



Section 3: Multibeam Mapping for Volume 2: How Do We Explore?



NOAA Ship *Okeanos Explorer*: America's Ship for Ocean Exploration.
Image credit: NOAA. For more information, see the following
Web site:
<http://oceanexplorer.noaa.gov/okeanos/welcome.html>



Okeanos Explorer's prominent VSAT (Very small aperture terminal) dome enables satellite communications between explorers ashore and at sea and provides multiple high-definition video streams for widespread dissemination. Image credit: NOAA.

Mapping the Deep-ocean Floor

Focus

Bathymetric mapping

Grade Level

7-8 (Physical Science/Earth Science)

Focus Question

What is multibeam sonar, and what are its advantages for ocean exploration?

Learning Objectives

- Students will explain the advantages of multibeam sonar, and its role in the exploration strategy used aboard the *Okeanos Explorer*.
- Students will use data from the *Okeanos Explorer* to create a bathymetric map.

Materials

- Copies of *Making Three-Dimensional Surface Charts using Microsoft Excel™* and *Bathymetric Data from the Vicinity of the Kawio Barat Volcano*; one copy for each student group

Audio Visual Materials

- Optional – Images of exploration technologies and animations (see Learning Procedure, Step 1c)

Teaching Time

Two or three 45-minute class periods

Seating Arrangement

Groups of three to four students

Maximum Number of Students

30

Key Words and Concepts

Ocean Exploration
Okeanos Explorer
Bathymetric map
Multibeam sonar



Background Information

NOTE: Explanations and procedures in this lesson are written at a level appropriate to professional educators. In presenting and discussing this material with students, educators may need to adapt the language and instructional approach to styles that are best suited to specific student groups.

On August 13, 2008, the NOAA Ship *Okeanos Explorer* was commissioned as “America’s Ship for Ocean Exploration;” the only U.S. ship whose sole assignment is to systematically explore Earth’s largely unknown ocean. The strategy for accomplishing this mission is to use state-of-the-art technologies to search the ocean for anomalies; things that are unusual and unexpected. When an anomaly is found, the exploration strategy shifts to obtaining more detailed information about the anomaly and the surrounding area. An important concept underlying this strategy is the distinction between exploration and research. As a ship of discovery, the role of *Okeanos Explorer* is to locate new features in the deep ocean, and conduct preliminary investigations that provide enough data to justify follow-up by future expeditions.

The *Okeanos Explorer* strategy involves three major activities:

- Underway reconnaissance;
- Water column exploration; and
- Site characterization.

Underway reconnaissance involves mapping the ocean floor and water column while the ship is underway, and using other sensors to measure chemical and physical properties of seawater. Water column exploration involves making measurements of chemical and physical properties “from top to bottom” while the ship is stopped. In some cases these measurements may be made routinely at pre-selected locations, while in other cases they may be made to decide whether an area with suspected anomalies should be more thoroughly investigated. Site characterization involves more detailed exploration of a specific region, including obtaining high quality imagery, making measurements of chemical and physical seawater properties, and obtaining appropriate samples.

In addition to state-of-the-art navigation and ship operation equipment, this strategy depends upon four types of technology:

- Telepresence;
- Multibeam sonar mapping;
- CTD (an instrument that measures conductivity, temperature, and depth) and other electronic sensors to measure chemical and physical seawater properties; and
- A Remotely Operated Vehicle (ROV) capable of obtaining high-quality imagery and samples in depths as great as 4,000 meters.

In many ways, telepresence is the key to the *Okeanos Explorer*’s exploration strategy. This technology allows people to observe and interact with events at a remote location. The *Okeanos Explorer*’s telepresence capability is based on advanced broadband satellite communication through which live images can be transmitted from the seafloor to scientists ashore, classrooms, and newsrooms, and opens new educational opportunities that are a major part of *Okeanos Explorer*’s mission for advancement of knowledge.



NOAA Ship *Okeanos Explorer*: America’s Ship for Ocean Exploration.
Image credit: NOAA. For more information, see the following Web site:
<http://oceanexplorer.noaa.gov/okeanos/welcome.html>

Okeanos Explorer Vital Statistics:

Commissioned: August 13, 2008; Seattle, Washington
Length: 224 feet
Breadth: 43 feet
Draft: 15 feet
Displacement: 2,298.3 metric tons
Berthing: 46, including crew and mission support
Operations: Ship crewed by NOAA Commissioned Officer Corps and civilians through NOAA’s Office of Marine and Aviation Operations (OMAO); Mission equipment operated by NOAA’s Office of Ocean Exploration and Research

For more information, visit <http://oceanexplorer.noaa.gov/okeanos/welcome.html>.
Follow voyages of America’s ship for ocean exploration with the *Okeanos Explorer* Atlas at http://www.ncddc.noaa.gov/website/google_maps/OkeanosExplorer/mapsOkeanos.htm

In the summer of 2010, years of planning, field trials, and state-of-the-art technology came together for the first time on the ship's maiden voyage as part of the INDEX-SATAL 2010 Expedition. This expedition was an international collaboration between scientists from the United States and Indonesia to explore the deep ocean in the Sangihe Talaud Region. This region is located in the 'Coral Triangle', which is the global heart of shallow-water marine biodiversity. A major objective of the expedition was to advance our understanding of undersea ecosystems, particularly those associated with submarine volcanoes and hydrothermal vents. Among the Expedition's many "firsts," this was the first time scientists have been able to use an underwater robot to get a first-hand look at deepwater biodiversity in the waters of the Sangihe Talaud Region. For more information about the INDEX-SATAL 2010 Expedition, see <http://oceanexplorer.noaa.gov/okeanos/explorations/10index/welcome.html>.

Sonar (which is short for SOund Navigation and Ranging) systems are used to determine water depth, as well as to locate and identify underwater objects. In use, an acoustic signal or pulse of sound is transmitted into the water by a sort of underwater speaker known as a transducer. The transducer may be mounted on the hull of a ship, or may be towed in a container called a towfish. If the seafloor or other object is in the path of the sound pulse, the sound bounces off the object and returns an "echo" to the sonar transducer. The time elapsed between the emission of the sound pulse and the reception of the echo is used to calculate the distance of the object. Some sonar systems also measure the strength of the echo, and this information can be used to make inferences about some of the reflecting object's characteristics. Hard objects, for example, produce stronger echoes than softer objects. This is a general description of "active sonar". "Passive sonar" systems do not transmit sound pulses. Instead, they "listen" to sounds emitted from marine animals, ships, and other sources.



