



Deepwater Coral Expedition: Reefs, Rigs and Wrecks

Call to Arms!

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 three to four students

MAXIMUM NUMBER OF STUDENTS

32

KEY WORDS

Gulf of Mexico
Deepwater coral
ROV
Robotic arm
Simple machines

BACKGROUND INFORMATION

In recent years, rising costs of energy and a growing desire to reduce the United States' dependence upon foreign petroleum fuels have led to intensified efforts to find more crude oil and drill more wells in the Gulf of Mexico. This region produces more petroleum than any other area of the United States, even though its proven reserves are less than those in Alaska and Texas. Managing exploration and development of mineral resources on the nation's outer continental shelf is the responsibility of the U.S. Department of the Interior's Minerals Management Service (MMS). Besides managing the revenues from mineral resources, an integral part of the Deepwater Coral Expedition: Reefs, Rigs, and Wrecks mission is to protect unique and sensitive environments where these resources are found.

To locate new sources of hydrocarbon fuels, MMS has conducted a series of seismic surveys to map areas between the edge of the continental shelf and the deepest portions of the Gulf of Mexico. These maps provide information about the depth of the water as well as the type of material that is found on the seafloor. Hard surfaces are often found where hydrocarbons are present. Carbonate rocks (such as limestone), in particular, are a part of nearly every site where fluids and gases containing hydrocarbons have been located. This is because when microorganisms consume hydrocarbons under anaerobic conditions, they produce bicarbonate which reacts with calcium and magnesium ions in the water and precipitates as carbonate rock. This rock, in turn, provides a substrate where the larvae of many other deep sea bottom-dwelling organisms may attach, particularly corals. In addition to carbonate rocks associated with hydrocarbon seeps, deepwater corals in the Gulf of Mexico are also found on anthropogenic (human-made) structures, particularly ship wrecks and oil platforms.

Deepwater coral reefs were discovered in the Gulf of Mexico nearly 50 years ago, but very

little is known about the ecology of these communities or the basic biology of the corals that produce them. Recent studies suggest that deepwater reef ecosystems may have a diversity of species comparable to that of coral reefs in shallow waters, and have found deepwater coral species on continental margins worldwide. One of the most conspicuous differences between shallow- and deepwater corals is that most shallow-water species have symbiotic algae (zooxanthellae) living inside the coral tissue, and these algae play an important part in reef-building and biological productivity. Deepwater corals do not contain symbiotic algae (so these corals are termed "azooxanthellate"). Yet, there are just as many species of deepwater corals (slightly more, in fact) as there are species of shallow-water corals. Deepwater reefs provide habitats for a variety of plant, animal, and microbial species, some of which have not been found anywhere else. Branching corals and other sessile (non-motile) benthic (bottom-dwelling) species with complex shapes provide essential habitat for other organisms including commercially- important fishes such as longfin hake, wreckfish, blackbelly rosefish, and grenadiers. In addition, recent research has shown that less obvious, obscure benthic species may contain powerful drugs that directly benefit humans.

The long-term goal of the Deepwater Coral Expedition: Reefs, Rigs, and Wrecks is to develop the ability to recognize areas where deepwater corals are "likely to occur" in the Gulf of Mexico. Achieving this goal involves three objectives:

- Discover and describe new locations in the deep (greater than 300m depth) Gulf of Mexico where there are extensive coral communities;
- Gain a better understanding of the processes that control the occurrence and distribution of deepwater coral communities in the Gulf of Mexico; and
- Study the relationships between coral communities on artificial and natural substrates with respect to species composition and function, genetics, and growth rates of key species.

