RESOURCE LIBRARY
LESSON

Engineering Pressure

Students will be inspired by James Cameron's historic *DEEPSEA CHALLENGE* dive to investigate pressure and use the engineering process to design, model, test, document, evaluate, and re-design a submersible vehicle.

GRADES

9 - 12+

SUBJECTS

Arts and Music, Earth Science, Oceanography, Engineering, Geography, Mathematics, Physics

CONTENTS

4 Activities, 1 PDF

Program

DEEPSEA CHALLENGE

ACTIVITY 1: EXPLORING PRESSURE | 50 MINS

DIRECTIONS

1. Activate prior knowledge by asking students to define pressure and give illustrative examples.

Accept several definitions of pressure. Then write the pressure equation (pressure = force/area) on the board and define pressure as the amount of force applied over a specific area. Ask for several volunteers to share examples that illustrate pressure. For example, a student might say "snowshoes versus regular shoes" or "a sharp knife versus a dull knife." After you write each example on the board, ask students to explain how the example illustrates pressure. If students do not offer examples involving fluids, encourage them to do so. For example, they might mention the pressure a person feels in their ears when they dive deep under water or when they fly in a plane. Refer students to the pressure equation on the board. Ask: *What would happen to the pressure if force increased?* (The pressure would increase.) *What would happen to pressure if the area increased?* (The pressure would decrease.) *How would you describe the relationship between pressure and force?* (Pressure and force are directly proportional; pressure increases proportionally with an increase in force.) *How would you describe the relationship between pressure and area?* (Pressure and area are inversely proportional; pressure decreases proportionally with an increase in area.) For example, the force a person exerts on snow when walking on it is the person's weight. Snowshoes spread this force out over a greater area than regular shoes; therefore, less pressure is applied to the snow. Explain that in this activity, students will be examining pressure in a fluid, specifically water, more closely. Leave the equation on the board for students' reference throughout the activity.

2. Introduce the *DEEPSEA CHALLENGE* expedition.

Provide students with the following focus questions prior to showing them the video, "Environment News: James Cameron Breaks Solo Dive Record":

- Where did the submersible dive?
- What effect did pressure have on the submersible under water?
- Why was the dive important?

Show students the video and ask them to take notes on these questions as they watch. At the end of the video, discuss the focus questions. Ask students if they were surprised to hear how much the submersible shrank under the pressure of the water. Ask: *Why was the pressure on the submersible so great in the Mariana Trench? Describe this change in pressure using the pressure equation (pressure = force/area). Which variable in this equation changed the most as James Cameron went deeper in the ocean?* (The variable of force—the weight of the water—changed the most.)

3. Have students conduct a demonstration to examine how pressure changes in different depths of water.

Divide students into small groups. Distribute the Demonstration 1: Pressure Streams worksheet and the materials listed on that worksheet to each group. Review the procedure described on the worksheet with students and answer any questions. Have students make a prediction, conduct the demonstration, and record their data and observations as described on the worksheet.

4. Review with students how and why the two streams were different in the Demonstration 1: Pressure Streams activity.

When students have completed the demonstration, ask them to share their results with the class. Ask: *What did you observe? Did it match your predictions? How can you explain what you saw in terms of pressure?* (The water exited the bottom hole with more force because there was greater pressure at that depth due to the greater mass of the water above that point. Since the pressure was greater at that depth and the area over which it was applied (the size of the hole) was the same at both depths, the force with which the water exited the bottom hole was greater than the force with which it exited the top hole.) Make sure that students can properly explain what they observed in terms of force and pressure. If necessary, illustrate this to the class using specific variables from the pressure and force equations: Go back to the pressure equation you wrote on the board (pressure = force/area). Go through each variable in the equation as it relates to the bottom hole in the demonstration; then repeat for the top hole. Pressure at the bottom hole was greater than pressure at the top hole because force was greater at the bottom hole and area stayed the same.

5. Have students conduct Demonstration 2: Measuring Pressure.

Distribute to each group the Demonstration 2: Measuring Pressure worksheet and the supplies listed on the worksheet. Have each group assemble a manometer as described in the Demonstration 2: Measuring Pressure worksheet. Be sure students understand that as the pressure increases, the level of the water will rise on the right side of the ruler. Have students discuss what they think will happen to the pressure as they lower the funnel in the water, and ask them to record their predictions on the worksheet. Have them test the pressure at several different levels and record the results on the worksheet. Also have students test with the funnel facing in different directions at the same depth and note any differences.

6. Discuss how the measurements changed with depth in Demonstration 2: Measuring Pressure.

Ask groups to share what they observed in this demonstration. Ask students to explain why the pressure increased as depth increased and to explain why the pressure reading was the same no matter which direction the funnel faced. Identify and address any misconceptions about pressure in fluids at this time. Common misconceptions include the idea that pressure only occurs during movement and that pressure is only applied downward. To address these misconceptions, ask: *What would happen if a hole opened on the side of Cameron's submersible while it was descending to the bottom of the ocean? What if the hole opened while the submersible was sitting still at the bottom of the ocean?* Guide students to answer that both situations would lead to an inrush of water.

7. Show students the "Cameron's Long Way Down: Mariana Trench" video, which includes a one-minute video recap of James Cameron's dive to the Mariana Trench.
Prior to viewing the video, ask students to note the pressure changes during Cameron's descent. Explain that the pressure is different at different locations. Brainstorm some factors that would influence how much pressure is felt at different locations both above and below sea level. Divide students into pairs, and distribute the Calculating Pressure worksheet. Give students the rule-of-thumb calculation for pressure underwater: pressure increases by 0.445 psi per foot of water. The total pressure on an object underwater also includes air pressure, so 14.7 psi—the standard air pressure at sea level— must be added to each of the students' underwater calculations. Have students calculate and record the pressure for the locations on the table. Review the table and discuss the data.