Multibeam sonar is one of the most powerful tools available for modern deep-sea exploration. A multibeam system uses multiple transducers pointing at different angles on either side of a ship to create a swath of signals. The *Okeanos Explorer* is equipped with a Kongsberg Simrad EM 302 multibeam system that can produce



up to 864 depth soundings in a single swath. The time interval between signal transmission and return echo arrival is used to estimate depth over the area of the swath. In some systems, the intensity of the return echo is also used to infer bottom characteristics that can be used for habitat mapping. In addition to high-resolution maps, multibeam data can be used to create three dimensional models or even “fly-through” videos that simulate a trip across the area being mapped. For a fascinating example of this, see <http://oceanexplorer.noaa.gov/explorations/02fire/logs/jul08/media/sm2k.html>. This 3D fly-through movie shows the seafloor in the Magic Mountain area of Explorer Ridge (near the coast of Vancouver Island) where there are active hydrothermal vents. To see what the vents look like, you can view other fly-throughs of the same area at <http://oceanexplorer.noaa.gov/explorations/02fire/logs/magicmountain>.

Recently, a new generation of multibeam sonars has been developed that are able to map features in the water column as well as the seafloor. This ability will potentially allow multibeam sonars to map the location of fish and marine mammals, as well as a wide range of physical oceanographic processes. On May 17, 2009, the *Okeanos Explorer* was testing its multibeam sonar mapping system off the coast of California. Suddenly, the multibeam image showed a plume of what scientists believe may be methane gas rising vertically 1,000 meters from the ocean floor. No such feature had ever been reported from this area before. You can see a video simulation that shows how multibeam sonar discovered this plume, and also provides a graphic overview of how multibeam works here: (http://ccom.unh.edu/NOAA_oceanexploration/PlumePoints2.mov). For more information about sonar systems, see <http://oceanexplorer.noaa.gov/technology/tools/sonar/sonar.html>.

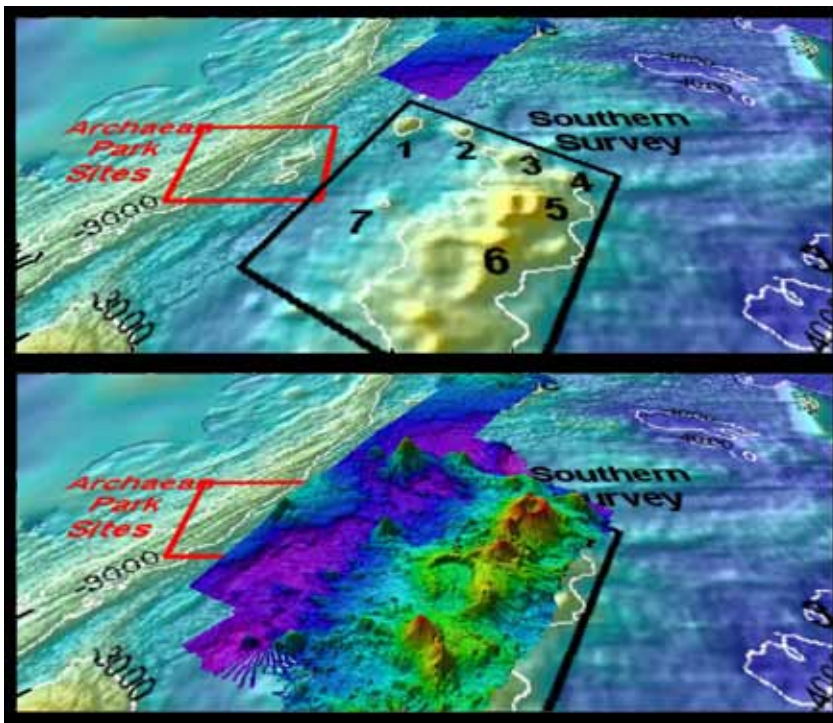
An important technique for studying multibeam images uses a three-dimensional data visualization system called Fledermaus (which is the German word for “bat,” and is pronounced “FLEE-der-mouse”). The “Watching in 3-D” lesson includes a simple analysis of multibeam data using free viewing software for multibeam imagery in the Fledermaus file format.

Multibeam Mapping Systems Aboard the *Okeanos Explorer*

Okeanos Explorer carries a Kongsberg Maritime EM302 deepwater multibeam sonar system. Transducers for the system are installed on the ship’s hull in a custom-designed housing. The system can transmit up to 288 beams, can collect as many as 432 depth measurements in a single swath, and automatically compensates for movements of the ship. The EM302 operates in depths ranging between 10 m and 7,000 m. The width of the swath is about 5.5 times the depth, to a maximum of about 8 km. Depth resolution of the system is 1 cm. At a depth of 4,000 m, the system can resolve features with a dimension of approximately 50 m.

Software packages used to process data from the EM302 and to integrate these data with GPS information about geographic position and sensor data about ship movements to compensate for pitch and roll include:

- Seafloor Information System
- CARIS
- Fledermaus
- arcGIS
- SonarWiz
- Hypack
- MapInfo



This “before and after” image provides a glimpse of *Okeanos Explorer*’s EM302 mapping system capabilities in deep water. The top image shows what we previously knew about the seafloor terrain in the southern Mariana region from satellite altimetry data. The bottom image includes an overlay of the information provided by the ship’s EM302 multibeam system. Image courtesy of NOAA Office of Ocean Exploration and Research. http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/hires/em302_before_after_hires.jpg

In this lesson, students will learn about multibeam sonar, and use data from the *Okeanos Explorer*'s multibeam sonar system to create a three-dimensional surface chart using Microsoft Excel™.

Note: mention of proprietary names does not imply endorsement by NOAA.

Learning Procedure

NOTE: This lesson uses Microsoft Excel™ version 12.2.0. Other versions may require modifications to instructions provided on the student worksheet.

1. To prepare for this lesson:

a) Review:

- Introductory essays for the INDEX-SATAL 2010 Expedition (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/welcome.html>);
- Minding the Multibeam at Midnight by Colleen Peters (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/aug05/aug05.html>); and
- State of the Art Seafloor Survey by Meme Lobecker and Elaine Stuart (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/july31/july31.html>).

(b) Review background information about the *Okeanos Explorer* exploration strategy and technologies.

(c) If desired, download images to accompany discussions in Step 2. You may also want to download this “before and after” image to illustrate the capabilities of multibeam sonar:

http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/bires/em302_before_after_bires.jpg,

as well as one or more of the animations referenced above to accompany discussions in Step 3:

<http://oceanexplorer.noaa.gov/explorations/02fire/logs/jul08/media/sm2k.html>;

<http://oceanexplorer.noaa.gov/explorations/02fire/logs/magicmountain>; and

http://ccom.unb.edu/NOAA_oceanexploration/PlumePoints2.mov.

(d) Review *Making Three-Dimensional Surface Charts using Microsoft Excel™*.

(e) (Optional) Review procedures for viewing multibeam imagery in the Fledermaus file format explained in the *Watching in 3-D* lesson, and decide whether to demonstrate this imagery as part of class discussions.

(f) Ensure that students will have access to Microsoft Excel™ on the computers they will use to complete chart activity (Step 5) and download the file **KawioBaratReduced.xlsx** (<http://oceanexplorer.noaa.gov/okeanos/edu/resources/media/KawioBaratReduced.xlsx>);

OR

KawioBaratReduced.xls (<http://oceanexplorer.noaa.gov/okeanos/edu/resources/media/KawioBaratReduced.xls>) depending upon which version of Microsoft Excel students will be using.

