Lessons from the Deep:

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

Image captions/credits on Page 2.

lesson plan

Call to Arms

(adapted from the *Lophelia* II 2008: Deepwater Coral Expedition)

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 to three 45-minute class periods

Seating Arrangement

Groups of 3-4 students

Maximum Number of Students

32

Key Words

Gulf of Mexico
Deepwater coral
ROV
Robotic arm
Simple machines

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.

Many of the tasks undertaken by ROVs during efforts to control the Deepwater Horizon blowout required a robotic arm capable of replicating many of the movements of a human arm. In this activity, students will investigate ways that these movements can be replicated with mechanical systems.

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

Okeanos Explorer crew launch the vehicle during test dives off Hawaii. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/rov/media/launch.html

Learning Procedure

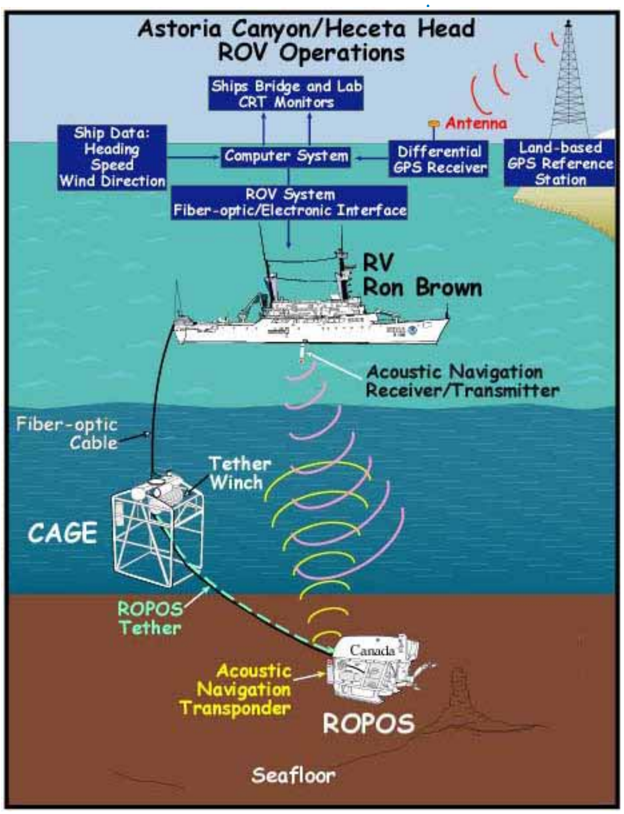
1.To prepare for this lesson:

(a) Review the following essay:
Little Hercules ROV (http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/rov/rov.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 and http://oceanexplorer.noaa.gov/gallery/technology/technology_collection3.html#ROV's for more images of ROVs.

(b) Review the *Robotic Arm Inquiry Worksheet*, and prepare materials for students' arm models.

2. Ask students how many of them have seen images of oil escaping from the Deepwater Horizon wellhead. Then ask, where did these images come from? At least some students should recognize that these images were obtained with underwater robots. Ask students why they think responders chose to use ROVs instead of SCUBA divers or manned submersible vehicles. Brainstorm the advantages and disadvantages of these three techniques. Students should realize that manned submersibles are very expensive to operate, are too large to maneuver easily in tight spaces, and involve significant risk to human life. SCUBA divers can only work underwater for a limited amount of time, and cannot descend to the depth of the Deepwater Horizon wellhead (about 5,000 feet below the surface).



Schematic image of ROV deployment and support equipment. (Drawing is not to scale.). Image courtesy of Lewis and Clark 2001, NOAA/OER.
http://oceanexplorer.noaa.gov/explorations/lewis_clark01/background/plan/media/shipandropos.html

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 typically 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. Usually the pilot is 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.

Hela, an ROV carrying a High Definition TV camera sits on the stern of the RV *Connecticut*.
http://oceanexplorer.noaa.gov/explorations/03portland/logs/sept15/media/helaisis.html

Tell students that one of the first things responders tried to do after the Deepwater Horizon blowout was to use ROVs to activate a switch on the blowout preventer at the wellhead. Ask students to consider what capabilities an ROV would need to perform this task. Students should recognize the need for appropriate artificial light and video cameras, as well as a manipulator arm capable of grasping and moving the switch. Tell students that their task is to design a robotic arm that could be attached to an underwater ROV capable of wrist rotation and elbow movements similar to those of the human arm.

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.

The robotic arm for the ROV Tiburon has to be both powerful and dextrous to collect many different sample types. Image courtesy of Davidson Seamount Exploration 2002, NOAA/OER. http://oceanexplorer.noaa.gov/explorations/02davidson/logs/may20/media/fig1.html

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 ROV crew designed and tested a new claw design, with a scissor-like edge and a flexible grip. Image courtesy M. Grady.
http://oceanexplorer.noaa.gov/explorations/04mountains/logs/may14/media/newclaw.html

A makeshift assemblage of milk crates and carrots simulates a seabed for testing the new claw. Image courtesy M. Grady.
http://oceanexplorer.noaa.gov/explorations/04mountains/logs/may14/media/clawtest.html

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.

NOTE: ROVs were capable of manipulating switches on the blowout preventer at the Deepwater Horizon wellhead, but these switches failed to cause the blowout preventer to stop the flow of oil.