8. Have students create models to show how and why pressure increases at greater depths in the ocean.
Explain that students will work with their partners to develop models to show how and why pressure increases at greater depths in the ocean. Tell students that the models could be illustrations, physical models, or demonstrations, but that they also must be able to use the models to explain how and why pressure increases as depth increases. Distribute the Exploring Pressure Model Rubric and review it with students to be sure they understand what is expected of them in this activity. Make available to students an assortment of materials such as packing peanuts, balloons, marshmallows, Styrofoam balls, and other items. Once students have created their models, have them present the models to the class.

Alternative Assessment

Use students' written predictions and explanations to assess their understanding of pressure throughout the activity and use that information to address any misconceptions. Use the Model Rubric to assess students' pressure models.

Extending the Learning

Have students use their models to give younger students an introduction to pressure in fluids.

OBJECTIVES

Subjects & Disciplines

- Arts and Music

  Earth Science

  - Oceanography
- Engineering

  Geography
- Mathematics
- Physics

Learning Objectives

Students will:

- accurately explain observations based on an understanding of pressure
- compare pressure at different depths in the ocean
- create a model to explain how and why pressure increases as depth increases in the ocean

Teaching Approach

- Learning-for-use

Teaching Methods

- Cooperative learning
- Discussions
- Hands-on learning

Skills Summary

This activity targets the following skills:

- 21st Century Student Outcomes
  - Learning and Innovation Skills
    - Communication and Collaboration
- Critical Thinking Skills
  - Analyzing
  - Applying

National Standards, Principles, and Practices

NATIONAL GEOGRAPHY STANDARDS

• **Standard 4:**
The physical and human characteristics of places

NATIONAL SCIENCE EDUCATION STANDARDS

• **(9-12) Standard B-2:**
Structure and properties of matter

ISTE STANDARDS FOR STUDENTS (ISTE STANDARDS*S)

• **Standard 2:**
Communication and Collaboration

Preparation

BACKGROUND & VOCABULARY

Background Information

Pressure is force per a specific unit of area (pressure = force/area). As force increases, pressure increases proportionally. As area increases, pressure decreases proportionally. Pressure can be measured in a variety of units including the pascal (Pa), which is the standard international (SI) unit equivalent to one newton per square meter, or in pounds per square inch (psi). Pressure can be important in describing the behavior of fluids such as air or water. Though we can't see the individual molecules in air or water, they have mass and therefore exert force. Air pressure and water pressure describe that force acting over a specific area. The water pressure on an object that is under water is proportional to the weight of the water above the object. Liquid pressure also depends on the density of the liquid. However, liquids are practically incompressible, which means the spacing between molecules does not change much with depth, so except for small changes produced by temperature, the density of a given liquid is almost the same at all depths. Therefore, the deeper an object goes under water, the more pressure it is under. This is because as an object goes deeper under water, there is more water above the object, and therefore more weight (force) to add to the pressure. As a rule of thumb, water pressure in seawater increases at a rate of 0.445 psi per foot deep. So an object under 10 feet (3 meters) of water would be under 4.445 psi of water pressure. The total pressure on the object is equal to the atmospheric pressure plus the pressure due to the weight of the water above the object. At sea level the atmospheric pressure is 14.7 psi. Therefore, the total pressure on an object at a depth of 10 feet (3 meters) in sea water would be 14.7 psi + 4.45 psi for a total of 19.15 psi.

Air pressure generally decreases with elevation above sea level. The air at higher elevations is generally less dense than at sea level since there are fewer “layers” of air molecules pressing down from above, and the pressure is also correspondingly lower. The lower density of the air at higher elevations also explains why mountain climbers can have trouble getting enough oxygen as they ascend higher and higher. Since there are fewer molecules of oxygen and other gases that make up air at high elevations, mountain climbers have to breathe faster to take in the oxygen they need.

Prior Knowledge

["A basic understanding of pressure", "A basic understanding of force", "A basic understanding of mass"]

Recommended Prior Activities

- None

Vocabulary

Term	Part of Speech	Definition
acceleration	*noun*	increase of speed or velocity.
DEEPSEA CHALLENGE	*noun*	ongoing expedition to study the deepest point in the ocean, with a record-breaking descent to the Challenger Deep in March 2012.

Term	Part of Speech	Definition
force	*noun*	power or energy that activates movement.
gravity	*noun*	physical force by which objects attract, or pull toward, each other.
mass	*noun*	measure of the amount of matter in a physical object.
pressure	*noun*	force pressed on an object by another object or condition, such as gravity.

FUNDER

Alfred P. Sloan Foundation

Before Moving on to the Next Activity

In Activity 1, students conducted experiments to see how depth affects water pressure. In Activity 2, they will use steps in the engineering process to analyze a problem involving water pressure and will design a solution for the problem.

ACTIVITY 2: UNDER PRESSURE: DEFINING THE PROBLEM | 2 HRS 40 MINS

DIRECTIONS

1. Activate students' prior knowledge by reviewing what they know about pressure.
Ask students to define pressure and to give a formula expressing pressure. Introduce or re-introduce students to James Cameron's *DEEPSEA CHALLENGE* expedition to the Mariana Trench and have students explain how pressure affected the expedition. If necessary, have students visit the provided *DEEPSEA CHALLENGE* website to become familiar with the expedition.

