Ocean Exploration and Research

The NOAA Ship *Okeanos Explorer* Education Materials Collection

For Grades 5 – 12

Volume 1:

Why Do We Explore?

National Oceanic and Atmospheric Administration
Office of Ocean Exploration and Research

National Marine Sanctuary Foundation

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Project Manager: Paula Keener, Director, Education Programs
NOAA Office of Ocean Exploration and Research
Lesson Plan Development: Mel Goodwin, PhD, Marine Biologist and Science Writer, Charleston, SC
Design/Layout: Sandy Goodwin, Coastal Images Graphic Design, Mt Pleasant, SC
Reviewer: Susan Haynes, Education Program Manager, NOAA Office of Ocean Exploration and Research,
Contractor: Collabralink Technologies, Inc.

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For more information, please contact:
Paula Keener, Director, Education Programs
NOAA Office of Ocean Exploration and Research
1315 East-West Highway
Silver Spring, MD 20910
Paula.Keener@noaa.gov

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

The NOAA Ship *Okeanos Explorer* Education Materials Collection

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Introduction

"The people who were putting up millions of dollars were asking my father, 'So, Captain, what do you expect to find?' and his answer to those people who were about to make major commitments was, 'If I knew, I wouldn't go.'"

Jean-Michel Cousteau, 2005

The wonders of the deep ocean and the mysteries of the universe. Inner Space and Outer Space. Both have historically and inextricably been linked with "exploration" and "discovery" since the beginning of humankind. For ages, people have gazed at planetary objects seemingly floating in the night sky and as early as 2,000 B.C., the Egyptians were exploring the seas. Astronomers and sailors– explorers driven by the human spirit of discovery and a fundamental need to know. What drives this quest for knowledge about the natural world, this fundamental need to know and understand what makes the planets move and the ocean change color?

Even as infants, humans are already exploring their world. In their book, *The Scientist in the Crib*, Gopnik *et al.* (2001) write "The tiny fingers and mouth are exploration devices that probe the alien world around them with more precision than any Mars rover. We are born with the ability to discover the secrets of the universe and of our own minds, and with the drive to explore and experiment until we do. Science isn't just the specialized province of a chilly elite; instead, it's continuous with the kind of learning every one of us does when we're very small." Can we capture and direct this innate need to know in novel ways to enhance science literacy?

The President's Panel on Ocean Exploration fully recognized the importance of the connections among our fundamental need to know, ocean exploration, and science literacy when it called for "reaching out in new ways to learners of all ages with respect to ocean issues" (*Discovering Earth's Final Frontier: A U.S. Strategy for Ocean Exploration*, 2000). The President's Panel also had a vision of "a flagship for the Ocean Exploration Program…that would facilitate multidisciplinary data management and educational outreach by centralizing much of the data collection and outreach technologies on a dedicated platform through telepresence."

In 2008, the National Oceanic and Atmospheric Administration (NOAA) commissioned the NOAA Ship *Okeanos Explorer* as the first Federally-dedicated ship of exploration intended to carry out systematic global ocean exploration linked in real time through satellite and internet telepresence technology to scientists, educators, media and the general public. This ship offers an unprecedented opportunity to bring learners of all ages onboard for voyages to poorly-known or unexplored areas of the global ocean. Through the use of innovative technologies, they participate in explorations and breakthrough discoveries that lead to increased scientific understanding and enhanced literacy about our ocean world.

The **Why Do We Explore? Education Materials Collection** is part of a two-volume set that introduces the NOAA Ship *Okeanos Explorer* into formal and informal learning environments. The concept for this Collection was developed by participants during a two-day NOAA Ship *Okeanos Explorer* Education Forum held at the NOAA Pacific Marine Environmental Laboratory Western Regional Center Campus in Seattle immediately following the commissioning of the ship. The Forum focused on how best to reach students, teachers, and other audiences in novel ways with the excitement of ocean exploration given the unique combination of assets and capabilities brought to the NOAA Ocean Exploration and Research Program by the *Okeanos Explorer*.

The NOAA Ship *Okeanos Explorer* presents a unique national ocean-based venue through which to continue to implement the President's Panel recommendation of "reaching out in new ways to learners." It is our hope that these education materials, along with the ship and her telepresence capabilities bringing ocean exploration and new discoveries to scientists educators and their students, will have a profound effect on ocean literacy around the world as we, through our fundamental need to know, strive to understand our intrinsic connections with the ocean more fully and why it is called the "lifeblood of Earth."

