanic seamount). Explain that limestone dissolves in weak acids. Because rainwater is weakly acidic due to the presence of dissolved carbon dioxide, caves are likely to be found in landscapes that contain a large amount limestone rock. Show students a few images of underwater caves, and say that scientists plan to search the vertical underwater cliffs beneath the island of Bermuda for evidence of deepwater caves. The first step in the search is to map the cliff faces with multibeam sonar, an instrument that uses sound waves to create pictures of underwater features. The next step is to use an underwater robot called a remotely operated vehicle (ROV) to explore areas where multibeam sonar surveys suggest there may be deep water caves.

   Ask students why they think scientists chose to use a ROV instead of SCUBA divers or a manned submersible vehicle.

   Brainstorm the advantages and disadvantages of these three techniques. Students should realize that manned submersibles are very expensive to operate, are too large to fit inside smaller caves, and involve significant risk to human life. SCUBA divers can only work underwater for a limited amount of time, and includes an element of risk. This should lead to the idea of using underwater robots as an alternative that reduces these problems. You may want to show some images of various ROVs at this point, from the Web site cited in Step #1. Explain to students that ROVs used for underwater exploration have a cable that attaches them to a ship at the surface. The cable carries instructions to the ROV from a pilot, as well as video and other information from the ROV to scientists. Usually the pilot and scientists are aboard the surface ship, but the newest ocean exploration ships can exchange information between an ROV and control centers thousands of miles away.

Briefly discuss the definition of robot. Most definitions involve the concepts of a mechanical device performing human or near-human tasks, and/or behaving in a human-like manner. The key ideas are that a robot has a purpose, and mimics certain human or animal functions.

Ask students to consider the task of obtaining video images in and around the entrances to deep water caves. Students should recognize the need for appropriate artificial light, as well as for pointing a video camera in various directions. Have one or two students hold a simulated video camera (such as a marker board eraser or similar-size object) and demonstrate how they would aim the camera to record various features. Students may hold the camera close to one eye and aim by turning their entire body in the desired direction, but they should also recognize that another option is to hold the camera more or less at arm's length and aim by a combination of wrist rotation and elbow movement. Tell students that their task is to design a robotic arm that could be attached to an underwater ROV to replicate the latter method of camera aiming.

3. Be sure students are familiar with the following concepts related to simple machines:

- The exact number of simple machines depends to some extent upon your perspective, but the list typically includes levers, pulleys, wheel-and-axles, inclined planes, wedges, and screws. In some ways, though, pulleys and wheel-and-axles are variations of the lever; and the wedge and screw are alternative forms of the inclined plane.

- Levers are divided into three classes, depending upon the positions of the input lever arm, the fulcrum, and the output arm (or load). In a Class I lever the fulcrum is between the input arm and the output arm (such as a crowbar). In a Class II lever, the output force is between the input force and the fulcrum (as in a wheelbarrow). In a Class III lever, the input force is between the output force and the fulcrum (as in a human arm).

- Mechanical advantage is the ratio of force output to force input. One of the big advantages of many simple machines is that they have high mechanical advantages, such as a crowbar that essentially multiplies the force applied by a human by a factor of 2, 3, or more. But in some machines the mechanical advantage is less than 1, because the machine's purpose is not to increase the input force but rather to change the direction or distance over which the force operates.

4. Provide each student group with a copy of the *Robotic Arm Inquiry Worksheet* and access to materials for constructing their model arms. Explain that they should use the human arm as a starting point for their design, and emphasize that they should brainstorm their design BEFORE beginning construction!

5. Have each student group present their robotic arm designs. These presentations should identify which simple machines were used in the design, and how the design is similar to and different from the human arm. Most arm designs will include one or more levers, wheel-and-axle combinations, and possibly pulleys. Inclined planes (in the form of screws) often appear in robotic grippers and some arm mechanisms, but are probably overly complex for this activity.

   Students should recognize that the human arm is a very complex mechanism, including seven bones, seven joints, and 21 muscles, not including the wrist. With this many moving parts, many different motions are possible, but for the purposes of this activity, the shoulder and elbow can be considered to have three basic motions: extension, flexion, and rotation. The wrist also has three motions (pitch, roll, and yaw) but these motions are not needed for the video camera aiming task. Depending upon their approach, student arm designs may be able to accomplish the assigned task with only one or two flexion/extension motions, and possibly one rotation.

   Robotic arms use two types of joints. A revolute or rotary joint is capable of rotation but not extension. A simple hinge joint is an example, as is a lazy susan. A prismatic joint is capable of a sliding motion, but not rotation. A drawer slide is a type of prismatic joint.

   Robotic arms are often divided into four types depending upon the shape of the space that the arm can reach. This space is called the work envelope. For the human arm, the work envelope is about three-fourths of the inside of a sphere whose diameter is equal to the length of the arm when fully extended. A robotic arm with the same work envelope is said to have a revolute or articulated configuration. Revolute robotic arms have a shoulder and an elbow. The shoulder is mounted on a rotating base (like a lazy susan) that allows the arm to rotate, and has a hinge joint that allows the upper arm to move up and down. The elbow of a revolute robotic arm also has a hinge joint that allows the forearm to move up and down.

