



## Invent a Robot!

### Focus

Engineering design

### Grade Level

6-8 (Physical Science/Technology)

### Focus Question

How can scientists design and build robotic arms that are capable of specific movements?

### Learning Objectives

- Students will explain how underwater robots are used in scientific exploration to gather data and help answer questions about the natural world.
- Students will design and optimize potential solutions for an ocean exploration problem.

### Materials

*For each student group:*

- Copy of *Student Worksheet*
- Five pieces of cardboard or heavy poster board, each approximately 12" x 12" (the stiffer the better)
- Duct tape, approximately 2" x 80'
- 10 - Machine screws with nuts, #8 x 1"
- 4 - Machine screws with nuts, #8 x 3"
- 21 - Flat washers, #8 hole
- 4 - Oral syringes
- Two pieces of plastic tubing, approximately 3/16" inside diameter; each approximately 12" long (should fit snugly over the end of the syringes)
- Water
- Small container, such as a 9-oz drinking cup

*Tools (may be shared by several student groups)*

- Heavy scissors to cut cardboard ("bandage scissors" are inexpensive and work well)
- Nail or Phillips screwdriver to punch holes in cardboard
- Screwdriver to fit the slot size and shape of the machine screws

Close up of the remotely operated vehicle (ROV) *Deep Discoverer*. Image courtesy of NOAA OER, Gulf of Mexico 2014 Expedition.

<http://oceanexplorer.noaa.gov/oceanos/explorations/ex1402/logs/apr15/media/drfront.html>

Another day at the office for the ROV pilot. Image courtesy of the NOAA OER 2017 Laulima O Ka Moana.  
<http://oceanexplorer.noaa.gov/oceanos/explorations/ex1706/logs/july15/welcome.html>



Electrical engineers picking up on some of the finer points of fiber optic measurements. Image courtesy of the NOAA OER 2017 Laulima O Ka Moana.  
<http://oceanexplorer.noaa.gov/oceanos/explorations/ex1706/logs/july15/media/fiber-optics.html>

### **Audiovisual Materials**

- Video projector or large screen monitor for showing downloaded images (see Learning Procedure, Step 1d)

### **Teaching Time**

Two or three 45-minute class periods, plus time for students to construct their robotic arm

### **Seating Arrangement**

Groups of two to four students

### **Maximum Number of Students**

30

### **Key Words and Concepts**

Ocean Exploration  
*Okeanos Explorer*  
Robot  
Remotely operated vehicle  
Engineering design

### **Background Information**

The site characterization component of NOAA Ship *Okeanos Explorer's* exploration strategy depends heavily upon remotely operated vehicles (ROVs). These are unoccupied robots usually linked to a surface ship by a group of cables. 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, equipment for collecting samples, and measuring instruments to expand the vehicle's capabilities for gathering data about the deep-ocean environment. For additional information about ROVs, please see the *Introduction to Remotely Operated Vehicles and Autonomous Underwater Vehicles* <http://oceanexplorer.noaa.gov/oceanos/edu/collection/media/hdwe-URintro.pdf>. For additional information about the exploration strategy, please see the *Introduction to Ships and Exploration Strategy* <http://oceanexplorer.noaa.gov/oceanos/edu/collection/media/hdwe-StrategyBkgnd.pdf>.

This lesson introduces students to the process used to design remotely operated vehicles.

### Learning Procedure

1. To prepare for this lesson:

a) Review:

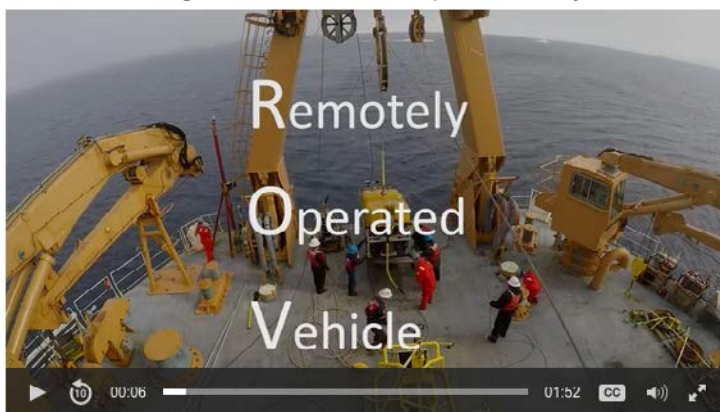
- Introductory essay about ROV *Deep Discoverer* <http://oceanexplorer.noaa.gov/technology/subs/deep-discoverer/deep-discoverer.html>;
- Daily log entries and video from the 2016 Deepwater Exploration of the Marianas Expedition <http://oceanexplorer.noaa.gov/oceanos/explorations/ex1605/dailyupdates/dailyupdates.html>