Paula Keener, Director, Education Programs
NOAA Office of Ocean Exploration and Research

Using the *Okeanos Explorer* Education Materials Collection

An essential component of NOAA's Ocean Exploration and Research Program mission is to enhance understanding of science, technology, engineering, and mathematics used in exploring the ocean; and build interest in careers that support ocean-related work. To help fulfill this mission, the ***Okeanos Explorer*** **Education Materials Collection** was developed to encourage educators and students to become personally involved with the voyages and discoveries of the *Okeanos Explorer*—America's first Federal ship dedicated to ocean exploration. The **Education Materials Collection** is presented in three volumes: ***Volume 1: Why Do We Explore?*** (reasons for ocean exploration), ***Volume 2: How Do We Explore?*** (exploration methods), and ***Volume 3: What Do We Expect to Find?*** (recent discoveries that give us clues about what we may find in Earth's largely unknown ocean). In the future, additional guides will be added to the **Education Materials Collection** to support the involvement of citizen scientists.

Education materials for ***Volume 1 - Why Do We Explore?*** begin with a lesson titled *To Boldly Go…* to guide students through some of the reasons for ocean exploration; and to provide educators background information on key topics of Ocean Exploration, Climate Change, Energy, Human Health, and Ocean Health. The Diving Deeper section, starting on page 21, offers additional information on some aspects and the subsequent 15 lessons guide further investigations into these topics. Some of these lessons have been adapted from lessons previously developed for various NOAA Ocean Explorer expeditions, while others have been created specifically for the *Okeanos Explorer* education initiative. Whenever possible, hands-on activities are included that involve manipulations other than paper-and-pencil exercises or Web-based research. The reason for doing this is that field science, and exploration in particular, depend heavily upon technology and problem-solving skills needed to create, use, and advance new technology.

Lesson plans developed for Volume 1 are correlated with Ocean Literacy Essential Principles and Fundamental Concepts as indicated in the back of this book. Additionally, a separate online document (*http://oceanexplorer.noaa.gov/okeanos/edu/collection/wdwe_ngss.pdf*) illustrates individual lesson support for the Performance Expectations and three dimensions of the Next Generation Science Standards and associated Common Core State Standards for Mathematics and for English Language Arts & Literacy. This information is provided to educators as a context or point of departure for addressing particular standards and does not necessarily mean that any lesson fully develops a particular standard, principle or concept.

Lessons also include links to other relevant lesson plans from the NOAA Office of Ocean Exploration and Research, as well as the Ocean Explorer Web site (*http://oceanexplorer.noaa.gov/*). Educators who use the ***Okeanos Explorer*** **Education Materials Collection** should regularly check the Education Page on the *Okeanos Explorer* Web site (*http://oceanexplorer.noaa.gov/okeanos/edu/welcome.html*) for the latest information about new education offerings and professional development opportunities.

Welcome aboard!

Mel Goodwin, PhD
Marine Biologist and Science Writer

Notes:

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

Section 1: Background Information for Volume 1: Why Do We Explore?

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.

Highlights in this Lesson

Ocean Exploration and Research

To Boldly Go…

This lesson guides student investigations into reasons for ocean exploration. Other lessons in Volume I guide additional investigations into key topics of Ocean Exploration, Energy, Climate Change, Human Health, and Ocean Health.

Focus
Ocean Exploration

Grade Level
Target Grade Level: 7-8; suggested adaptations for grades 5-6 and 9-12 are provided on pages 19-20.

Focus Question
Why do we explore the ocean?

Learning Objectives
- Students discuss why scientists believe there are important undiscovered features and processes in Earth's ocean.
- Students discuss at least three motives that historically have driven human exploration.
- Students explain why ocean exploration is relevant to climate change.
- Students discuss at least three benefits that might result from ocean exploration.

Materials
- Internet and/or library access for student research
- Stiff paper such as card or cover stock
- Learning Shape patterns (photocopied from page 18, or downloaded from the Internet)
- Scissors or craft knives
- Markers and/or photo images
- Glue or glue stick
- Two stopwatches
- Seaweed crackers (from the Asian section of a grocery store) or other prizes

Audiovisual Materials
- Multimedia board, marker board, or overhead projector

Key Words and Concepts
Ocean exploration
NOAA Ship *Okeanos Explorer*
Climate change

Deep-sea medicines
pH
Ocean acidification
Telepresence
Methanogenic
Archaeobacteria

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.