2. Watch a video to introduce one of the design challenges the *DEEPSEA CHALLENGE* team had to address.
Provide students with the following focus questions prior to watching "Cracking the Code": What was the big challenge James Cameron describes? Why was this challenge unexpected? What was the problem with commercially available foam? Have students take notes as they watch the video, and use the questions to launch a discussion at the end of the video. Explain that this was just one of many design challenges the team faced.

3. Distribute the Engineering Process handout and review the steps in the process with students.

Explain that students will use the engineering process to solve a design problem similar to the one James Cameron's team solved. Explain that although the engineering process has seven steps, students will only complete the first four steps in this activity. When reviewing step 1, go over constraints and considerations, and give examples of both. Constraints are absolute requirements or limitations in a design or decision-making process. If a choice or solution doesn't meet the constraints, then it must be eliminated. For example, if you are shopping for new bookshelves for your living room, there will be a size constraint. The bookshelves must be small enough to fit in the available space in your living room. Any bookshelves that are too big must be eliminated as a choice, even if they are otherwise perfect. Considerations are desired, but not necessary, elements in a design, solution, or decision. Considerations can be used to rank choices and solutions. For example, if your living room has a lot of dark wood, the tone of the wood for your bookshelves would be a consideration; you might prefer to have dark wood so that it will match the other wood in the room. However, you wouldn't necessarily eliminate a shelf just because it has lighter wood.

4. Have students redefine the problem description from the Problem Scenario: Design a Submersible handout in their own words.

Read aloud to students the problem description section of the Problem Scenario: Design a Submersible handout. Explain that in this activity students will use the first four steps in the Engineering Process handout they were given earlier to plan and design a solution to the problem presented in the scenario. Provide students with the Design a Submersible: Design Rubric and review it to be sure students understand the expectations. Divide students into small groups and have each group define the problem in their own words per step 1 of the handout. Invite groups to share their problem definitions with the class, and then go over the problem definition provided on the Problem Scenario: Design a Submersible handout. Briefly review the concepts of constraints and considerations. Have each group list constraints and considerations for the problem. Have groups share their ideas with the class, and then provide the final list of constraints for the problem as listed on the Problem Scenario: Design a Submersible handout.

5. Have students conduct research that will help them solve the problem.

Have groups brainstorm questions they have, information they need, and keywords and topics they could use to conduct research to solve the problem. Have students record their ideas as described in step 2 of the Engineering Process handout. Tell students to consider all aspects of the problem in their research, including dive location and vehicle design. Have students use the provided websites to research basic designs for underwater submersibles and explore different materials available for constructing a submersible. To help them determine a good location for the dive, have them read the National Geographic Education encyclopedic entry about hydrothermal vent communities. Have students record detailed notes and research summaries as described on the Engineering Process handout.

6. Have students propose a solution.
Have students look at their lists of constraints and brainstorm ways to address each constraint in their designs, based on their research. If necessary, have them return to the research step to gather more information. Once students have identified ways to address each constraint, have them plan out their solutions and explain them as described in step 3 of the Engineering Process handout. Tell students that their solutions need to contain profiles of their dive locations, including a map of the location, the maximum depth of the location, the pressure they will need to withstand, the anticipated water temperature, the life forms they might see, etc. Have all students map their locations using the MapMaker Interactive and add labels to record basic information about the dive sites. Their problem solutions should also include basic design information for their vehicles and how the designs will address the constraints of the problem.

7. Have students develop a design.
Have students create detailed concept designs for their submersible vehicles based on their proposed solutions. They should draw and label their designs as described in step 4 of the Engineering Process handout and write brief reports explaining how their designs will work to solve the problem. Remind them to address the constraints and considerations of the project in their drawings and reports and to be as specific as possible in their drawing and labeling.

8. Have students present their concepts to the class.
Review with students the peer review expectations and the concept of constructive criticism. Give each group time to present its proposed solution and concept design to the class. Allow students to ask questions and to give feedback to each group. Following the presentations, give groups time to make adjustments to their designs based on feedback.

9. Discuss the design process.
Discuss the design process with students. Ask: *What would you have done differently? What worked well? What was most challenging for you?* Note that students should keep all documentation from this activity in preparation for the next activity.

Tip

Check in with groups frequently as they are developing their proposed solutions and concept drawings. Students will need encouragement to push their solutions further and to include more detail.

Modification

During the research phase, check in with students and guide their research as needed to make sure they consider areas where there are hydrothermal vents as potential dive areas. These areas tend to have greater biodiversity than other places in the abyssopelagic zone. Students could select a known hydrothermal vent or pick an area that is likely to contain vents.

Modification

You can simplify the activity by assigning students a dive location instead of having them research to find one.

Alternative Assessment

Observe students and their notes throughout the process and provide feedback as needed to focus their designs. Use the Design a Submersible: Design Rubric to assess students' location profiles, descriptions of the problem, and concept designs and reports.

OBJECTIVES

Subjects & Disciplines

Earth Science
- Oceanography

- Engineering

Geography
- Mathematics
- Physics

Learning Objectives

Students will:

- define and analyze a problem
- identify constraints and considerations for solving a problem
- research parameters related to a problem
- design a solution to a problem using what they know about deep ocean conditions, including pressure

Teaching Approach

- Learning-for-use

Teaching Methods

- Brainstorming
- Cooperative learning
- Discussions
- Reflection

Skills Summary

This activity targets the following skills:

- 21st Century Student Outcomes
  - Learning and Innovation Skills
    - Communication and Collaboration
    - Creativity and Innovation
- Critical Thinking Skills
  - Analyzing
  - Applying
  - Creating
- Geographic Skills
  - Analyzing Geographic Information

National Standards, Principles, and Practices

NATIONAL GEOGRAPHY STANDARDS

- **Standard 4:**

The physical and human characteristics of places

NATIONAL SCIENCE EDUCATION STANDARDS

- **(9-12) Standard B-2:**

Structure and properties of matter

OCEAN LITERACY ESSENTIAL PRINCIPLES AND FUNDAMENTAL CONCEPTS

- **Principle 7a:**

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.