You may want to assign one or more of these as background reading prior to beginning the rest of the lesson.

b) Review background information about ocean exploration strategy and technologies.

c) Review the *Student Worksheet*. Two options are provided: Option A leaves the design and construction entirely to the students, while Option B provides step-by-step instructions for assembling a working model that meets the design requirement. Decide which approach is most appropriate for your students and learning objectives, and delete the option that will not be used. Copy the *Student Worksheet*, one copy for each student group.

d) Download images referenced in Step 2. You may also want



Onboard science leads discuss and take a closer look at deepwater habitats explored with remotely operated vehicle *Deep Discoverer* on Horizon Guyot. Image courtesy of the NOAA Office of Ocean Exploration and Research, 2017 Laulima O Ka Moana. <http://oceanexplorer.noaa.gov/oceanos/explorations/ex1706/dailyupdates/media/july13-1.html>

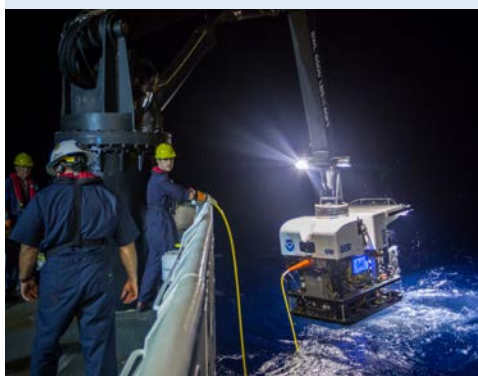
Learn more about the ROV's role in Arctic research in this video from The Hidden Ocean 2016: Chukchi Borderlands expedition. Video courtesy of Caitlin Bailey, GFOE, The Hidden Ocean 2016: Chukchi Borderlands, Oceaneering-DSSI. [http://oceanexplorer.noaa.gov/explorations/16arctic/logs/video/interview/interview\\_video.html](http://oceanexplorer.noaa.gov/explorations/16arctic/logs/video/interview/interview_video.html)

## Exploring the Deep Ocean with NOAA



Water samples are collected from the Niskin bottles on the CTD. All 20 Niskin bottles take water samples from various depths, starting near the seafloor and ending close to the surface. Photo courtesy of Caitlin Bailey, GFOE, *The Hidden Ocean 2016: Chukchi Borderlands*.

<http://oceanexplorer.noaa.gov/explorations/16arctic/logs/july24/media/shipton.html>



Remotely operated vehicle *Deep Discoverer* being recovered after a dive. Image courtesy of NOAA Office of Ocean Exploration and Research, 2016 Deepwater Exploration of the Marianas.

<http://oceanexplorer.noaa.gov/okeanos/explorations/ex1605/logs/may1/media/1605rovrecovery.html>



A Video Engineer adjusts the zoom, focus, and lighting on remotely operated vehicle *Deep Discoverer's* main HD camera to obtain the best shot of a tiny jellyfish. Image courtesy of the NOAA OER, 2017 *Laulima O Ka Moana*.

<http://oceanexplorer.noaa.gov/okeanos/explorations/ex1706/dailyupdates/media/july27-2.html>



The NOAA Ship *Okeanos Explorer*, America's ship for ocean exploration. Image courtesy NOAA. <http://oceanexplorer.noaa.gov/okeanos/explorations/ex1702/logs/mar1/media/okeanos.html>

to download examples of imagery from underwater robots: [http://oceanexplorer.noaa.gov/okeanos/media/slideshow/flash\\_slideshow.html](http://oceanexplorer.noaa.gov/okeanos/media/slideshow/flash_slideshow.html) and [http://oceanexplorer.noaa.gov/okeanos/media/slideshow/video\\_playlist.html](http://oceanexplorer.noaa.gov/okeanos/media/slideshow/video_playlist.html)); and the following video about ROV design: <http://oceanexplorer.noaa.gov/okeanos/explorations/ex1302/edu.html>

2. Briefly introduce the ships of exploration NOAA Ship *Okeanos Explorer*, E/V *Nautilus*, and R/V *Falkor*; the *Introduction to Ships of Exploration and Their Strategy for Ocean Exploration* <http://oceanexplorer.noaa.gov/okeanos/edu/collection/media/hdwe-StrategyBkgnd.pdf>, and the 2017 *Discovering the Deep: Exploring Remote Pacific MPAs Expedition* <http://oceanexplorer.noaa.gov/okeanos/explorations/ex1703/background/plan/welcome.html>.