> *"We know more about the dead seas of Mars than our own ocean."*
> *– Jean-Michel Cousteau*

It may be hard to believe that 95% of Earth's ocean is unexplored, particularly if we look at recent satellite maps of Earth's ocean floor. These maps seem to show seafloor features in considerable detail. But satellites can't see below the ocean's surface. The "images" of these features are estimates based on the height of the ocean's surface, which varies because the pull of gravity is affected by seafloor features. And if we consider the scale of these maps, it is easy to see how some things might be missed. To show our planet's entire ocean, a typical wall map has a scale of about 1 cm = 300 km. At that scale, the dot made by a 0.5 mm pencil represents an area of over 60 square miles! The reality is that most of the ocean floor has never been seen by human eyes.

NOAA Ship *Okeanos Explorer*

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 our largely unknown ocean for the purposes of discovery and the advancement of knowledge. To fulfill its mission, the *Okeanos Explorer* has specialized capabilities for finding new and unusual features in unexplored parts of Earth's ocean, and for gathering key information that will support more detailed investigations by subsequent expeditions. These capabilities include:

- Underwater mapping using multibeam sonar capable of producing high-resolution maps of the seafloor to depths of 6,000 meters;
- Underwater robots (remotely operated vehicles, or ROVs) that can investigate anomalies as deep as 6,000 meters; and
- Advanced broadband satellite communication and telepresence.

Capability for broadband telecommunications provides the foundation for telepresence: technologies that allow people to observe and interact with events at a remote location. This allows live images to be transmitted from the seafloor to scientists ashore, classrooms, newsrooms and living rooms, and opens new educational opportunities, which are a major part of *Okeanos Explorer's* mission for advancement of knowledge. In addition, telepresence makes it possible for shipboard equipment to be controlled by scientists in shore-based Exploration Command Centers. In this way, scientific expertise can be brought to the exploration team as soon as discoveries are made, and at a fraction of the cost of traditional oceanographic expeditions.

Seven Modern Reasons for Ocean Exploration

Ocean exploration supports and enhances the work of many individuals and organizations working on America's key science issues, including:

- **Climate Change** – The ocean has a major influence on weather and climate, but we know very little about deep-ocean processes that affect climate.
- **Energy** – Ocean exploration contributes to the discovery of new energy sources, as well as protecting unique and sensitive environments where these resources are found.
- **Human Health** – Expeditions to the unexplored ocean almost always discover species that are new to science, and many animals in deep-sea habitats have been found to be promising sources for powerful new antibiotic, anti-cancer and anti-inflammatory drugs.
- **Ocean Health** – Many ocean ecosystems are threatened by pollution, overexploitation, acidification and rising temperatures. Ocean exploration can improve understanding of these threats and ways to improve ocean health.
- **Research** – Expeditions to the unexplored ocean can help focus research into critical areas that are likely to produce tangible benefits.
- **Innovation** – Exploring Earth's ocean requires new technologies, sensors and tools and the need to work in extremely hostile environments is an ongoing stimulus for innovation.
- **Ocean Literacy** – Ocean exploration can help inspire new generations of youth to seek careers in science, technology, engineering and mathematics and offers vivid examples of how concepts of biology, physical science, and earth science are useful in the real world.

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 Ocean Exploration and Research Program

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*

The science and ship crew of the HMS *Challenger* in 1874. The original crew of 216 had dwindled to 144 by the end of the long expedition. Image credit: NOAA.

Many Reasons to Explore

Historically, explorers have been driven by a variety of motives. For some, the primary reason to explore was to expand their knowledge of the world. For others, economic interests provided powerful incentives, and many expeditions have launched on such missions as finding a sea route to access the spices of Asia, or quests for gold, silver, and precious stones. Political power and the desire to control large empires motivated other explorations, as did the desire to spread religious doctrines. In the case of space exploration, additional reasons have been offered, including understanding our place in the cosmos, gaining knowledge about the origins of our solar system and about human origins, providing advancements in science and technology, providing opportunities for international collaboration, and keeping pace with other nations involved in developing space technology. The first ocean exploration for the specific purpose of scientific research is often considered to be the voyage of the HMS *Challenger*, conducted between 1872-1876 (visit *http://oceanexplorer.noaa.gov/explorations/03mountains/background/challenger/challenger.html* and *http://www.coexploration.org/hmschallenger/html/AbouttheProject.htm* for more information about the *Challenger* expedition and comparisons with modern oceanographic exploration).

Curiosity, desire for knowledge, and quest for adventure continue to motivate modern explorers. But today, there are additional reasons to explore Earth's ocean, including climate change, energy, human health, ocean health, innovation, research and ocean literacy.