- **Principle 7d:**

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.

ISTE STANDARDS FOR STUDENTS (ISTE STANDARDS*S)

- **Standard 1:**

Creativity and Innovation

- **Standard 2:**

Communication and Collaboration

- **Standard 4:**

Critical Thinking, Problem Solving, and Decision Making

Preparation

BACKGROUND & VOCABULARY

Background Information

Today, Earth's ocean remains largely unexplored, although new technologies and innovations are increasing our ability to study the ocean depths. James Cameron's record-setting 2012 solo dive to the bottom of the Mariana Trench is one example of how these advances increase our ability to explore. Cameron and his team engineered the submersible *DEEPSEA CHALLENGER* specifically to explore the deepest known parts of the ocean. The only other manned vehicle to reach the bottom of the Mariana Trench was the *Trieste* in 1960. Engineers are problem-solvers. Engineering has given us many of the systems and products we rely on daily. Items such as the cars we drive to school, the computers on which we do research, and even the complex systems that bring water and electricity to our homes were all engineered. Engineers apply a wide range of science knowledge and skills, problem-solving, and mechanical expertise to design and build complex products, machines, systems, and structures. Engineering often involves complex designs that have to be broken down into smaller chunks and problem-solved. For example, the *DEEPSEA CHALLENGER* submersible is made of many parts, including the body design, the mechanics involved in moving the submersible, the communication systems, the cameras and lighting used for exploration, the safety systems, and much more. Cameron and his team had to address each of these parts of the *DEEPSEA CHALLENGER* to optimize it for its mission to explore the deepest known parts of the ocean.

There are many areas of interest in ocean exploration. One area is studying life under deep-sea conditions that are so different than the conditions on Earth's surface or even in shallower ocean zones. The lack of light, the cold, and extreme pressure make the deepest ocean zones—the abyssopelagic and hadalpelagic zones—uniquely challenging environments for life. Hydrothermal vents are mineral-rich geysers on the ocean floor that can provide energy for life. Hydrothermal vent communities in the abyssopelagic zone offer unique opportunities to study life in some of the deepest areas of the ocean.

Prior Knowledge

[]

Recommended Prior Activities

- Exploring Pressure

Vocabulary

Term	Part of Speech	Definition
abyssopelagic zone	*noun*	zone of the open ocean, starting at 3,962 meters (13,000 feet) below sea level.
buoyancy	*noun*	the power to float or rise in a fluid.
consideration	*noun*	a matter weighed or taken into account when formulating an opinion or plan.
constraint	*noun*	limitation or obstacle.
engineer	*noun*	person who plans the building of things, such as structures (construction engineer) or substances (chemical engineer).
hadalpelagic zone	*noun*	deepest zone of the open ocean, starting at around 6,000 meters (20,000 feet).
hydrothermal vent	*noun*	opening on the seafloor that emits hot, mineral-rich solutions.
pressure	*noun*	force pressed on an object by another object or condition, such as gravity.
submersible	*noun*	small submarine used for research and exploration.
syntactic foam	*noun*	material consisting of tiny hollow "microballoons" made from material such as glass or carbon.

FUNDER

Alfred P. Sloan Foundation

Before Moving on to the Next Activity

In Activity 2, students designed a submersible that could meet the constraints and considerations of a given problem. In Activity 3, they will build a testable model of their design.

ACTIVITY 3: UNDER PRESSURE: CREATING A MODEL | 1 HR 50 MINS

DIRECTIONS

1. Activate prior knowledge by having each group summarize how its concept design from Activity 2: Under Pressure: Defining the Problem addresses the extreme pressure present at the bottom of the ocean.
Have students bring out the Engineering Process handout from the previous activity and refer to it for their summary. Have groups keep the handout handy. Briefly review the concept of pressure and how pressure changes as water depth increases.

2. View and discuss "The First Launch" video.
Provide students with the following focus questions prior to viewing the video: What role did the dummy sub play in preparing for the actual dive? Why was lowering the sub so dangerous? Have students use these questions to take notes during the video, and then use the questions as a focal point to discuss the video.

3. Explain that groups are going to build simplified models, or prototypes, of their concept designs that can be tested.
Distribute the Prototype Parameters handout to students and read the activity information to students. Make sure students understand that their ultimate goal will be to create prototypes that can rise slowly to the surface from a depth of 3 meters (10 feet) under water, but that in this activity they will be testing their prototypes in shallow water. Go over with students the constraints of the testing environment as described on the handout. Review step 5 on the Engineering Process handout. Distribute and review the Submersible Modeling Rubric with students so they know what is expected in this activity.

4. Review neutral buoyancy and positive buoyancy with students.
Ask students to share what they know about buoyancy. Ask: *What is buoyancy?* (Buoyancy is the upward force exerted by a fluid on an object.) *How does an object that is positively buoyant in water behave when submerged in water?* (It rises to the surface and floats.) *How does an object that is neutrally buoyant in water behave when submerged in water?* (It hovers.) Be sure students understand these concepts before moving forward. Ask students to identify what type of buoyancy their prototypes will need to have in order to meet the parameters described for this activity. Make sure students understand that the prototypes will need to be slightly positively buoyant in order to rise slowly, rather than sinking, staying in place, or rising quickly to the surface.