Briefly discuss why this kind of exploration is important (for background information, please see the lesson *To Boldly Go...* [http://oceanexplorer.noaa.gov/okeanos/edu/collection/media/wdwe\\_toboldlygo.pdf](http://oceanexplorer.noaa.gov/okeanos/edu/collection/media/wdwe_toboldlygo.pdf).) Highlight the overall exploration strategy used by ships of exploration, including the following points:

- The overall strategy is to develop baseline information about the biological, geological, and water chemistry features of unexplored areas to provide a foundation for future exploration and research.
- This information includes:
  - High resolution maps of the area being explored, as well as areas that the ship crosses while underway from one location to the next (underway reconnaissance);
  - Exploration of water column chemistry and other features; and
  - High definition close-up video of biological and geological features in the exploration area (site characterization).

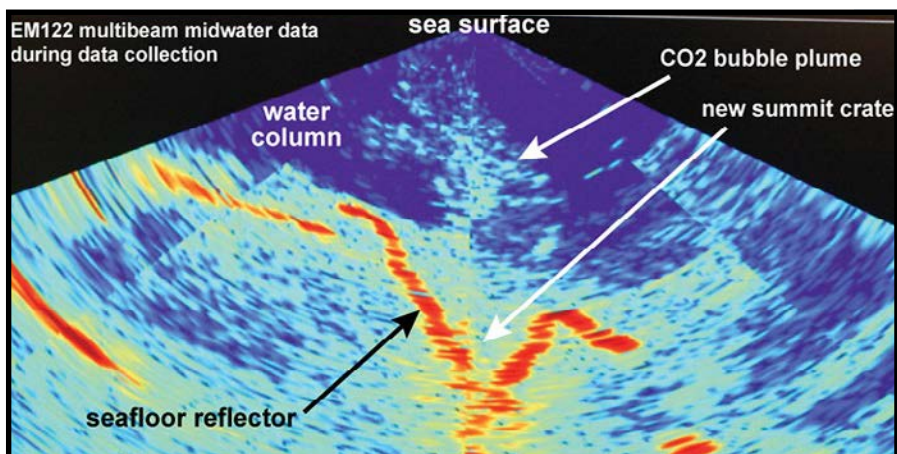


Image of the seafloor and midwater data during collection. The new crater at the summit is depicted by the red seafloor reflector. The CO<sub>2</sub> bubble plume rising from the crater is revealed by the light blue reflectors rising above the crater. Image courtesy of Submarine Ring of Fire 2014 - Ironman, NSF/NOAA.

<http://oceanexplorer.noaa.gov/explorations/14fire/logs/december04/media/multibeam.html>

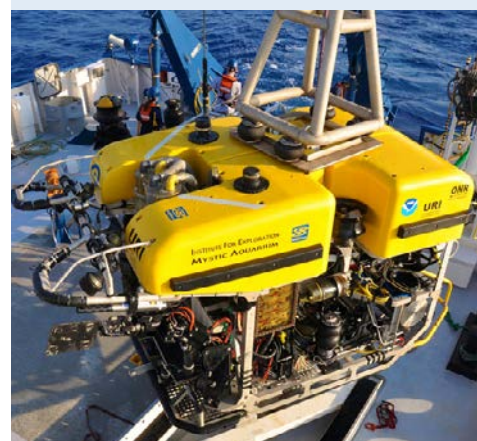
- This strategy relies on four key technologies:
  - Multibeam sonar mapping system and other types of sonar that can detect specific features in the water column and on the seafloor;
  - Conductivity, Temperature, and Depth profilers (CTDs) and other electronic sensors to measure chemical and physical seawater properties;
  - A Remotely Operated Vehicle (ROV) capable of obtaining high-quality imagery and samples in depths as great as 6,000 meters; and
  - Telepresence technologies that allow scientists with many different areas of expertise to observe and interact with exploration activities, though they may be thousands of miles from the ship.