The black and white photograph of Muir Glacier taken on August 13, 1941; the color photograph was taken from the same vantage on August 31, 2004. Between 1941 and 2004 the glacier retreated more than 12 kilometers (seven miles) and thinned by more than 800 meters (875 yards). Ocean water has filled the valley, replacing the ice of Muir Glacier; the end of the glacier has retreated out of the field of view. The glacier's absence reveals scars where glacier ice once scraped high up against the hillside. In 2004, trees and shrubs grew thickly in the foreground, where in 1941 there was only bare rock. Image credit: National Snow and Ice Data Center, W. O. Field, B. F. Molnia. *http://nsidc.org/data/glacier_photo/repeat_photography.html*

Climate Change

Earth's average temperature is warmer than it has been at any time since at least 1400 AD. While debate continues about the causes of climate change and the relative importance of long-term climate cycles, greenhouse gases, and other factors, it is clear that:

- Mountain glaciers are melting;
- Polar ice is decreasing;
- Springtime snow cover has been reduced;
- Ground temperature has been increasing in many areas;
- Sea level has risen by several inches in the last 100 years.

Potential impacts of global climate include weakening the deep-ocean thermohaline circulation (THC), which plays an important role in transporting heat, dissolved oxygen and nutrients, accelerating the widespread decline of coral reefs, extinction of species such as the polar bear, and year-round access to sea routes through the Arctic. Ocean exploration can provide some of the essential knowledge about ocean-atmosphere interactions that is needed to understand, predict, and respond to these impacts. For additional discussion about climate change and the THC, please see the Diving Deeper section starting on page 21.

Energy

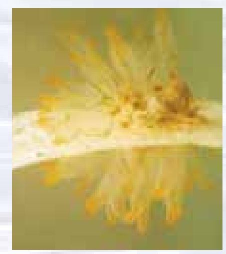
"For kicks, oceanographer William P. Dillon likes to surprise visitors to his lab by taking ordinary-looking ice balls and setting them on fire. 'They're easy to light. You just put a match to them and they will go,' says Dillon, a researcher with the U.S. Geological Survey (USGS) in Woods Hole, Mass. If the truth be told, this is not typical ice. The prop in Dillon's show is a curious and poorly known structure called methane hydrate."

from "The Mother Lode of Natural Gas" by Rich Monastersky
http://www.sciencenews.org/sn_arch/11_9_96/bob1.htm

Methane hydrates are ice-like substances formed when molecules of water form an open lattice that surrounds molecules of methane without forming chemical bonds between the two materials. In deep-ocean sediments, conditions of low temperature and high pressure allow methane hydrate deposits to form. There is growing interest in these deposits as an alternative energy source, because the U.S. Geological Survey has estimated that on a global scale, methane hydrates may contain roughly twice the carbon contained in all reserves of coal, oil, and conventional natural gas combined. In addition, methane hydrates are associated with unusual and possibly unique biological communities containing previously-unknown species that may be sources of beneficial pharmaceutical materials. Methane hydrates may also cause big problems, because when heated they can release large amounts of methane, a greenhouse gas that could have (and may already have had) major consequences to the Earth's climate. At the same time, a sudden release of pressurized methane gas may cause submarine landslides that in turn can trigger catastrophic tsunamis.

A marine worm, *Hesiocaeca methanicola*, on the surface of an orange gas hydrate. A variety of animals use methane hydrates as a source of energy. Image credit: Ian MacDonald.
http://oceanexplorer.noaa.gov/explorations/deepeast01/logs/sep23/media/icewormsmed_600.jpg

Besides methane hydrates, regions such as the Gulf of Mexico produce significant quantities of petroleum. Often, the presence of hydrocarbons at the surface of the seafloor is accompanied by cold-seep communities which are biological communities that derive their energy from gases (such as methane and hydrogen sulfide) and oil seeping out of sediments. In addition to locating new sources of hydrocarbon fuels, exploration of these communities frequently reveals species that are new to science and provides information on ecology and biodiversity that is needed to protect these unique and sensitive environments. For additional discussion about energy, methane hydrates and cold-seep communities, please see Diving Deeper, page 26.



Though they may be visually unimpressive, *Forcepia* sponges (left) are the source of the lasonolides and tunicates (right) are the source of ecteinascidin, potential new drugs for treating cancer. Image credit: NOAA.
http://oceanexplorer.noaa.gov/explorations/03bio/logs/hirez/lasonolide1_hirez.jpg
http://oceanexplorer.noaa.gov/explorations/03bio/logs/hirez/figure4_hirez.jpg

Human Health

Improving human health is another motive for ocean exploration. Almost all drugs derived from natural sources come from terrestrial plants. But recent explorations have found that some marine invertebrates such as sponges, tunicates, ascidians, bryozoans, and octocorals can also produce powerful drug-like substances. Many of these are sessile (non-moving), bottom-dwelling animals that do not appear particularly impressive; yet, they produce more antibiotic, anti-cancer, and anti-inflammatory substances than any group of terrestrial organisms. The potential for discovering important new drugs from deep-ocean organisms is even greater when one considers that most of Earth's seafloor is still unexplored, and deep-sea explorations routinely find species that have never been seen before. For additional discussion about drugs from the sea, please see the Diving Deeper section on page 32.