5. Give students an opportunity to experiment with the buoyancy of various materials.
Provide students with a tub of water and a variety of objects from the materials list that they can use to construct their submersibles. Give students time to explore the buoyancy of these

objects.

6. Have students sketch their prototypes.

Have groups discuss which aspects of their concept design from the Under Pressure: Defining the Problem activity will need to be present in their model in order to test it for the given parameters. For example, they will not need video cameras, but they will need to construct a basic shape for their submersible vehicle and will need to add foam, weights, etc. Have students create a simple sketch of their prototypes and list the materials they will use based on the ones they experimented with in step 5 above.

7. Have students build their prototypes.

Have each group build a physical prototype based on their design and using the available materials. Remind students of the size constraints for their prototypes. Have students list the materials they use, including amounts, per step 5 of the Engineering Process handout. Have them include step-by-step instructions for how to build the prototypes. Point out that these instructions must be specific and thorough enough that someone else could use them to replicate the prototypes.

8. Have students test their prototypes in shallow water.

Describe the basic testing procedure to students. Explain that in this activity, they will conduct shallow-water tests in water about 30 centimeters (1 foot) deep. Students will be able to test, evaluate, and adjust their prototypes, and retest as long as time permits. Per step 6 of the Engineering Process handout, have students list the data they need to collect in order to evaluate their solutions and describe how they will use the data to improve their designs. At a minimum, students should include the depth and the time it takes to reach the surface. Have students specify how they want to conduct the tests. Ask: *How will you collect data from the tests? What role will each group member play in the testing process?* Have students create tables to record the data for each test. Provide students with a large tub, cooler, or trashcan full of water at least 30 centimeters (1 foot) deep. Have students conduct the test in about 30 centimeters (1 foot) of water, record their data, and use it to evaluate the success of their designs. To conduct a test, students will need to push their prototype to the bottom of the container and then let go of it to determine whether it is positively buoyant and thus able to rise to the surface on its own. The slower the prototype rises, the closer it is to neutrally buoyant. A negatively buoyant prototype will remain on the bottom of the container. Ask students to determine what, if any, changes need to be made to their designs in order to better solve the problem, and have them record that information. Give students time to re-make their prototypes and make any adjustments needed. Then have them test again. Give students as many opportunities as time permits to test and retest their prototypes in about 30 centimeters (1 foot) of water.

9. Have groups evaluate their shallow-water tests and prepare for deep-water testing.
Have each group review their test data and summarize their shallow-water testing. Have them list factors that could affect their designs in deeper water. Have students consider how changes in pressure in deeper water will affect the buoyancy of their designs. Read aloud to students the section of the Background Information on buoyancy. Have them brainstorm adjustments they will need to make to their designs to have the prototypes remain slightly positively buoyant when they test it in deeper water.

10. Have students reflect on the modeling process.
Discuss the modeling process as a class. Ask: *What worked and what didn't work? What was the most difficult part of the process? The most helpful? What would you do differently next time?* Note that students should keep all documentation from this activity in preparation for the Under Pressure: Testing a Model activity.

Tip

Hand-held PVC pipe cutters can be used to cut PVC pipe to whatever length necessary. Consider pre-cutting the pipe into 5 cm (2 in) segments for students. For safety reasons, do not allow students to handle the pipe cutters.

Tip

If you opt to test the materials and prototypes in shallow water in the classroom, keep in mind that many of the designs are likely to retain water. Surround the coolers or buckets with towels; give each group a towel for drying materials; and have students place their materials directly into a plastic bag after testing.

Tip

Review your standard lab safety procedures with students before they begin creating the prototypes.

Alternative Assessment

Use the Submersible Modeling Rubric to assess students' testable prototypes.

OBJECTIVES

Subjects & Disciplines

Earth Science

- Oceanography

- Engineering

Geography

- Mathematics
- Physics

Learning Objectives

Students will:

- create a physical submersible model and assess its buoyancy at different depth and pressures
- analyze essential components of a testable submersible model

Teaching Approach

- Learning-for-use

Teaching Methods

- Cooperative learning
- Discussions
- Hands-on learning
- Reflection

Skills Summary

This activity targets the following skills:

- 21st Century Student Outcomes

    - Learning and Innovation Skills
        - Communication and Collaboration
        - Creativity and Innovation
- Critical Thinking Skills
    - Analyzing
    - Applying
    - Creating
- Geographic Skills
    - Analyzing Geographic Information

National Standards, Principles, and Practices

NATIONAL GEOGRAPHY STANDARDS

• **Standard 15**:
How physical systems affect human systems

NATIONAL SCIENCE EDUCATION STANDARDS

• **(9-12) Standard B-2**:
Structure and properties of matter

OCEAN LITERACY ESSENTIAL PRINCIPLES AND FUNDAMENTAL CONCEPTS

• **Principle 7a**:
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.
• **Principle 7d**:
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.

ISTE STANDARDS FOR STUDENTS (ISTE STANDARDS*S)

• **Standard 1**:
Creativity and Innovation

• **Standard 2**:
Communication and Collaboration
• **Standard 4**:
Critical Thinking, Problem Solving, and Decision Making

Preparation

BACKGROUND & VOCABULARY

Background Information

Preparations for James Cameron's historic 2012 solo dive to the bottom of the Mariana Trench took years to complete. Because many aspects of the *DEEPSEA CHALLENGER* were engineered specifically for the unique conditions at the very bottom of the ocean, the *DEEPSEA CHALLENGE* team designed, tested, evaluated, redesigned, and retested parts, components, and systems before assembling them into a whole vessel capable of carrying Cameron deep into the ocean. Testing is a key part of the engineering process, and elements of a design are often isolated and tested before being incorporated into an overall design. This allows for fewer variables at each stage of testing and makes identifying problems much easier. Models and prototypes provide ways to test specific elements of a design.