(g) Review *Hands-On Activity Guide Multibeam Mapping: PING)))™ Sonar Simulation* and decide whether you wish to include the activity as part of this lesson.

2. Briefly introduce the NOAA Ship *Okeanos Explorer* and the INDEX-SATAL 2010 Expedition. Briefly discuss why this kind of exploration is important (for background information, please see the lesson, *Earth's Ocean is 95% Unexplored: So What?*; <http://oceanexplorer.noaa.gov/okeanos/>

STEM Connections

Ocean exploration aboard the *Okeanos Explorer* is a real-world example of STEM concepts in action:

Science provides the overall objective – to better understand Earth's ocean – as well as a methodology for systematically acquiring this understanding;

Technology includes the tools, systems and processes that have been made to make deep-ocean exploration possible;

Engineering designs the technologies that can function in the deep-ocean environment;

Mathematics provides the basis for measurements, data analysis, and engineering design.

With increasing attention to developing integrated approaches to STEM education and technological literacy, the How Do We Explore? theme offers an exciting context for educators who wish to bring more STEM content to their classrooms.

To assist with such efforts, most lessons developed for the *How Do We Explore?* theme identify opportunities to include specific benchmarks and standards for technological literacy that have been developed by the International Technology and Engineering Education Association (ITEA, 2007). While these standards have not been widely adopted, they provide useful guidance for efforts to enhance STEM content in advance of its inclusion in formal curricula.

In addition, the *How Do We Explore?* suite of lessons includes activities that are intended to provide opportunities to apply design processes, build technological devices, and develop some of the hands-on abilities that are an integral part of most concepts about STEM education. These activities are directly tied to the technologies and scientific methodologies used for ocean exploration aboard the *Okeanos Explorer*.

For more information, see: http://www.iteaconnect.org/TAA/Publications/TAA_Publications.html



[explorations/10index/background/edu/media/so_what.pdf](http://oceanexplorer.noaa.gov/explorations/10index/background/edu/media/so_what.pdf)). Highlight the overall exploration strategy used by *Okeanos Explorer*, including the following points:

- The overall strategy is based on finding anomalies;
- This strategy involves
 - Underway reconnaissance;
 - Water column exploration; and
 - Site characterization;
- This strategy relies on four key technologies:
 - Multibeam sonar mapping system;
 - CTD 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 4,000 meters; and
 - Telepresence technologies that allow people to observe and interact with events at a remote location.

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

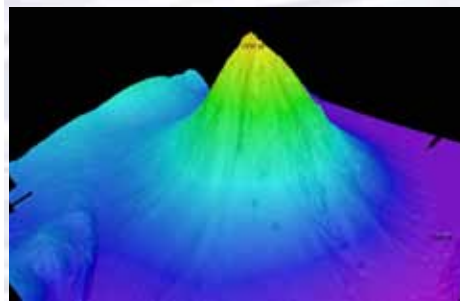
4. Ask students what they know about sonar, and provide additional information as necessary. Be sure students understand that sonar (which stands for SOund NAvigation and Ranging) uses an acoustic signal or pulse of sound that is transmitted into the water by a sort of underwater speaker known as a transducer. Transducers may be mounted on the hull of a ship, or may be towed in a container called a towfish. If the seafloor or other object is in the path of the sound pulse, the sound bounces off the object and returns an “echo” to the sonar transducer. The time elapsed between the emission of the sound pulse and the reception of the echo is used to calculate the distance of the object. Some sonar systems also measure the strength of the echo, and this information can be used to make inferences about some of the reflecting object’s characteristics. Hard objects, for example, produce stronger echoes than softer objects. Sonar systems can be used to determine water depth, as well as to locate and identify underwater objects. A multibeam sonar system uses multiple transducers pointing at different angles on either side of a ship to create a swath of signals. The time interval between signal transmission and return echo arrival is used to estimate depth over the area of the swath. In addition to high-resolution maps, multibeam data can be used to create three dimensional models or even “fly-through” videos that simulate a trip across the area being mapped. You may want to show one or more of the video clips referenced in Step 1c.

Describe the role of multibeam sonar in ocean exploration aboard the *Okeanos Explorer*. Based on their homework reading, students should realize that this is the key technology for the “reconnaissance” component of the overall exploration strategy, and provides the “big picture” view as explorers look for anomalies. Another important point is that, thanks to telepresence, images from mapping results could be shared in real time with scientists in Exploration Command Centers, so that these scientists could have input into selecting sites where water column studies and underwater robot dives were to take place.

Briefly discuss other types of bathymetric maps, and how they were made. Before the invention of sonar, water depths were determined by dropping a weighted line over the side of a ship and measuring the amount of line needed to reach the bottom. These measurement (called soundings) were recorded on nautical charts.



The ROV Little Hercules descends through deep water to an undersea volcano in the Celebes Sea to search for hydrothermal vents and associated ecosystems. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/hires/1june29_hires.jpg



Okeanos Explorer's EM302 multibeam sonar mapping system produced this detailed image of the Kawio Barat seamount, which rises around 3800 meters from the seafloor. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/hires/june26fig1_hires.jpg



Scientists in the Exploration Command Center at NOAA's Pacific Marine Environmental Laboratory in Seattle view live video from the *Okeanos Explorer*'s ROV. Image courtesy NOAA
<http://www.pmel.noaa.gov/images/headlines/ecc.jpg>



Senior Survey Technician Elaine Stuart holds onto the CTD as it comes aboard the *Okeanos Explorer*. Image courtesy NOAA
<http://www.moc.noaa.gov/visitor/photos/photospage-b/CAP%20015.jpg>



Physical Scientist Meme Lobecker teaches Indonesian scientist Cecep Sujana how to conduct an XBT cast. The XBT measures temperature through the water column. The XBT software calculates sound velocity, which is applied to the multibeam data for accurate measure of bathymetry. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.

http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/hires/xbt_cast_hires.jpg

Many nautical charts are still in use today that are covered with tiny numbers that represent individual soundings, some of which were made many years ago. Sonar made it possible to collect many more depth readings, but until recently these could only be recorded directly beneath a ship. Improvements in electronics and modern computer technologies led to the development of multibeam sonar, which provides three-dimensional images of the seafloor, in much greater detail than older methods. Maps generated by multibeam sonar systems are particularly useful for ocean exploration, since they allow scientists to focus on areas that are geologically interesting or have a high probability of being inhabited by unusual organisms. This image: http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/hires/em302_before_after_hires.jpg. shows how much *Okeanos Explorer*'s EM302 mapping system adds to what we know about seafloor terrain.