You may want to show some or all of the images in the sidebars to accompany this review.

3. Explain that building complicated ROV systems such as *Deep Discoverer* involves a process called Engineering Design. If students are not already familiar with this concept, explain that Engineering Design is a process that engineers use to create solutions to problems. There are many versions of the process, but the basic steps are:

- Define the problem;
- Gather relevant information;
- Brainstorm possible solutions;
- Analyze possible solutions and select the most promising;
- Test the solution;
- Report results;
- Repeat to refine the design solution.

Defining the problem includes identifying constraints such as available materials and resources. Emphasize that research on a problem should be carried out before beginning to design a solution. This may involve Internet searches, market research, field observations, or consulting with others who have



*Hercules* is one of the very few Remotely Operated Vehicles (ROV) specifically designed to be used as a scientific tool. Built for the Institute For Exploration (IFE), *Hercules* is equipped with special features that allow it to perform intricate tasks while descending to depths of 4,000 meters (2.5 miles).

<http://oceanexplorer.noaa.gov/technology/subs/hercules/hercules.html>



Scientist Scott France participates in the dives from his home office via telepresence. Image courtesy of NOAA OER, 2016 Deepwater Exploration of the Marianas.

<http://oceanexplorer.noaa.gov/oceanos/explorations/ex1605/logs/jun28/media/1605scott-france.html>



Rock samples collected are used to better understand the age and geologic history of complex regions. Image courtesy of the NOAA Office of Ocean Exploration and Research, Deep-Sea Symphony: Exploring the Musicians Seamounts. <http://oceanexplorer.noaa.gov/oceanos/explorations/ex1708/dailyupdates/media/sept13-1.html>



Lava sampled to help shed light about this very rapidly erupting volcanic feature on Wagner Seamount. Image courtesy of NOAA OER, Deep-Sea Symphony: Exploring the Musicians Seamounts. <http://oceanexplorer.noaa.gov/oceanos/explorations/ex1708/logs/sept16/media/sampling.html>

experience with the defined problem. Often, a productive way to generate ideas is for people to work together to brainstorm, test, and refine possible solutions. Different proposals for solutions can be compared on the basis of how well each one meets the specified criteria for success and how well each takes the constraints into account.

Testing the solution often involves building models of simplified designs to be sure an idea will work before investing a lot of time and money to construct something more elaborate. This step is sometimes called prototyping or “proof of concept.” If the prototype works, the designers will continue to develop their solution with the same materials and techniques. If the prototype does not work, then designers must go back to a previous step and consider solutions that use other materials and techniques. This entire process may be repeated several times to improve the solution until results are satisfactory. For complex projects, these steps may be done by teams that work on different parts of the problem. An ROV such as *Deep Discoverer* might have a design team working on the video system, another team working on propulsion, and another responsible for electronics.

You may also want to point out that explorers often encounter unexpected problems or challenges during an expedition. A famous example is the Apollo 13 mission during which engineers on Earth had to design a “scrubber” that would remove carbon dioxide from the air that the astronauts had to breathe, using only materials that were already aboard the spacecraft. To find solutions for these kinds of challenges, explorers often turn to Engineering Design.

Remind students that *Deep Discoverer* is designed to obtain high quality video images in ocean environments as deep as 6,000 meters. It can also carry electronic instruments to measure environmental features such as temperature, and has a specialized robotic arm to provide a limited sample collection capability. Tell students that their task is to use the methods of Engineering Design to develop a robotic arm that is able to pick up objects that are about the size of a soda can.

Say that other teams working on this problem have decided that a hydraulic control system may be part of the solution to the robotic arm design task. So to begin their design process, students need to review some basic concepts of hydraulics and simple mechanics.

4. 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, through pulleys and wheel-and-axles

Remotely operated vehicle *Deep Discoverer's* manipulator arm, labeled. Image courtesy of Art Howard, GFOE; edited by Jeffery Laning, GFOE.  
<http://oceanexplorer.noaa.gov/oceanos/explorations/ex1702/logs/feb28/media/d2arm.html>

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.