Robotic arms with a polar configuration also have a rotating base, but do not have a joint that allows the upper arm to move up or down. There is a hinge joint at the elbow which allows the forearm to move up and down, and also a sliding (prismatic) joint that allows the forearm to move in and out. The polar configuration creates a work envelope that is half of the inside of a sphere.

The third type of robotic arm is the cylindrical configuration. These arms have a rotating base, and two prismatic joints that give the arm up/down and in/out movements; sort of like a forklift on a lazy susan. The work envelope of these arms is (you guessed it!) shaped like the inside of a cylinder.

The Cartesian configuration is the fourth type of robotic arm, and consists of three prismatic joints arranged at right angles to each other so that the arm can slide in x, y, and z directions. The work envelope of the Cartesian configuration is a rectangle that extends to one side of the arm assembly.

Students should realize that while most robotic arms do not have the variety of movements found in the human arm, their joints can move through greater angles. The human elbow, for example, has a bending range of less than 180 degrees, but a robotic arm elbow with a simple hinge joint can move through nearly 360 degrees.

You may want to discuss other options for activating robotic arms besides electric motors. Pneumatic and hydraulic cylinders offer more power than is usually possible with electric motors, but they are more complex and expensive. An alternative form of pneumatic power is "air muscle" which consists of a flexible rubber tube surrounded by a plastic mesh. When air is forced into the tube, its width expands causing the length of the mesh to contract. Because this length contraction is similar to human muscles, air muscles have considerable potential for mimicking human motion.

Another unusual alternative way to activate robotic limbs are shape memory alloys (SMAs), which are metals that contract and relax when exposed to heat. In robotics, the heat is usually applied by passing an electrical current through the alloy. SMAs are available for experimenters under a variety of names such as Muscle Wire, BioMetal, and Dynalloy. Electroactive polymers are similar to SMAs in that they change shape when exposed to electric fields, but are made from organic molecules rather than metal alloys.

## The BRIDGE Connection

www.vims.edu/bridge/ – In the Site Navigation menu on the left, scroll over 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 or societal benefit.

## Connections to Other Subjects

English/Language Arts, Mathematics, Earth Science

## Assessment

Written reports and class discussions provide opportunities for assessment.

## Extensions

1. Visit http://oceanexplorer.noaa.gov/explorations/09bermuda/welcome.html for more about the Bermuda: Search for Deep Water Caves 2009 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/explorations/05lostcity/background/edu/media/lostcity05_i_robot.pdf).

## Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

*(The following Lesson Plans are targeted toward grades 5-6 unless otherwise noted)*

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

Focus: Deep-sea habitats (Life Science)

In this activity, students will be able to 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 will also be able to describe the process of chemosynthesis in general terms, contrast chemosynthesis and photosynthesis, and describe major deep-sea habitats and list at least three organisms typical of each habitat.

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

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

In this activity, students will be able to 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 (9 pages, 293k) (from AUVfest 2008)**
http://oceanexplorer.noaa.gov/explorations/08auvfest/background/edu/media/shipline.pdf

Focus: Marine Archaeology (Maritime History/Physical Science/Social Science)

In this activity, students will be able to 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/09bermuda/welcome.html – Web site for the for the Bermuda: Search for Deep Water 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.

## 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 E: Science and Technology**
- Abilities of technological design
- Understandings about science and technology

**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 1.**
**The Earth has one big ocean with many features.**
*Fundamental Concept g.* The ocean is connected to major lakes, watersheds and waterways because all major watersheds on Earth drain to the ocean. Rivers and streams transport nutrients, salts, sediments and pollutants from watersheds to estuaries and to the ocean.

**Essential Principle 2.**
**The ocean and life in the ocean shape the features of the Earth.**
*Fundamental Concept a.* Many earth materials and geochemical cycles originate in the ocean. Many of the sedimentary rocks now exposed on land were formed in the ocean. Ocean life laid down the vast volume of siliceous and carbonate rocks.

*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 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.

**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 send your comments to:
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## For More Information

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## Call to Arms

# Robotic Arm Inquiry Guide

Your task is to design a robotic arm that could be attached to an underwater ROV to aim a video camera, using the human arm as model for a starting point. Assume that your robotic arm will need to be able to reach out at least one foot. For this project, assume that your arm will be powered with strong electric motors, and that you can use as many motors as necessary.

**HINT: Be sure to brainstorm your arm design BEFORE beginning construction!**

Here are some ways to get started:

1. Think about the motions of your own arm:
   - List and describe how many ways your shoulder can move.
   - List and describe how many ways your elbow can move.
   - Which motions are necessary for your robotic arm? Describe them.
2. How important is mechanical advantage for a robotic arm that can perform the assigned tasks? Is it more important to multiply force, or is range of motion more important? Explain.

## Call to Arms
# Robotic Arm Inquiry Guide

3. How can simple machines be arranged to have the required motions? Remember that the human arm offers one design for accomplishing these motions, but there may also be other designs that could work as well. Think about touching your shoulder with your hand, then stretching your hand straight out. Your arm can accomplish this motion with hinge joints, but are there other options for robots? (Hint: Think about a drawer.)

Use the space below to sketch your ideas.