5. Tell students that one of the priorities for the INDEX-SATAL 2010 Expedition was to explore a submarine volcano named Kawio Barat, which they read about as part of their homework assignment. Say that their assignment is to create a three-dimension graph called a surface plot using depth data from the Kawio Barat area. Provide each student group with a copy of *Making Three-Dimensional Surface Charts using Microsoft Excel™* as well as *Bathymetric Data from the Vicinity of the Kawio Barat Volcano*. Tell students that these data were collected by the *Okeanos Explorer*'s multibeam sonar mapping system during the INDEX-SATAL 2010 Expedition.

Be sure students understand that each data point represents the depth of water at the location described by the geographic coordinates. Note that for the purposes of this exercise, we are only using a small sample of all the data collected, which for this site amounts to hundreds of thousands of data points.

When students have completed their surface plots, lead a discussion of their results. Figure 1 shows a typical plot of the data, and the results of several rotations as described on the worksheet. This discussion may also include the following components of technological literacy (ITEA, 2007):

- **Scope of technology** – Development of multibeam sonar technology provides detailed images of the ocean floor that were not possible before this technology was developed.
- **Core concepts of technology** – Multibeam sonar is an example of several technological systems connected together; including sonar systems to obtain depth data, global positioning systems for geographic location, sensors to detect ship motion so that data can be corrected for pitch and roll, and computer systems to analyze raw data and convert the data to accurate depth estimates and visual images.
- **Relationships between technologies and other fields of study** – Improvements to each of the technologies listed above improves the overall capability of bathymetric information from multibeam sonar systems; and this information is useful to geologists, biologists, and many other branches of science.
- **Effects of technology on the environment** – Some scientists are concerned that marine mammals may be harmed if they are close to ships using certain types of sonar technology. *Okeanos Explorer*'s EM 302 multibeam system is equipped with a function that reduces transmission power to avoid harming mammals if they are nearby.

6. If desired, have students complete the *PING)))™ Sonar Simulation Activity* (Step 1f). This activity addresses additional components of technological literacy, including:

- Attributes of design;
- Understanding of engineering design;
- Problem-solving approaches;
- Abilities to apply design processes; and
- Abilities to use and maintain technological products.

The BRIDGE Connection

www.vims.edu/bridge/ – Scroll over “Ocean Science Topics” in the menu on the left side of the page, then “Human Activities,” then “Human Activities,” then click on “Technology” for activities and links about ocean exploration technologies.

The “Me” Connection

Have students write a first-hand account of their experiences on an exploratory mission to the Kawio Barat volcano, including topographic features revealed by multibeam sonar surveys.

Connections to Other Subjects

English/Language Arts, Social Studies, Mathematics

Assessment

Class discussions and students’ work with the charting activity provide opportunities for assessment.

Extensions

See the *Calling All Explorers* lesson for an activity involving maps and GPS technology: <http://oceanexplorer.noaa.gov/okeanos/edu/lessonplans/media/10callingallexplorers.pdf>.

Multimedia Discovery Missions

<http://oceanexplorer.noaa.gov/edu/learning/welcome.html> – Click on the links to Lessons 5 and 6 for interactive multimedia presentations and Learning Activities on Chemosynthesis and Hydrothermal Vent Life, and Deep-Sea Benthos.

Other Relevant Lesson Plans from NOAA’s Ocean Exploration Program

Earth’s Ocean is 95% Unexplored: So What?

(from the INDEX-SATAL 2010 Expedition)

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

Focus: Importance of deep-ocean exploration (Grades 5-6; Life Science/Earth Science)

Students describe at least three different deep-ocean ecosystems, explain at least three reasons for exploring Earth’s deep ocean, and explain at least three ways that deep-ocean ecosystems may benefit humans, and create a wall magazine to communicate scientific ideas.

Sonar Simulation

(from the Cradle of the Earthquake: Exploring the Underwater San Andreas Fault 2010 Expedition)





<http://oceanexplorer.noaa.gov/explorations/10sanandreas/background/edu/media/sonarsim78.pdf>

Focus: Side scan sonar (Grades 7-8; Earth Science/Physical Science)

Students describe side-scan sonar, compare and contrast side-scan sonar with other methods used to search for underwater objects, and make inferences about the topography of an unknown and invisible landscape based on systematic discontinuous measurements of surface relief.

Mapping the Ocean Floor

(from the INSPIRE: Chile Margin 2010 expedition)

<http://oceanexplorer.noaa.gov/explorations/10chile/background/edu/media/mapping.pdf>

Focus: Bathymetric Mapping (Grades 7-8; Physical Science/Earth Science)

Students create a two-dimensional topographic map from bathymetric survey data, create a three-dimensional model of seafloor topography from a two-dimensional topographic map, and interpret two- and three-dimensional topographic data.

How Does Your Magma Grow?

(from the 2005 GalAPAGos: Where Ridge Meets Hotspot Expedition)

http://oceanexplorer.noaa.gov/explorations/05galapagos/background/edu/media/05galapagos_magma.pdf

Focus: Hot spots and midocean ridges (Grades 7-8; Physical Science)

Students identify types of plate boundaries associated with movement of the Earth's tectonic plates, compare and contrast volcanic activity associated with spreading centers and hot spots, describe processes which resulted in the formation of the Galapagos Islands, and describe processes that produce hydrothermal vents.

Sound Pictures

(from the Cradle of the Earthquake: Exploring the Underwater San Andreas Fault 2010 Expedition)

<http://oceanexplorer.noaa.gov/explorations/10sanandreas/background/edu/media/soundpics912.pdf>

Focus: Sonar (Grades 9-12; Physical Science)

Students explain the concept of sonar, describe the major components of a sonar system, explain how multibeam and sidescan sonar systems are useful to ocean explorers, and simulate sonar operation using a motion detector and a graphing calculator.

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.

Anonymous. 2010. Web site for the INDEX-SATAL 2010 Expedition [Internet]. Office of Ocean Exploration and Research, NOAA [cited January 7, 2011]. Available from <http://oceanexplorer.noaa.gov/okeanos/explorations/10index/welcome.html> – Includes links to lesson plans, career connections, and other resources



Anonymous. Ocean Explorer [Internet]. NOAA Office of Ocean Exploration and Research [cited January 4, 2011]. Available from: <http://oceanexplorer.noaa.gov>.

Anonymous. 2011. *Okeanos Explorer* Education Materials Collection [Internet]. NOAA Office of Ocean Exploration and Research [cited January 4, 2011]. Available from: <http://oceanexplorer.noaa.gov>

Anonymous. Sonar [Internet]. NOAA Ocean Explorer [cited January 17, 2011]. Available from: <http://www.oceanexplorer.noaa.gov/technology/tools/sonar/sonar.html>

International Technology Education Association. 2007. Standards for Technological Literacy: Content for the Study of Technology. Reston, VA. 260 pp.