One of the biggest challenges for the *DEEPSEA CHALLENGE* expedition, as for any deep-sea exploration, was the extreme pressure at the bottom of the ocean. This extreme pressure affects all parts of a deep-sea vehicle and can cause materials to compress or to crack or fail. Pressure is also related to buoyancy. Buoyancy is the upward force exerted by a fluid on an object, equal to the weight of the fluid displaced by the object. (Note that both liquids and gases are considered fluids.) Buoyancy works to make objects float because the pressure at the bottom of the object, which is deeper in the fluid, is greater than the pressure at the top of the object. This creates a net upward force. When an object is placed into a fluid, it displaces a volume of fluid equal to the volume of the part of the object immersed in the fluid. As an object is lowered into a fluid, the volume of the part of the object immersed in the fluid increases, and so does the amount of fluid being displaced. The weight of the fluid being displaced is equal to the buoyant force. The buoyant force reaches a maximum when the object is completely submerged, that is, when the object is displacing a volume of fluid equal to the object's entire volume. If the buoyant force is less than the weight of the object, the object is negatively buoyant and will sink. If the buoyant force is equal to the object's weight, the object is neutrally buoyant and will “hover” under the surface without sinking or moving upward. If the buoyant force is greater than the weight of the object, the object is positively buoyant and will accelerate upward in the fluid. It is not necessary to calculate the maximum buoyant force to determine if an object will float. Simply compare the density (mass/volume) of the object to the density of the fluid. The net force acting on an object placed in a fluid depends on the relative weight of equal volumes of the object and the fluid. With equal volumes, greater density means greater weight. When the density of an object is greater than that of the fluid, it is negatively buoyant in that fluid. When the density of the object is less than that of the fluid, the object is positively buoyant. When the density of the object is the same as that of the fluid, it is neutrally buoyant. In the deep ocean, pressure can also affect buoyancy by compressing materials. This will make those materials more dense (the same mass but a smaller volume), and thus less buoyant.

Prior Knowledge

["Students should have a basic understanding of pressure, particularly as it pertains to water.", "Students should have an understanding of density and buoyancy. "]

Recommended Prior Activities

- Exploring Pressure
- Under Pressure: Defining the Problem

Vocabulary

Term	Part of Speech	Definition
buoyancy	*noun*	the power to float or rise in a fluid.
model	*noun*	image or impression of an object used to represent the object or system.
pressure	*noun*	force pressed on an object by another object or condition, such as gravity.
prototype	*noun*	early version or model.

FUNDER

Alfred P. Sloan Foundation

Before Moving on to the Next Activity

In Activity 3, students built a testable model of a submersible and tested it in shallow water. In Activity 4, students will extend the testing and evaluation of their design to deeper water.

ACTIVITY 4: UNDER PRESSURE: TESTING A MODEL | 2 HRS 40 MINS

DIRECTIONS

1. Activate students' prior knowledge by having groups share their brainstorming ideas from Activity 3: Under Pressure: Creating a Model for adjustments they will make to keep their submersibles slightly positively buoyant at different depths.
Have students bring out the Engineering Process handout from the previous activity and refer to it as they share their brainstorming notes. Have groups keep the handout handy.

2. View and discuss the "Charting the Course" video.
Provide students with the following focus questions prior to viewing the video: What factors did James Cameron and his team consider when selecting their testing location? What made their choice of location unusual? What made it a good choice? Have students use these questions to take notes during the video, and use the questions to launch a discussion at the end of the video.

3. Review the testing procedure for deep-water tests.
Explain to students that they will conduct a series of deeper-water tests on their prototypes at depths of 1 meter, 1.5 meters, and 3 meters (3 feet, 5 feet, and 10 feet). Distribute the Deep-Water Testing Rubric and review it with students to make sure they understand what is expected of them in this activity. Then, per step 6 of the Engineering Process handout, have students review the testing procedure and data table they used in the shallow-water tests in the Under Pressure: Creating a Model activity.

4. Have students adjust their prototypes in preparation for the deep-water testing.
Give groups time to make adjustments to their models at this point based on their ideas from brainstorming in the Under Pressure: Creating a Model activity. Remind students to document any changes they make.

5. Have students test the prototypes in 1 meter (3 feet) of water.

Give each group an opportunity to test their model three times at a water depth of 1 meter (3 feet) using the water column described in the How to Create a Water Column handout or an alternative container. Students should use a pole to submerge their prototype to a depth of 1 meter (3 feet) and then remove the pole to see what happens to the prototype. A negatively buoyant prototype will sink; a neutrally buoyant prototype will hover at 1 meter (3 feet), and a positively buoyant prototype will rise to the surface. The slower a positively buoyant prototype rises, the closer it is to neutrally buoyant. As students test their prototypes, have them record their data during each test, including the time it takes their prototypes to rise to the surface. Between tests, have students evaluate their results and determine any changes they want to make to their prototypes to improve their performance. Have students make any changes to their prototypes and record the details of those changes in their tables before testing again.