5. Provide each student group with a copy of the *Student Worksheet*, and the materials listed in Part B of the *Worksheet*. Have each group complete Parts A and B of the *Worksheet*. Then lead a discussion of students' results. Students should understand that:

- Hydraulic refers to the use of confined liquid to transmit power, multiply force, or produce motion;
- Hydraulic systems use a liquid while pneumatic systems use air or other gases;
- An actuator is a mechanical device that converts energy into some kind of motion; and
- The energy that operates the actuators they built in Part B is mechanical energy from their own muscles that is transferred to the moving arm by the hydraulic system of the actuator.

This gorgeous squid, probably *Taningia danae*, was seen as *Deep Discoverer* was descending to the seafloor. Image courtesy of the NOAA OER.  
<http://oceanexplorer.noaa.gov/oceanos/explorations/ex1605/logs/jul8/media/1605squid.html>

A robot arm completed in a Professional Development Workshop. Image courtesy Susan Haynes, NOAA OER.





Provide additional materials listed in Part C of the *Worksheet*, and any additional instructions or advice that may be needed. Encourage students to consider several possible solutions, and point out that optimization of designs involves testing different solutions to determine which of them best solves the problem, given the criteria and the constraints. You may want to require each group to present the concept for their model before they actually begin construction; if this is a requirement, you may want to provide the additional materials after the concept has been approved.

6. When students have completed Part C of the *Worksheet*, have each group present their model and explain its operation to the rest of the class. Ask students to describe the criteria and constraints that influenced their design, how they developed their solutions, and how they optimized their chosen solution. There are many ways to construct a model that meets the design requirements. The essential points are:
- Design requirements are clearly identified. For instance, the model must be able to grasp an object, such as an empty plastic cup, and lift the object at least one inch.
  - Several options are considered.
  - The selected option fulfills the design requirements.
  - If the model does not fulfill the design requirements, students should identify necessary modifications.

When all groups have presented their results, lead a class discussion about the next steps in designing a robotic arm that would be able to retrieve objects from the ocean floor, and what additional design decisions would be needed. The list of decisions includes:

- Materials for constructing the arm, considering environmental conditions in the deep ocean;
- Number of movements needed (this is called “degrees of freedom;” the actuator in Part B of the *Worksheet* has one degree of freedom; the human arm has more than 26 degrees of freedom);
- How the arm will be powered (are hydraulics the best solution; what are some other options);
- How the arm will be controlled from the surface; and
- What other sensors might be needed (such as a video camera mounted on the arm to show what is being lifted, or a pressure sensor on the gripper to know how much an object is being squeezed).

Be sure students realize that in a real hydraulic system, their hand muscles would be replaced by a pump to move hydraulic fluid in and out of actuators.



An unusual umbrella-shaped pedestal covered with corals and sponges. Zooming in revealed numerous shrimp, crabs, brittle stars, and fish living within this structure. Image courtesy of the NOAA OER, Mountains in the Deep: Exploring the Central Pacific Basin.

<http://oceanexplorer.noaa.gov/oceanos/explorations/ex1705/dailyupdates/media/may5-1.html>



A crinoid observed during a dive as ROV *Deep Discoverer* (D2) explored a ridge feature along the outer slopes of Maug, one of the volcanoes within the Islands Unit of the Marianas Trench Marine National Monument. In the deep sea, absent of D2's artificial lights, this organism would appear black or disappear completely as red is one of the first colors to disappear from the visual spectrum in the ocean. Image courtesy of NOAA OER, 2016 Deepwater Exploration of the Marianas.  
<http://oceanexplorer.noaa.gov/oceanos/explorations/ex1605/logs/jul11/welcome.html>

7. (Optional) Some Math Connections – Have students calculate the volume of hydraulic fluid (water in this case) needed to fill the system in their design. This will involve measuring the length and diameter of the syringes and tubing, and calculating volume as

$$V = \pi \cdot r^2 \cdot L$$

where V is volume, r is the radius of the tubing or syringe, and L is its length.

You may also have students verify their calculations by measuring the volume of water contained in their system.

### The BRIDGE Connection

[www.vims.edu/bridge/](http://www.vims.edu/bridge/) – Scroll over “Ocean Science Topics” in the menu on the left side of the page, 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 they might personally use the process of Engineering Design. Emphasize that they might use this process to solve a problem that is not directly related to engineering, such as writing an essay, planning a road trip, or dealing with homework.

### Connections to Other Subjects

English/Language Arts, Life Science, Mathematics, Physics

### Assessment

Student’s models and class discussions provide opportunities for assessment.