Lobecker, M. and E. Stuart. 2010. State of the Art Seafloor Survey [Internet]. NOAA Ocean Explorer [cited January 10, 2011]. Available from: <http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/july31/july31.html>

Malik, M. E. Lobecker, E. Stuart, C. Peters, and N. Verplanck. 2010 NOAA Ship *Okeanos Explorer* Maps Kawio Barat [Internet]. NOAA Ocean Explorer [cited January 10, 2011]. Available from: <http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/june26/june26.html>

Peters, C. 2010. Minding the Multibeam at Midnight [Internet]. NOAA Ocean Explorer [cited January 10, 2011]. Available from: <http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/aug05/aug05.html>

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

- Transfer of energy

Content Standard D: Earth and Space Science

- Structure of the Earth system
- Earth's history
- Earth in the solar 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

- Science and technology in society

Content Standard G: History and Nature of Science

- Science as a human endeavor
- Nature of science





Ocean Literacy Essential Principles and Fundamental Concepts

Because most Fundamental Concepts are broad in scope, some aspects of some Concepts may not be explicitly addressed in this lesson. Such aspects, however, can be easily included at the discretion of the individual educator.

Essential Principle 1.

The Earth has one big ocean with many features.

Fundamental Concept b. An ocean basin's size, shape and features (such as islands, trenches, mid-ocean ridges, rift valleys) vary due to the movement of Earth's lithospheric plates. Earth's highest peaks, deepest valleys and flattest vast plains are all in the ocean.

Essential Principle 5.

The ocean supports a great diversity of life and ecosystems.

Fundamental Concept e. The ocean is three-dimensional, offering vast living space and diverse habitats from the surface through the water column to the seafloor. Most of the living space on Earth is in the ocean.

Fundamental Concept g. There are deep-ocean ecosystems that are independent of energy from sunlight and photosynthetic organisms. Hydrothermal vents, submarine hot springs, and methane cold seeps rely only on chemical energy and chemosynthetic organisms to support life.

Essential Principle 6.

The ocean and humans are inextricably interconnected.

Fundamental Concept b. From the ocean we get foods, medicines, and mineral and energy resources. In addition, it provides jobs, supports our nation's economy, serves as a highway for transportation of goods and people, and plays a role in national security.

Fundamental Concept g. Everyone is responsible for caring for the ocean. The ocean sustains life on Earth and humans must live in ways that 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, subsea observatories and unmanned submersibles.

Fundamental Concept f. Ocean exploration is truly interdisciplinary. It requires close collaboration among biologists, chemists, climatologists, computer programmers, engineers, geologists, meteorologists, and physicists, and new ways of thinking.

Send Us Your Feedback

We value your feedback on this lesson, including how you use it in your formal/informal education settings.

Please send your comments to:

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Making Three-Dimensional Surface Charts using Microsoft Excel™

Table 1 lists 182 data points from a bathymetric survey in the vicinity of the Kawio Barat volcano. Each depth measurement is listed with a corresponding geographic location described by latitude and longitude. Your assignment is to plot these data points in a way that gives a sense of the topography in the survey area. To do this, you can make a surface plot using Microsoft Excel™. We just have to re-arrange the data somewhat so that Excel™ will give us what we want.

1. Open Microsoft Excel™, then open the file “KawioBaratReduced.xlsx” or “KawioBaratReduced.xls”. Your screen should resemble Figure 1. Notice that latitude values are across the top of the page as columns, and the longitude values are on the left side of the page in rows. The depth measurements are in the middle of the page, in grid cells that correspond to the latitude and longitude of the location where each measurement was made. You can also see that a row and a column have been added that have numbers from 1 to 14 corresponding to the longitude values, and numbers from 1 to 13 corresponding to the latitude values. This will cause Excel™ to use a simple linear scale when it plots the data.

Figure 1.

		C	D	E	F	G	H	I	J	K	L	M	N	O	
	Latitude	4.02° N	4.025° N	4.03° N	4.035° N	4.04° N	4.045° N	4.05° N	4.055° N	4.06° N	4.065° N	4.07° N	4.075° N	4.08° N	
1	Longitude														
2	125.725° E	1	-4594	-4445	-4296	-4147	-4152	-4157	-4162	-4242	-4322	-4402	-4429	-4470	-4510
3	125.716° E	2	-4404	-4245	-4096	-3947	-3910	-3908	-3907	-4021	-4136	-4212	-4301	-4377	-4454
4	125.706° E	3	-4213	-4054	-3905	-3876	-3868	-3859	-3851	-3900	-3950	-4009	-4124	-4205	-4297
5	125.7° E	4	-4057	-3900	-3543	-3286	-3219	-3182	-3285	-3510	-3738	-3901	-4060	-4208	-4356
6	125.691° E	5	-3900	-3566	-3231	-2997	-2771	-2704	-2918	-3220	-3522	-3824	-3947	-4131	-4316
7	125.681° E	6	-3744	-3332	-2919	-2507	-2323	-2227	-2552	-2930	-3308	-3686	-3833	-4054	-4275
8	125.671° E	7	-3793	-3411	-3030	-2644	-2412	-2461	-2713	-3094	-3405	-3752	-3865	-4104	-4324
9	125.661° E	8	-3843	-3531	-3220	-2913	-2433	-2091	-2874	-3188	-3503	-3818	-3956	-4164	-4372
10	125.651° E	9	-3892	-3631	-3370	-2988	-2818	-2909	-3034	-3317	-3600	-3883	-4018	-4219	-4421
11	125.641° E	10	-3941	-3731	-3520	-3110	-3072	-3123	-3195	-3644	-3896	-3949	-4079	-4274	-4469
12	125.631° E	11	-4134	-3955	-3776	-3398	-3543	-3729	-3495	-3697	-3900	-4103	-4216	-4411	-4605
13	125.621° E	12	-4326	-4179	-4032	-3685	-3855	-3824	-3794	-3948	-4102	-4257	-4354	-4547	-4741
14	125.611° E	13	-4519	-4403	-4288	-4173	-4146	-4120	-4064	-4199	-4305	-4410	-4491	-4636	-4781
15	125.601° E	14	-4711	-4627	-4544	-4460	-4438	-4415	-4393	-4450	-4507	-4564	-4628	-4724	-4820

2. To make a surface plot, click on the “Charts” tab at the top of the spreadsheet (or select “Chart” from the “Insert” menu). A chart menu will open at the top of the spreadsheet. Click on the “Surface” button, and four boxes will appear in the chart menu showing the types of surface charts that are available.
3. Click and hold in the blank cell just below the “Latitude” label (cell B2) and drag down and to the right to select all of the depth measurements as well as the row and column numbers (in column B and Row 2). Now your screen should resemble Figure 2.

Figure 2.