6. Have students test the prototypes in 1.5 meters (5 feet) of water.
After students have completed the round of testing at 1 meter (3 feet), ask them to consider differences they encountered between testing at 1 meter (3 feet) and testing at 30 centimeters (1 foot) during the shallow-water test in the previous activity. Ask: *What factors were different at the new depth? Did these factors significantly affect how the prototypes worked? How might these factors change at a depth of 1.5 meters (5 feet)?* Have students repeat the testing process at a depth of 1.5 meters (5 feet) using the water column. Again, make sure they record detailed data for each of the three tests, including any adjustments made to their designs.

7. Have students test the prototypes in 3 meters (10 feet) of water.
Explain that students will have three opportunities to test and adjust their models at the target depth of 3 meters (10 feet). Their third test at this depth will be their final test. Have students review their testing data from the previous tests and consider what factors will be different in 3 meters (10 feet) of water from factors in 30 centimeters (1 foot), 1 meter (3 feet), and 1.5 meters (5 feet) of water. For example, a prototype that is positively buoyant at 1.5 meters (5 feet) might or might not remain positively buoyant at 3 meters (10 feet) due to compression of foam pieces from the increased pressure. Have students list these factors, along with how they might affect the functioning of the prototypes. Have students make and record any adjustments to their prototypes to address these factors before beginning the final set of tests. Have students repeat the testing process at a depth of 3 meters (10 feet) using the water column. Again, make sure they record detailed data for each test, including any adjustments made to their designs. Have students note their best time for this set of tests. The best time would be the slowest time for the prototype to rise to the surface from a

depth of 3 meters (10 feet).

8. Have students write detailed deep-water testing reports.
Have students use their data from testing to document changes they made to their prototypes during the testing process and to explain why those changes were necessary. Have students use numerical data, such as the time it took the prototype to rise to the surface, to describe the changing conditions they encountered and the adjustments they made and why. Have them describe the effects of pressure on their models and how they dealt with those effects.

9. Have students revise their original concept drawings based on the testing process.
Have groups return to their original concept drawings from the Under Pressure: Defining the Problem activity. Ask: *Is there anything you would change about your original concept based on the testing you conducted on your prototype?* Have students revise their concept drawings to make any adjustments based on the testing they have done.

10. Discuss the process of modeling, testing, and revising.
Give each group a chance to brief the class on their testing results. As a class discuss the overall testing process. Talk about what worked well and what didn't work as well. Discuss the following points: What adjustments did groups make, and why were these adjustments necessary? How did the necessary adjustments differ among groups? What factors might have caused these differences?

11. Explore the *DEEPSEA CHALLENGE* team's design process and solution.
Have students read about and discuss the solution James Cameron and his team came up with to solve the problem with the foam on the provided *DEEPSEA CHALLENGE*: Systems and Technology website. View and discuss the "Contingency Plans" and "Systems Failure" videos. Provide students with the following focus questions prior to viewing the videos: What went wrong during the final dive? How did these issues affect the plans for the dive? What adjustments did the team make to address the problem? Have students use these questions to guide their note taking for each video. Then use the focus questions to open a discussion about the videos. Ask: *Are you surprised that the DEEPSEA CHALLENGE team encountered these problems after spending so much time and money to design and test the submersible prior to the final dive? How does this reflect the nature of engineering challenges?* As a class, discuss any similarities between students' engineering experiences in this activity and the expedition team's engineering process and experience.

Modification

As an alternative to using a water column built from soda bottles, you can use a 3 meter (10 foot) length of 10 cm (4 in) wide PVC, capped at the bottom.

Tip

As students test in deeper water, they may need to increase the amount of foam used or decrease the amount of items they initially used for weight (such as coins) to maintain buoyancy under increasing pressure. They may also make adjustments to increase the amount of air in the design.

Tip

Decrease your preparation time by enlisting students to help cut the bottles for the water column.

Tip

Hand-held PVC pipe cutters can be used to cut PVC pipe to whatever length necessary. Consider pre-cutting the pipe into 5 cm (2 in) segments for students. For safety reasons, do not allow students to handle the pipe cutters.

Modification

If you have access to an existing body of water at least 3 meters (10 feet) deep, such as a swimming pool, you can test the prototypes there instead of constructing the water column. Be sure to create submersion and retrieval tools that match the depth of the water.

Tip

Increase students' motivation by turning the trials at 3 meters (10 feet) into a competition. Award one point for each second that it takes a prototype to return to the surface. After all groups have completed their testing, offer prizes for the highest score and the most improved score.

Tip

Keep safety in mind while testing with the water column. One person will need to be able to reach the top of the 3 meter (10 foot) water column in order to launch the prototype. Consider drafting an adult helper for this role. If possible, locate the water column near an outdoor stairwell or tall playground equipment, such as a slide. If necessary, use a ladder to reach the top of the water column, and the water column can be attached to the ladder for stability.

Tip

Rather than using the tall water column for testing in 1 meter (3 feet) of water, you can use a smaller container, such as a large trash can. This could make it easier for students to get the prototypes into and out of the water and could allow multiple teams to test at once.

Tip

Some groups might finish steps 3 or 4 early. Have these teams create a retrieval rod to rescue any prototypes that get stuck in the water column during testing. These rods must be able to retrieve a capsule from up to 3 meters (10 feet) of water. For example, students might bend a coat hanger into a hook and attach it to the end of a long piece of bamboo or ½-inch PVC pipe.

Alternative Assessment

Use the Deep-Water Testing Rubric to assess students' testing reports.

Extending the Learning

Have groups exchange submersible models. Challenge each group to adapt the model they receive to remain neutrally buoyant in 30 centimeters (1 foot) of water. Discuss why this is more challenging than adjusting the model to be positively or negatively buoyant.