### Extensions

1. Visit the *Okeanos Explorer* Web page <http://oceanexplorer.noaa.gov/oceanos/welcome.html> for reports, images, and other products from *Okeanos Explorer* cruises.
2. Visit <http://www.marinetech.org/rov-competition-2/> for a video from the most recent Marine Technology Society’s student ROV competition, and links to other sites about underwater robots.
3. Visit [http://seaperch.org/online\\_training\\_videos](http://seaperch.org/online_training_videos) for ideas about building ROVs.

### Multimedia Discovery Missions

<http://www.oceanexplorer.noaa.gov/edu/learning/welcome.html>

Click on the links to Lessons 1, 5 and 6 for interactive multimedia presentations and Learning Activities on Plate Tectonics, Chemosynthesis and Hydrothermal Vent Life, and Deep-Sea Benthos.

## Other Relevant Lessons from NOAA OER

### Call to Arms

<http://oceanexplorer.noaa.gov/edu/guide/media/gomdse11calltoarms56.pdf>

Focus - Robotic analogues for human structures (Grades 5-6; Life Science/Physical Science)

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

### The Robot Ranger

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

Focus - Robotic Analogues for Human Structures (Vision, Distance Estimation) (Grades 5-6; 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.

### The Multi-Talented Underwater Robot

[http://oceanexplorer.noaa.gov/explorations/16carolina/background/edu/CarolinaCanyons\\_SentryAUV\\_2016.pdf](http://oceanexplorer.noaa.gov/explorations/16carolina/background/edu/CarolinaCanyons_SentryAUV_2016.pdf)

Focus - Autonomous Underwater Vehicle (AUV) Sentry (Grades 9-12; Engineering Design)

Students understand how engineers approach complex real-world problems by breaking them down into smaller, more manageable problems.

## Next Generation Science Standards and Ocean Literacy Essential Principles and Fundamental Concepts

This lesson supports the Ocean Literacy Essential Principles and Fundamental Concepts as indicated here <http://oceanexplorer.noaa.gov/oceanos/edu/collection/media/hdwe-Standards.pdf>. Additionally, while it is not intended to target specific Next Generation Science Standards, activities in this lesson may be used to address the Performance Expectation as described below.

### Specific NGSS Performance Expectation relevant to this lesson:

**MS-ETS1-2. Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.**



### The Next Generation Science Standards

The Next Generation Science Standards integrate three dimensions within each standard: Science and Engineering Practices, Disciplinary Core Ideas, and Crosscutting Concepts. The standards are written as student performance expectations. While specific performance expectations may emphasize only a few of the practice categories, teachers are encouraged to utilize several practices in any instruction. Similarly, only a few crosscutting concepts may be emphasized, but this is not intended to limit instruction.

### For Information and Feedback

We value your feedback on this lesson, including how you use it in your formal/informal education settings. Please send your comments to: [oceanexeducation@noaa.gov](mailto:oceanexeducation@noaa.gov)

### Acknowledgments

Produced by Mel Goodwin, PhD, Marine Biologist and Science Writer, Charleston, SC. Design/layout: Coastal Images Graphic Design, Charleston, SC. If reproducing this lesson, please cite NOAA as the source, and provide the following URL: <http://oceanexplorer.noaa.gov>

## Student Worksheet

### Design Requirement

Your group is one of several teams working to design a robotic arm that is able to pick up objects that are about the size of a soda can from the ocean floor. One of the other design teams has suggested that hydraulic actuators may be part of the final design. Your team's task is to build a model that demonstrates how this could be done.

### A. Review of Background Information

1. What does "hydraulic" mean?
2. What is the difference between "hydraulic" and "pneumatic?"
3. What is an actuator?

### B. Build a Simple Hydraulic Actuator

#### Materials

- One piece of cardboard or heavy poster board, approximately 12" x 12" (the stiffer the better)
- Duct tape, approximately 2" x 60"
- Machine screw with nut, #8 x 1"
- 3 - Flat washers, #8 hole
- 2 - Oral syringes
- Plastic tubing, approximately 3/16" inside diameter x 12" (should fit snugly over the end of the syringes)
- Water
- Small container, such as a 9-oz drinking cup

#### Tools

- Heavy scissors to cut cardboard ("bandage scissors" are inexpensive and work well)
- Nail or Phillips screwdriver to punch holes in cardboard
- Screwdriver to fit machine screw
- Tape measure