Table 1
Bathymetric Survey Data from Kawio Barat Volcano
***Okeanos Explorer* INDEX-SATAL 2010 Expedition**

North Latitude	East Longitude	Depth (m)	North Latitude	East Longitude	Depth (m)	North Latitude	East Longitude	Depth (m)
4.050	125.725	-4594	4.075	125.725	-4147	4.100	125.725	-4162
4.050	125.717	-4404	4.075	125.717	-3912	4.100	125.717	-3907
4.050	125.708	-4213	4.075	125.708	-3676	4.100	125.708	-3651
4.050	125.700	-4057	4.075	125.700	-3286	4.100	125.700	-3285
4.050	125.692	-3900	4.075	125.692	-2897	4.100	125.692	-2918
4.050	125.683	-3744	4.075	125.683	-2507	4.100	125.683	-2552
4.050	125.675	-3793	4.075	125.675	-2344	4.100	125.675	-2713
4.050	125.667	-3843	4.075	125.667	-2363	4.100	125.667	-2874
4.050	125.658	-3892	4.075	125.658	-2988	4.100	125.658	-3034
4.050	125.650	-3941	4.075	125.650	-3310	4.100	125.650	-3195
4.050	125.642	-4134	4.075	125.642	-3598	4.100	125.642	-3495
4.050	125.633	-4326	4.075	125.633	-3885	4.100	125.633	-3794
4.050	125.625	-4519	4.075	125.625	-4173	4.100	125.625	-4094
4.050	125.617	-4711	4.075	125.617	-4460	4.100	125.617	-4393
4.058	125.725	-4445	4.083	125.725	-4152	4.108	125.725	-4242
4.058	125.717	-4240	4.083	125.717	-3910	4.108	125.717	-4021
4.058	125.708	-4034	4.083	125.708	-3668	4.108	125.708	-3800
4.058	125.700	-3800	4.083	125.700	-3219	4.108	125.700	-3510
4.058	125.692	-3566	4.083	125.692	-2771	4.108	125.692	-3220
4.058	125.683	-3332	4.083	125.683	-2323	4.108	125.683	-2930
4.058	125.675	-3431	4.083	125.675	-1912	4.108	125.675	-3059
4.058	125.667	-3531	4.083	125.667	-2433	4.108	125.667	-3188
4.058	125.658	-3631	4.083	125.658	-2818	4.108	125.658	-3317
4.058	125.650	-3731	4.083	125.650	-3272	4.108	125.650	-3446
4.058	125.642	-3955	4.083	125.642	-3563	4.108	125.642	-3697
4.058	125.633	-4179	4.083	125.633	-3855	4.108	125.633	-3948
4.058	125.625	-4403	4.083	125.625	-4146	4.108	125.625	-4199
4.058	125.617	-4627	4.083	125.617	-4438	4.108	125.617	-4450
4.067	125.725	-4296	4.092	125.725	-4157	4.117	125.725	-4322
4.067	125.717	-4076	4.092	125.717	-3908	4.117	125.717	-4136
4.067	125.708	-3855	4.092	125.708	-3659	4.117	125.708	-3950
4.067	125.700	-3543	4.092	125.700	-3182	4.117	125.700	-3736
4.067	125.692	-3231	4.092	125.692	-2704	4.117	125.692	-3522
4.067	125.683	-2919	4.092	125.683	-2227	4.117	125.683	-3308
4.067	125.675	-3070	4.092	125.675	-1961	4.117	125.675	-3405
4.067	125.667	-3220	4.092	125.667	-2091	4.117	125.667	-3503
4.067	125.658	-3370	4.092	125.658	-2809	4.117	125.658	-3600
4.067	125.650	-3520	4.092	125.650	-3233	4.117	125.650	-3698
4.067	125.642	-3776	4.092	125.642	-3529	4.117	125.642	-3900
4.067	125.633	-4032	4.092	125.633	-3824	4.117	125.633	-4102
4.067	125.625	-4288	4.092	125.625	-4120	4.117	125.625	-4305
4.067	125.617	-4544	4.092	125.617	-4415	4.117	125.617	-4507



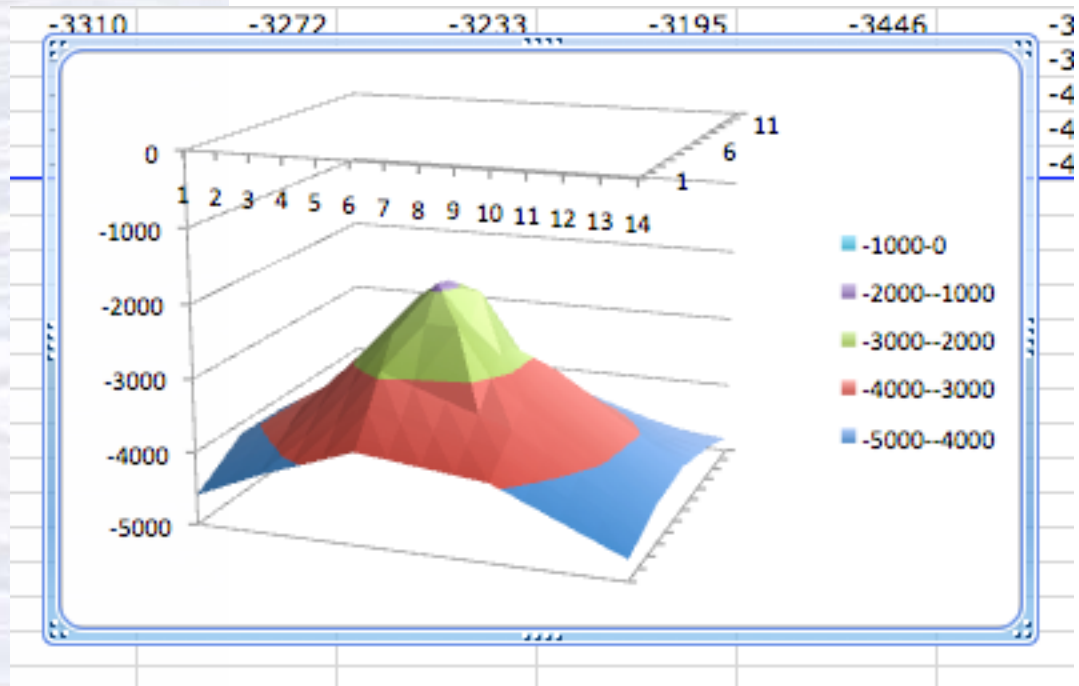
Table 1 (continued)
Bathymetric Survey Data from Kawio Barat Volcano
Okeanos Explorer INDEX-SATAL 2010 Expedition