Activities to meet these objectives are expected to extend over a four-year period. During 2008, major activities will include:

- Preliminary site surveys of areas that have been identified as possible locations of new hard-bottom communities;
- Preliminary survey and imaging of two to three wrecks, and if appropriate, installing deterioration platforms (small thin bars of various metals used to measure and monitor corrosion);
- Collecting deterioration platforms previously deployed on the *Gulfpenn* wreck and installation of new platforms;
- Quantitative digital imaging of *L. pertusa* colonies on the *Gulfpenn* and very limited collection of *L. pertusa* samples for genetic analyses;
- Collection of imagery for transect analyses, construction of mosaics, and faunal inventory as time and ROV abilities allow; and
- Survey of areas in the vicinity of oil rigs that may have been impacted by anchor chains, including limited collections of live *L. pertusa* for laboratory studies and other fauna for identification and preliminary genetic work.

All of these activities depend upon a Remotely Operated Vehicle (ROV), which is an underwater robot that allows scientists to visit and work in deep-ocean sites without the expense and risk involved in using a manned submersible. To collect samples of live corals and other organisms, the ROV needs to have a robotic arm that is capable of many 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, review introductory essays for the Deepwater Coral Expedition: Reefs, Rigs, and Wrecks at <http://oceanexplorer.noaa.gov/explorations/08lophelia/welcome.html>.

You may also want to visit

- http://www.bio.psu.edu/cold_seeps for a virtual tour of a cold seep community in the Gulf of Mexico;
- http://oceanexplorer.noaa.gov/gallery/livingocean/livingocean_coral.html for images of deep-sea corals and their communities; and
- <http://oceanexplorer.noaa.gov/technology/subs/rov/rov.html> for images and discussions of various types of ROVs used in ocean exploration.

Review the "Robotic Arm Inquiry Worksheet," and prepare materials for students' arm models.

2. Briefly introduce the mission Deepwater Coral Expedition: Reefs, Rigs, and Wrecks, emphasizing that very little is known about deep-water coral communities, but these communities may be important to humans in a variety of ways, including their potential as sources for new drugs to treat human diseases (for more information on this point, see the 2003 Ocean Explorer Deep Sea Medicines expedition, <http://oceanexplorer.noaa.gov/explorations/03bio/welcome.html>).

List some of the activities planned for the 2008 portion of the Deepwater Coral Expedition: surveys of deep-ocean hard-bottom communities; survey and imaging of shipwrecks; collecting live corals and other fauna, and ask students how they think scientists will accomplish these tasks. If students suggest manned submersibles, brainstorm advantages and disadvantages, and ask if there are alternatives that reduce problems such as cost and risk to human life. This should lead to the idea of using underwater robots. You may want to show some images of various ROVs at this point, from the Web site cited in Step #1. Tell 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 collecting specimens of branching corals. To make the task more familiar, tell students to imagine this task is similar to collecting a small, woody bush with very strong roots. It may be hard to apply enough force to simply pull the bush out of the ground, and the bush might be damaged with this procedure. So, we need to cut the bush close to the ground with some kind of tool. We also need to be able to hold onto the bush once it's cut. If we want to collect more than one bush, we need to put the cut specimen into some kind of container so that we can free our hands and tools to collect other bushes.

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.
3. Tell students that their task is to design a robotic arm that could be attached to an underwater ROV to collect deep-sea corals, using the human arm as a starting point. Provide each student group with a copy of the "Robotic Arm Inquiry Worksheet" and access to materials for constructing their model arms. Remind students to brainstorm their design BEFORE beginning construction!
 4. 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 coral collection task. Depending upon their approach, student arm designs may be able to accomplish the assigned tasks 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 rotary (hinge) joint that allows the "upper arm" to move up and down. The elbow of a revolute robotic arm also has a rotary 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" (SMA), 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. SMA are available for experimenters under a variety of names such as "Muscle Wire," "BioMetal," and "Dynalloy."

Electroactive polymers are similar to SMA 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, 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, Mathematics

ASSESSMENT

Written reports and class discussions provide opportunities for assessment.

EXTENSIONS

1. Have students visit <http://oceanexplorer.noaa.gov/explorations/08lophelia/welcome.html> to find out more about the Deepwater Coral Expedition: Reefs, Rigs, and Wrecks and to learn about opportunities for real-time interaction with scientists on the current 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)

MULTIMEDIA LEARNING OBJECTS

<http://www.learningdemo.com/noaa/> Click on the links to Lessons 3, 5, 6, 11, and 12 for interactive multimedia presentations and Learning Activities on Deep-Sea Corals, Chemosynthesis

and Hydrothermal Vent Life, Deep-Sea Benthos, Energy from the Oceans, and Food, Water, and Medicine from the Sea.