OBJECTIVES

Subjects & Disciplines

Earth Science

- Oceanography
- Engineering

Geography

- Mathematics
- Physics

Learning Objectives

Students will:

- test, evaluate, and improve models designed to remain slightly positively buoyant in 1 to 3 meters (3 to 10 feet) of water
- experience how engineers use the engineering process to test, evaluate, and improve a model

Teaching Approach

- Learning-for-use

Teaching Methods

- Cooperative learning
- Discussions
- Hands-on learning
- Reflection

Skills Summary

This activity targets the following skills:

- 21st Century Student Outcomes
  - Learning and Innovation Skills
    - Communication and Collaboration
    - Creativity and Innovation
    - Critical Thinking and Problem Solving
- Critical Thinking Skills
  - Analyzing

    - Applying
    - Creating
- Geographic Skills
    - Analyzing Geographic Information

National Standards, Principles, and Practices

NATIONAL GEOGRAPHY STANDARDS

• **Standard 15**:
How physical systems affect human systems

NATIONAL SCIENCE EDUCATION STANDARDS

• **(9-12) Standard B-2**:
Structure and properties of matter

OCEAN LITERACY ESSENTIAL PRINCIPLES AND FUNDAMENTAL CONCEPTS

• **Principle 7a**:
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.
• **Principle 7d**:
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.

ISTE STANDARDS FOR STUDENTS (ISTE STANDARDS*S)

• **Standard 1**:
Creativity and Innovation
• **Standard 2**:
Communication and Collaboration
• **Standard 4**:
Critical Thinking, Problem Solving, and Decision Making

BACKGROUND & VOCABULARY

Background Information

James Cameron and the *DEEPSEA CHALLENGE* team faced a number of design challenges as they were engineering the *DEEPSEA CHALLENGER* submersible for Cameron's historic 2012 solo dive to the bottom of the Mariana Trench. One of these challenges was designing a material that was strong and light, and that could maintain its shape under the enormous pressure nearly 11 kilometers (7 miles) down in the ocean. The team devised a syntactic foam made of tiny spheres of hollow glass suspended in a resin. The foam they designed was so light and strong and held up so well under pressure that the team was able to use it as the main body of the submersible. Many ordinary foams, such as Styrofoam, also contain large amounts of air, but they are highly compressible under pressure. For example, Styrofoam is made up of tiny pellets of a synthetic material and is almost 90% air. Under high pressure, air is forced out of the foam, compressing it. Compressed foam can be less buoyant than foam in its normal, uncompressed state.

Buoyancy is the upward force exerted by a fluid on an object, equal to the weight of the fluid displaced by the object. (Note that both liquids and gases are considered fluids.) Buoyancy works to make objects float because the pressure at the bottom of the object, which is deeper in the fluid, is greater than the pressure at the top of the object. This creates a net upward force. When an object is placed into a fluid, it displaces a volume of fluid equal to the volume of the part of the object immersed in the fluid. As an object is lowered into a fluid, the volume of the part of the object immersed in the fluid increases, and so does the amount of fluid being displaced. The weight of the fluid being displaced is equal to the buoyant force. The buoyant force reaches a maximum when the object is completely submerged, that is, when the object is displacing a volume of fluid equal to the object's entire volume. If the buoyant force is less than the weight of the object, the object is negatively buoyant and will sink. If the buoyant force is equal to the object's weight, the object is neutrally buoyant and will "hover" under the surface without sinking or moving upward. If the buoyant force is greater than the weight of the object, the object is positively buoyant and will accelerate upward in the fluid. It is not necessary to calculate the maximum buoyant force to determine if an object will float. Simply compare the density (mass/volume) of the object to the density of the fluid. The net force acting on an object placed in a fluid depends on the relative weight of equal volumes of the object and the fluid. With equal volumes, greater density means greater weight. When the density of an object is greater than that of the fluid, it is negatively buoyant in that fluid. When the density of the object is less than that of the fluid, the object is positively buoyant. When the density of the object is the same as that of the fluid, it is neutrally buoyant. In the deep ocean, pressure can also affect buoyancy by compressing materials. This will make those materials more dense (the same mass but a smaller volume), and thus less buoyant. The *DEEPSEA CHALLENGER* was designed with syntactic foam because the foam is light, strong, and not as compressible as other types of foam. This helped keep the *DEEPSEA CHALLENGER* light and minimized the effects of pressure on the vehicle's buoyancy.

Prior Knowledge

[]

Recommended Prior Activities

- Exploring Pressure
- Under Pressure: Creating a Model
- Under Pressure: Defining the Problem

Vocabulary

Term	Part of Speech	Definition
buoyancy	*noun*	the power to float or rise in a fluid.
pressure	*noun*	force pressed on an object by another object or condition, such as gravity.
syntactic foam	*noun*	material consisting of tiny hollow "microballoons" made from material such as glass or carbon.

FUNDER

Alfred P. Sloan Foundation

Alternative Assessment

Have students write a reflection on the process they used to solve the original problem presented to them to design a submersible vehicle and plan a dive to collect information about deep-sea life. Distribute the Engineering Process Reflection Rubric to each student and review the criteria you will use to assess their written reflections. Tell students to refer to their notes from the Engineering Process handout, their data collection, and the reports they wrote at each stage of the process as they write their reflection. Explain that the reflection should include a summary of the problem they had to solve, an overview of their original design, a summary of how they tested an element of their design, an explanation of how pressure affected their design in deeper water, an evaluation of how well their design worked, including what they would change to make it work better, and an evaluation of how well the overall process worked for them.

FUNDER

Alfred P. Sloan Foundation