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 and oral reports provide opportunities for evaluation.

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.

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).

Multimedia Discovery Missions

http://www.learningdemo.com/noaa/ Click on the links to Lessons 3, 5, and 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

Let's Make a Tubeworm! (15 pages, 1946 KB)

http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/edu/media/tubeworm.pdf

Focus - Symbiotic relationships in cold seep communities (Life Science)

Students describe the process of chemosynthesis in general terms, contrast chemosynthesis and photosynthesis, describe major features of cold seep communities, and list at least five organisms typical of these communities. They will be able to define symbiosis, describe two examples of symbiosis in cold seep communities, describe the anatomy of vestimentiferans, and explain how these organisms obtain their food.

Animals of the Fire Ice (5 pages, 364 KB)

http://oceanexplorer.noaa.gov/okeanos/edu/lessonplans/media/09animalsoffireice.pdf

Focus - Methane hydrate ice worms and hydrate shrimp (Life Science)

Students define and describe methane hydrate ice worms and hydrate shrimp, infer how methane hydrate ice worms and *hydrate shrimp obtain their food, and infer how methane hydrate ice worms and hydrate shrimp may interact with other species in the biological communities of which they are part.*

The Robot Ranger (14 pages, 1.1 MB)

http://oceanexplorer.noaa.gov/explorations/09lophelia/background/edu/media/09ranger.pdf

Focus - Robotic Analogues for Human Structures (Vision, Distance Estimation) (Life Science/Physical Science)

Students describe how humans are able to estimate the distance to visible objects, and describe a robotic system with a similar capability.

Big Enough? (15 pages, 964 KB)

http://oceanexplorer.noaa.gov/explorations/09lophelia/background/edu/media/09bigenough.pdf

Focus - Buoyancy (Physical Science)

Students define buoyancy, mass, volume, and density, and explain the relationships between these properties. Given the mass and volume of an object, students calculate the minimum buoyancy required to keep the object afloat in seawater. Students also explain why objects in seawater are more buoyant than the same objects in fresh water.

Cool Lights (7 pages, 220 KB)

http://oceanexplorer.noaa.gov/explorations/04deepscope/background/edu/media/coollights.pdf

Focus - Light-producing processes and organisms in deep-sea environments (Life Science/Physical Science)

Students compare and contrast chemiluminescence, bioluminescence, fluorescence, and phosphorescence. Given observations on materials that emit light under certain conditions, students infer whether the light-producing process is chemiluminescence, fluorescence, or phosphorescence. Students explain three ways in which the ability to produce light may be useful to deep-sea organisms and explain how scientists may be able to use light-producing processes in deep-sea organisms to obtain new observations of these organisms.

Now You See Me, Now You Don't (5 pages, 281 KB)

http://oceanexplorer.noaa.gov/explorations/05deepscope/background/edu/media/now_u_see_me.pdf

Focus - Light, color, and camouflage in the deep ocean (Life Science)

Students explain light in terms of electromagnetic waves, and explain the relationship between color and wavelength; compare and contrast color related to wavelength with color perceived by biological vision systems; and explain how color *and light may be important to deepsea organisms, even under conditions of near-total darkness. Students also predict the perceived color of objects when illuminated by light of certain wavelengths.*

Microfriends (6 pages, 420 KB)
http://oceanexplorer.noaa.gov/okeanos/edu/lessonplans/media/09microfriends.pdf
Focus - Beneficial microorganisms (Life Science)
Students describe at least three ways in which microorganisms benefit people, describe aseptic procedures, and obtain and culture a bacterial sample on a nutrient medium.

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

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

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

http://www.noaa.gov/sciencemissions/bpoilspill.html – Web page with links to NOAA Science Missions & Data relevant to the Deepwater Horizon/BP Oil Spill

http://ecowatch.ncddc.noaa.gov/jag/data.html – Data Links page on the Deepwater Horizon Oil Spill Joint Analysis Group Web site

http://ecowatch.ncddc.noaa.gov/jag/reports.html – Reports page on the Deepwater Horizon Oil Spill Joint Analysis Group Web site

http://www.education.noaa.gov/Ocean_and_Coasts/Oil_Spill.html - "Gulf Oil Spill" Web page from NOAA Office of Education with links to multimedia resources, lessons & activities, data, and background information

http://www.geoplatform.gov/gulfresponse/ - Web page for GeoPlatform.gov/gulfresponse—an online map-based tool developed by NOAA with the EPA, U.S. Coast Guard, and the Department of Interior to provide a "one-stop shop" for spill response information; includes oil spill trajectory, fishery area closures, wildlife data, locations of oiled shoreline and positions of deployed research ships

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

Sulak, K. J., M. T. Randall, K. E. Luke, A. D. Norem, and J. M. Miller (Eds.). 2008. Characterization of Northern Gulf of Mexico Deepwater Hard Bottom Communities with Emphasis on *Lophelia* Coral - *Lophelia* Reef Megafaunal Community Structure, Biotopes, Genetics, Microbial Ecology, and Geology. USGS Open-File Report 2008-1148; http://fl.biology.usgs.gov/coastaleco/OFR_2008-1148_MMS_2008-015/index.html

National Science Education Standards

Content Standard A: Science As Inquiry

- Abilities necessary to do scientific inquiry
- Understanding 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 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

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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 a 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 robotic 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.

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.