OTHER RELEVANT LESSON PLANS FROM NOAA’S OCEAN EXPLORATION PROGRAM

Ship of the Line

(9 pages, 293k) (from AUVfest 2008)

<http://oceanexplorer.noaa.gov/explorations/08auvfest/background/edu/media/shipline.pdf>

Focus: 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.

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.

Animals of the Fire Ice

(5 pages, 364k) (from the Expedition to the Deep Slope 2007)

<http://oceanexplorer.noaa.gov/explorations/07mexico/background/edu/media/animals.pdf>

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

In this activity, students will be able to 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.

A Piece of Cake

(7 pages; 282kb PDF) (from the Cayman Islands Twilight Zone 2007 Expedition)

<http://oceanexplorer.noaa.gov/explorations/07twilightzone/background/edu/media/cake.pdf>

Focus: Spatial heterogeneity in deepwater coral communities (Life Science)

In this activity, students will be able to explain what a habitat is, describe at least three functions or benefits that habitats provide, and describe some habitats that are typical of deepwater hard bottom communities. Students will also be able to explain how organisms, such as deepwater corals and sponges, add to the variety of habitats in areas such as the Charleston Bump.

Forests of the Deep

(4 pages, 232k) (from the 2004 Gulf of Alaska Seamount Expedition)

<http://oceanexplorer.noaa.gov/explorations/04alaska/background/edu/media/GOA04.Forests.pdf>

Focus: Deep-sea coral communities associated with seamounts (Life Science)

In this activity, students will be able to explain at least three ways in which seamounts are important to biological communities, infer at least three ways in which deep-sea corals are important to seamount ecosystems, and explain why many scientists are concerned about the future of seamount ecosystems.

Deep Gardens

(11 pages; 331kb PDF) (from the Cayman Islands Twilight Zone 2007 Expedition)

<http://oceanexplorer.noaa.gov/explorations/07twilightzone/background/edu/media/deepgardens.pdf>

Focus: Comparison of deep-sea and shallow-water tropical coral communities (Life Science)

In this activity, students will compare and contrast deep-sea coral communities with their shallow-water counterparts, describe three types of coral associated with deep-sea coral communities, and explain three benefits associated with deep-sea coral communities. Students will explain why many scientists are concerned about the future of deep-sea coral communities.

Let's Make a Tubeworm!

(6 pages, 464k) (from the 2002 Gulf of Mexico Expedition)

http://oceanexplorer.noaa.gov/explorations/02mexico/background/edu/media/gom_tube_gr56.pdf

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

In this activity, students will be able to 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. Students will also 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.

Looking for Clues

(8 pages, 556k) (from the RMS *Titanic* Expedition 2004)

<http://oceanexplorer.noaa.gov/explorations/04titanic/edu/media/Titanic04.Clues.pdf>

Focus: Marine archaeology of the *Titanic* (Physical Science)

In this activity, students will be able to draw inferences about a shipwreck given information on the location and characteristics of artifacts from the wreck, and will list three processes that contribute to the *Titanic's* deterioration.

Journey to the Unknown & Why Do We Explore

(10 pages, 596k) (from the 2002 Galapagos Rift Expedition)

http://oceanexplorer.noaa.gov/explorations/02galapagos/background/education/media/gal_gr5_6_11.pdf

Focus: Ocean Exploration

In this activity, students will experience the excitement of discovery and problem-solving to learn about organisms that live in extreme environments in the deep ocean and come to understand the importance of ocean exploration.