### Procedure

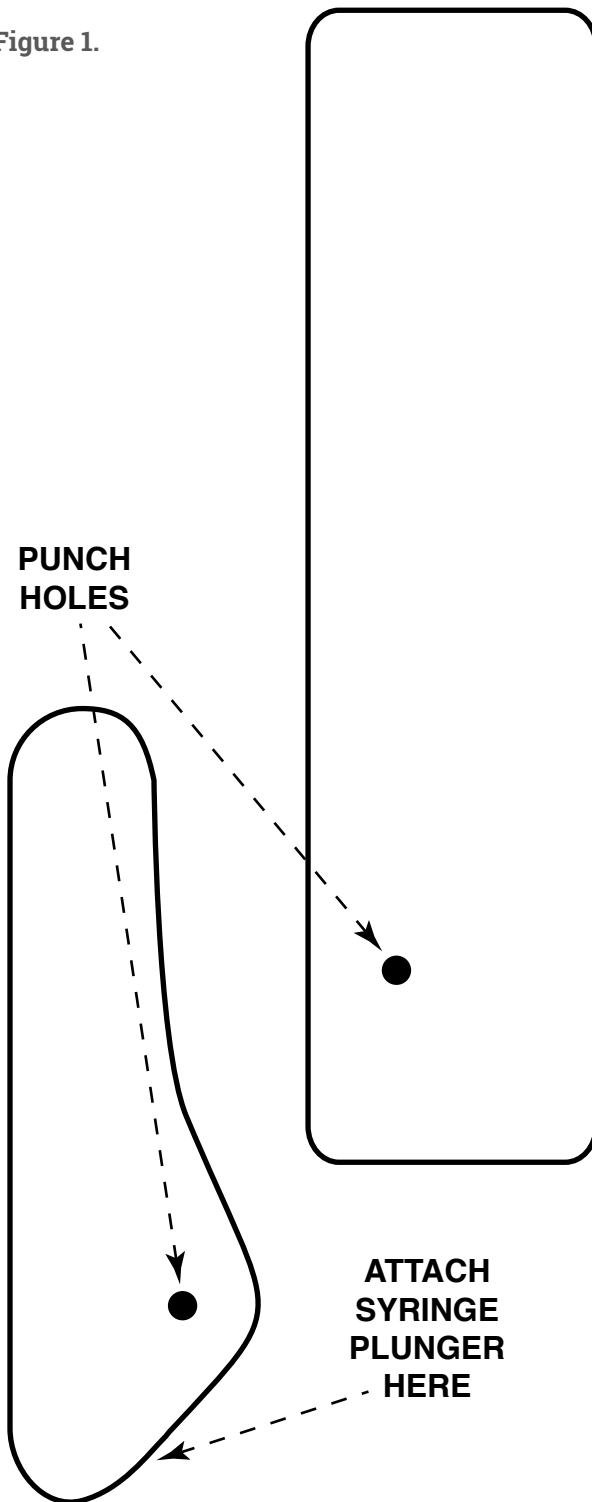
#### Option A

Your group has access to the tools and materials listed above. Use these resources to complete the Design Requirement.

#### Option B

- Build a Simple Hydraulic Actuator
  1. Cut two pieces of cardboard using the pattern on page 13 (Figure 1).

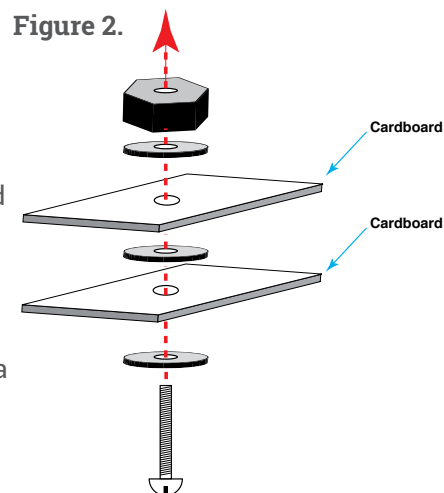
Figure 1.



2. Reinforce the cardboard pieces: Put a piece of duct tape on one side, then cut off the excess tape around the edges. Put a second piece of duct tape on the other side, and trim the edges. Repeat this process, if necessary, until the pieces are very stiff.