North Latitude	East Longitude	Depth (m)	North Latitude	East Longitude	Depth (m)
4.125	125.725	-4402	4.142	125.725	-4470
4.125	125.717	-4251	4.142	125.717	-4377
4.125	125.708	-4099	4.142	125.708	-4285
4.125	125.700	-3961	4.142	125.700	-4208
4.125	125.692	-3824	4.142	125.692	-4131
4.125	125.683	-3686	4.142	125.683	-4054
4.125	125.675	-3752	4.142	125.675	-4109
4.125	125.667	-3818	4.142	125.667	-4164
4.125	125.658	-3883	4.142	125.658	-4219
4.125	125.650	-3949	4.142	125.650	-4274
4.125	125.642	-4103	4.142	125.642	-4411
4.125	125.633	-4257	4.142	125.633	-4547
4.125	125.625	-4410	4.142	125.625	-4636
4.125	125.617	-4564	4.142	125.617	-4724
4.133	125.725	-4429	4.150	125.725	-4510
4.133	125.717	-4301	4.150	125.717	-4454
4.133	125.708	-4174	4.150	125.708	-4397
4.133	125.700	-4060	4.150	125.700	-4356
4.133	125.692	-3947	4.150	125.692	-4316
4.133	125.683	-3833	4.150	125.683	-4275
4.133	125.675	-3895	4.150	125.675	-4324
4.133	125.667	-3956	4.150	125.667	-4372
4.133	125.658	-4018	4.150	125.658	-4421
4.133	125.650	-4079	4.150	125.650	-4469
4.133	125.642	-4216	4.150	125.642	-4605
4.133	125.633	-4354	4.150	125.633	-4741
4.133	125.625	-4491	4.150	125.625	-4781
4.133	125.617	-4628	4.150	125.617	-4820



4. While the cells are still highlighted, click on the icon for “3D Surface.” Now you should see a 3D surface plot that looks a lot like the Kawio Barat volcano! (Figure 3).

Figure 3.



5. You can even rotate it to see what the other side looks like: Under the “Chart” menu, select “3D Rotation.” A “Format Chart Area” window will open. Select 3-D Rotation from the choices on the left, then experiment with the X and Y settings to view your chart from various positions. When you find a view you like, print the image.

Hands-On Activity Guide

Multibeam Mapping: PING)))™ Sonar Simulation

Materials

Option 1 –

- 1- PING)))™ Ultrasonic Distance Sensor
- 1 - Arduino microcontroller with a prototyping board (also called a Proto Shield)
- 1 - Computer with a USB port

Option 2 –

- 1- PING)))™ Ultrasonic Distance Sensor
- 1 - BASIC Stamp microcontroller with a prototyping board (such as Parallax Board of Education)
- 1 - Computer with a USB port

Option 3 –

- 1 - Lego® NXT Ultrasonic Sensor
- 1 - Lego® NXT Brick microcontroller
- 1 - Computer with a USB port

Option 4 –

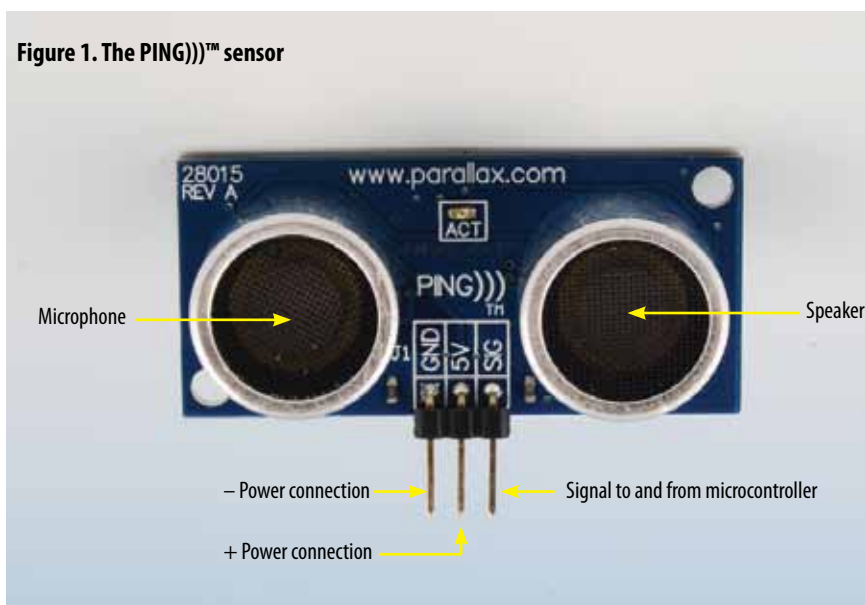
- 1 - Vernier Motion Detector
- 1 - LabQuest® or CBL 2® interface
- 1 - Computer or calculator compatible with the interface

Background

This activity uses ultrasonic sound waves to measure distance (this kind of measurement is known as “ranging”). “Ultrasonic” means that the frequency of the sound waves is higher than the range of normal human hearing (about 20 - 20,000 Hz). The PING)))™ sensor (Figure 1) uses ultrasonic sound waves whose frequency is 40 kHz. The sensor consists of an ultrasonic microphone, an ultrasonic speaker, and electronic circuits that

- Generate an ultrasonic pulse (“chirp”); and
- Communicate with a microcontroller.

Figure 1. The PING)))™ sensor





In addition to the sensor, a typical ultrasonic ranging system includes a microcontroller that tells the sensor when to make a measurement and receives measurement data from the sensor, and a computer or calculator where the data can be displayed, stored, and analyzed.

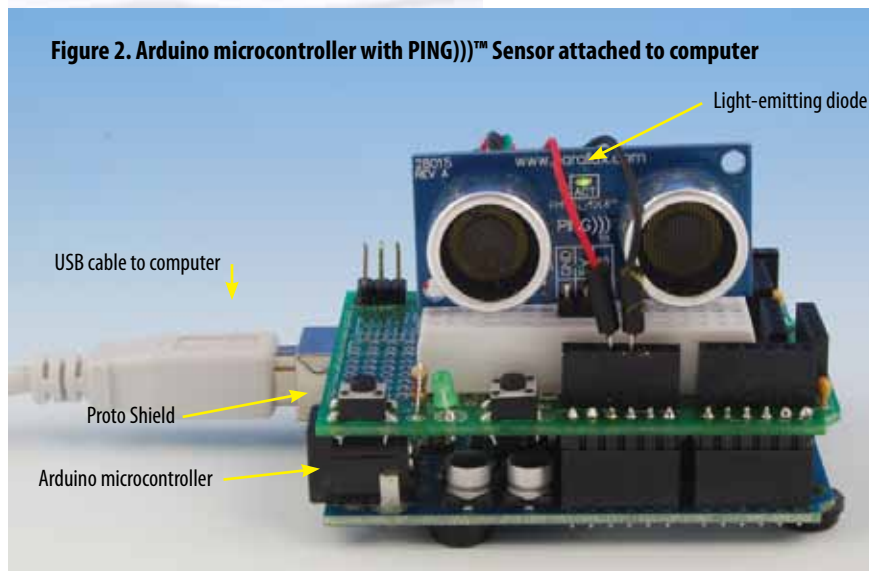
To measure the distance between the PING)))™ sensor and another object, the microcontroller sends a signal that tells the sensor to chirp. The sensor chirps its 40 kHz pulse, and sends a signal to the microcontroller. When the sensor receives an echo with its ultrasonic microphone, it sends another signal to the microcontroller. The microcontroller measures the time between the first signal and second signal from the PING)))™ sensor, and sends this information to a computer.