Chemists with No Backbones

(4 pages, 356k) (from the 2003 Deep Sea Medicines Expedition)

http://oceanexplorer.noaa.gov/explorations/03bio/background/edu/media/Meds_ChemNoBackbones.pdf

Focus: Benthic invertebrates that produce pharmacologically-active substances (Life Science)

In this activity, students will be able to identify at least three groups of benthic invertebrates that are known to produce pharmacologically-active compounds and will describe why pharmacologically-active compounds derived from benthic invertebrates may be important in treating human diseases. Students will also be able to infer why sessile marine invertebrates appear to be promising sources of new drugs.

Keep Away

(9 pages, 276k) (from the 2006 Expedition to the Deep Slope)

<http://oceanexplorer.noaa.gov/explorations/06mexico/background/edu/GOM%2006%20KeepAway.pdf>

Focus: Effects of pollution on diversity in benthic communities (Life Science)

In this activity, students will discuss the meaning of biological diversity and compare and contrast the concepts of variety and relative abundance as they relate to biological diversity. Given information on the number of individuals, number of species, and biological diversity at a series of sites, students will make inferences about the possible effects of oil drilling operations on benthic communities.

What's In That Cake?

(9 pages, 276k) (from the 2006 Expedition to the Deep Slope)

<http://oceanexplorer.noaa.gov/explorations/06mexico/background/edu/GOM%2006%20Cake.pdf>

Focus: Exploration of deep-sea habitats

In this activity, students will be able to explain what a habitat is, describe at least three functions or benefits that habitats provide, and describe some habitats that are typical of the Gulf of Mexico. Students will also be able to describe and discuss at least three difficulties involved in studying deep-sea habitats and describe and explain at least three techniques scientists use to sample habitats, such as those found on the Gulf of Mexico.

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://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://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.

<http://home.comcast.net/~homebuiltrovs/links.html> – Web site by Steve Thone, with lots of instructions and details about homebuilt ROVs

http://www.gomr.mms.gov/index_common.html – Minerals Management Service Web site

<http://www.gomr.mms.gov/homepg/lagniapp/chemcomp.pdf> – “Chemosynthetic Communities in the Gulf of Mexico” teaching guide to accompany a poster with the same title, introducing the topic of chemosynthetic communities and other ecological concepts to middle and high school students.

<http://www.gomr.mms.gov/homepg/lagniapp/lagniapp.html> – Kids Page on the Minerals Management Service Web site, with posters, teaching guides and other resources on various marine science topics

<http://www.coast-nopp.org/> – Resource Guide from the Consortium for Oceanographic Activities

for Students and Teachers, containing modules, guides, and lesson plans covering topics related to oceanography and coastal processes

<http://cosee-central-gom.org/> – Web site for The Center for Ocean Sciences Education Excellence: Central Gulf of Mexico (COSEE-CGOM)

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.

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

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 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 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.

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 e. Humans affect the ocean in a variety of ways. Laws, regulations and resource management affect what is taken out and put into the ocean. Human development and activity leads to pollution (such as point source, non-point source, and noise pollution) and physical modifications (such as changes to beaches, shores and rivers). In addition, humans have removed most of the large vertebrates from the ocean.

Fundamental Concept g. Everyone is responsible for caring for the ocean. The ocean sustains life on Earth and humans must live in ways that sustain the 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 c. Over the last 40 years, use of ocean resources has increased significantly, therefore the future sustainability of ocean resources depends on our understanding of those resources and their potential and limitations.

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, sub-sea 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:

oceaneducation@noaa.gov

FOR MORE INFORMATION

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Student Handout

Robotic Arm Inquiry Worksheet

Your task is to design a robotic arm that could be attached to an underwater ROV to collect deep-sea corals, using the human arm as a starting point. Assume that your ROV can get one foot away from the corals, so your arm will need to be able to reach out at least one foot, and will need to be able to return the collected coral to a basket somewhere on the ROV. Don't worry about grippers or cutters that would be attached to the end of your arm – that's another design project! Right now, we are only concerned with designing an arm that can reach out from the ROV and bring an object back to the basket. 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:
 - How many ways can your shoulder move?
 - How many ways can your elbow move?
 - Which motions are necessary for your robotic arm?
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?
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.)