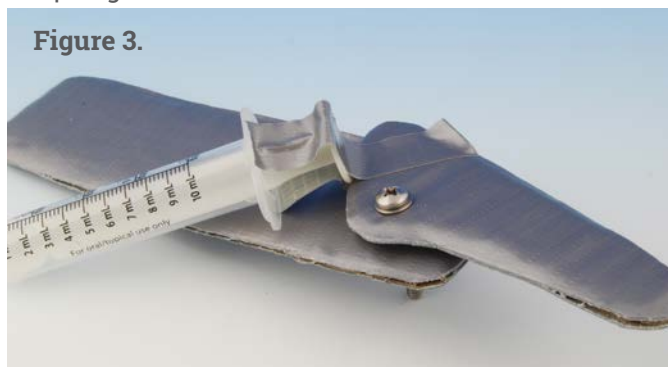
3. Punch a hole in each of the pieces as shown on the pattern. The hole should be large enough for the #8 machine screw, but not much larger.

4. Attach the two pieces with a #8 machine screw, three flat washers, and a #8 nut as shown in Figure 2. You may need a screwdriver to twist the machine screw through the holes. Do not tighten the machine screw assembly too much; the pieces need to be able to move freely around the machine screw. You may find that an extra washer or nut between the two cardboard pieces allows for more motion.



5. Take a piece of duct tape 6" long, and tear it in half lengthwise, and then tear one of these pieces in half lengthwise again. These narrower pieces of duct tape will be useful for attaching a syringe to the shorter piece of cardboard.

6. Attach the plunger of one syringe to the shorter piece of cardboard as indicated on the pattern. Tear one of the narrower pieces of duct tape in half, and wrap it around the plunger and cardboard as shown in Figure 3. Now wrap a second narrow piece of duct tape around the plunger at right angles to the first piece of tape. Add more tape if necessary, but you do not want the joint between the plunger and cardboard to be too tight.



7. Tape the syringe onto the larger piece of cardboard as shown in Figure 4. Be sure the plunger is fully inserted into the barrel of the syringe.



8. Press one end of the plastic tubing onto the end of the other syringe so it is firmly attached. Place the other end of the plastic tubing into a small container of water, and pull the plunger back so that water is drawn into the tubing and syringe. Fill the syringe as full as possible, then hold the end of the plastic tubing so that it is higher than the end of the syringe, and slowly push on the plunger until the syringe is about half-full, and there is no air

in the syringe or plastic tubing. You may have to refill the syringe with more water and repeat this procedure a few times to get rid of all the air.

9. Attach the open end of the plastic tubing to the syringe that is taped to the cardboard assembly. Slowly press the plunger on the unattached syringe, and you should see the small arm on the cardboard assembly rotate around the machine screw. Pull out slowly on the plunger to reverse this motion. Your hydraulic actuator is completed!

### C. Design and Build a Hydraulic Mechanism for a Robotic Arm

Remember that your team's task is to build a model that demonstrates how hydraulic actuators could be used for a robotic arm that is able to pick up objects that are about the size of a soda can from the ocean floor. This model does NOT have to have all of the features that will be needed in the final robotic arm. You only need to show that a design using hydraulic actuators could produce the movements that would be needed to accomplish the purpose of the robotic arm. Your model needs to be able to do two things:

- Grasp an object (such as an empty plastic cup); and
- Lift the object at least one inch.

So that other teams can learn from your experience, it is very important to document how you apply the process of Engineering Design. In addition to creating a model that meets the two requirements, your team should produce a report that:

1. Defines the problem;
2. Describes your solution, including a drawing of your model;
3. Explains your construction procedure; and
4. Reports the results of your tests of the model.

If your model cannot meet the design requirements, describe the modifications that you think are necessary to make it work.

#### Additional Materials

- Four pieces of cardboard or heavy poster board, each approximately 12" x 12"
- Duct tape, approximately 2" x 20'
- 9 - Machine screws with nuts, #8 x 1"
- 4 - Machine screws with nuts, #8 x 3"
- 17 - Flat washers, #8 hole

- 2 - Oral syringes
- Plastic tubing, approximately 3/16" inside diameter x 12"

**Note:** These materials are sufficient to construct many models that will meet the design requirements, but your model may not need all of them.

**Tip:** Cardboard arms and supports are much stronger if they are folded and taped to form beams with square or triangular cross-sections (see Figure 5).

Figure 5.