Learning Procedure

- To get started, be sure you know the answers to the following questions:
 - “SONAR” is an acronym. What does it mean?
 - What are the basic components of a sonar system?
 - Why are transducers sometimes contained in a “towfish” that is towed behind the survey vessel?
 - What are the advantages and disadvantages of high frequency (500 kHz and up) sonar signals compared to lower frequency (50 kHz or 100 kHz) signals?
 - What is the difference between multibeam sonar and other types of sonar?
- Now, set up your ultrasonic ranging system.
 - If you are using a PING)))™ sensor, connect the sensor to a microcontroller (such as Arduino, or Parallax BASIC Stamp®), and connect the microcontroller to your computer (with a USB cable or wireless connection).
 - If you are using a Lego® NXT Ultrasonic Sensor, connect the sensor to an NXT brick microcontroller, and connect the microcontroller to your computer (with a USB cable or wireless connection).
 - If you are using a Vernier Motion Detector with a LabQuest® or CBL 2® interface, connect the motion detector to the interface, and connect the interface to your computer or calculator.
- Load a program to run the ultrasonic sensor/microcontroller system you are using (some sources for appropriate programs are listed below). Set up the program to

measure distance according to instructions in the documentation for the specific program you are using. Make a few test measurements to confirm that your system is working and providing acceptable measurements. Figure 2 shows a PING)))™ sensor attached to an Arduino microcontroller, making distance measurements (the small green light-emitting diode in the middle of the sensor flashes whenever a measurement is made; the program loaded into the microcontroller in Figure 2 causes measurements to be made about ten times per second).

When using a particular sensor/microcontroller system for the first time, it is always a good idea to check the accuracy



of the system by obtaining several measurements of an object at known distances, and comparing the measurements with the actual distances. Graphing the results of several tests can give you a good idea about the accuracy and limits of your system.

4. You may want to try one or more of the activities provided with the program for operating your microcontroller to become more familiar with your ultrasonic ranging system.

Test Your Engineering Design Skills

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 as follows.

- Define the problem.
- Gather relevant information.
- Brainstorm possible solutions.
- Analyze possible solutions and select the most promising.
- Test the solution.

Depending upon the results of the last step, the entire process may be repeated one or more times to improve the solution until the results are satisfactory. Sometimes, you may have to go back to a previous step because the selected solution doesn't work.

The Challenge: Your ultrasonic ranging system is capable of making distance measurements over a range of about 3 cm to 250 cm. Suppose you want to make a 3-D surface plot (as in the *Mapping the Deep Ocean Floor* lesson) of the floor of a small, dry lake, roughly 12 ft in diameter, and 2 m deep at its deepest point. You can stand on the edge of the lake around its entire perimeter, but you cannot actually walk on the lake floor because your footsteps would alter the topography of the soft mud. Your challenge is to design a way to use your ultrasonic ranging system to obtain enough data points to make a 3-D surface plot that will show features that are 6 inches in diameter or larger.

Use the Engineering Design Process to develop a workable solution for this challenge. Document your solution in writing, showing how you used the Engineering Design Process to arrive at your solution.

Sources for operating programs and activities for ultrasonic sensors:

PING)))™ sensor, Parallax BASIC Stamp microcontroller, and Board of Education® prototyping board – Parallax, Inc. Web site (<http://www.parallax.com>); Lindsay, A. Smart Sensors and Applications. Parallax Inc. Rockland, CA; Lindsay, A. 2003. What's a Microcontroller? Parallax Inc. Rockland, CA. 315 pp.

Arduino microcontroller – Arduino Web site (<http://www.arduino.cc>); Banzi, M. 2008. Getting Started with Arduino. O'Reilly Media, Inc. Sebastopol, CA. 118 pp.

Lego® NXT Ultrasonic Sensor and NXT brick microcontroller – Lego® Web site (<http://www.lego.com/en-us/Default.aspx>); Kelly, J. R. 2010. Lego Mindstorms Nxt-g Programming Guide. Apress. New York. 336 pp.

Vernier Motion Detector and LabQuest® or CBL 2® interface – Vernier Web site (<http://www.vernier.com/>); File #19, "Mapping Ocean Floor" from the Earth Science with Vernier activities collection (<http://www.vernier.com/cmat/cmatdnl.html>, Lab #19 under the "Earth Science" menu)





Notes for Educators

1. This activity assumes that students have a basic understanding of sound waves and the meaning of frequency, and that students and/or their instructor have a basic understanding of the microcontroller system that will be used for this activity. Additional background about waves and their properties can be found in the “Day in the Life of an Ocean Explorer” lesson, and additional background about microcontrollers can be found in the “Hands-On Activity Guide Underwater Robots: Getting Control,” and in the documentation provided by the manufacturer of the microcontroller system that will be used for this activity.

2. Answers to questions in Step 1:

a. “SONAR” is an acronym for “SOund NAVigation and Ranging”

b. The basic components of a sonar system are:

- A transmitter capable of emitting an acoustic signal;
- A receiver capable of detecting echoes from the transmitted signal; and
- A processing unit to interpret the reflected signal.

Students may also mention:

- A cable to connect the processor with the transmitter and receiver;
- A transducer (which is analogous to the antenna on a radio transmitter or receiver); and
- A towfish to allow the transducer(s) to be towed behind the survey vessel.

c. Transducers are sometimes towed behind the survey vessel because:

- Being able to tow the transducer at some depth below the surface means that there is less water through which the acoustic signal must travel, so there is less absorption and scattering of the acoustic energy, and consequently, the signal is stronger;
- The transducer is less affected by the surface motion of the survey vessel (particularly rolling motion); and
- The transducer can be towed beneath a thermocline (the boundary between two water masses of different temperature) which can interfere with the acoustic signal.

d. Higher frequencies give better image resolution (more detail) but travel shorter distances than lower frequencies.

e. Multibeam sonar systems use multiple transducers pointing at different angles on either side of a ship to create a swath of signals. The time interval between signal transmission and return echo arrival is used to estimate depth over the area of the swath. In some systems, the intensity of the return echo is also used to infer bottom characteristics that can be used for habitat mapping. Other sonar systems typically use only one transducer and measure depth in a very narrow path along the track of the ship. Sidescan sonars also transmit a fan-shaped pattern of acoustic signals, and continuously record the strength of the return echo caused by the transmitted signal bouncing off of the sea floor or other object (in contrast to multibeam systems that estimate depth by measuring the time elapsed between transmission of a sound signal and detection of the reflected signal by the sonar’s receiver).

3. The Engineering Design problem may be solved many ways. The key points for evaluating students' responses to the Challenge are:
- The students clearly show how they addressed each step in the Engineering Design Process to arrive at their solution;
 - The proposed solution is plausible; and
 - Students have undertaken some practical tests of their solution.

Unless a test site is available that matches the characteristics of the described lake bed, a complete test of the proposed solution may not be possible; but students should document reasonable efforts to test their ideas.

For a description of one approach to this challenge, see <http://www.vernier.com/innovate/innovativeuse86.html>.