Ocean Health

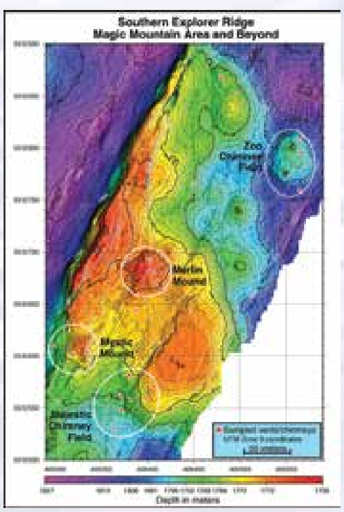
> *"Anyone familiar with the state of the world's oceans would have a hard time feeling optimistic. From coral reefs overwhelmed by coastal runoff to tiny but ecologically-vital plankton that are suffering from climate change, the diversity of sea life is fading."*
>
> (Allsopp, *et al.*, 2007)

Limacina helicina, a free-swimming planktonic snail. These snails, known as pteropods, form a calcium carbonate shell and are an important food source in many marine food webs. As levels of dissolved CO2 in seawater rise, skeletal growth rates of pteropods and other calcium-secreting organisms will be reduced due to the effects of dissolved CO2 on ocean acidity. Image credit: Russ Hopcroft, UAF/NOAA.
http://www.noaanews.noaa.gov/stories2006/images/pteropod-limacina-helicina.jpg

The health of Earth's ocean is simultaneously threatened by over-exploitation of large species, destruction of benthic habitats, invasive species, rising temperatures, pollution, and ocean acidification (Jackson, 2008). On June 5, 2008, NOAA Oceanographer Richard A. Feely told the U.S. House of Representatives Subcommittee on Energy and Environment that by the end of the century, surface ocean pH could be lower than it has been for more than 20 million years.

Dr. Shirley Pomponi, one of three co-principal investigators on the 2003 Deep Sea Medicines Expedition, removing a bright yellow sponge from a seafloor sample. Image credit: NOAA. *http://oceanexplorer.noaa.gov/explorations/03bio/logs/summary/media/10249_bio.html*

A spectacular photo of the NOAA Ship *Okeanos Explorer* Control Room while ROV operations are underway. Image credit: NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.



Bathymetric map of the Magic Mountain area on Explorer Ridge, part of the Submarine Ring of Fire. Visit *http://oceanexplorer.noaa.gov/explorations/02fire/logs/magicmountain/welcome.html* for a virtual tour of the Magic Mountain site. Image credit: NOAA. *http://oceanexplorer.noaa.gov/explorations/02fire/logs/hirez/magic-hires.jpg*

"Life will find a way," according to chaos theorist Ian Malcolm in Jurassic Park (Crichton, 1990). But the question is, "Which life?" Deep-sea explorers often find biological organisms thriving in conditions that would be extremely hostile to humans. But his does not mean that species can simply adapt to stresses from falling pH, rising sea levels and temperatures, pollution and overfishing. We urgently need to learn more about ocean ecosystems and how they affect the rest of our planet. This is one of the most important modern reasons for ocean exploration. Without a doubt, human curiosity, the desire to understand our world, and the excitement of discovery are still among the reasons we explore Earth's ocean; but we also explore to survive.

For more information about ocean health issues, please see page 33 in Diving Deeper.

Research

It is important to note that expeditions to the unexplored ocean can help focus research into critical geographic and subject areas that are likely to produce tangible benefits. Telepresence technology aboard the *Okeanos Explorer* allows many explorers to participate at a fraction of the cost of traditional expeditions, as well as opportunities for students and the general public to have a first-hand look at the processes of scientific exploration.

Technological Innovation

The challenges of working in the extremely hostile environments of the deep ocean are an ongoing stimulus for technology innovation and development.

Science Education and Ocean Literacy

Ocean exploration can help inspire new generations of youth to seek careers in science, technology, engineering and mathematics, and offers vivid examples of how concepts of biology, physical science, and Earth science are useful in the real world. Similarly, the challenges of exploring the deep ocean can provide the basis for problem-solving instruction in technology and engineering. Ocean exploration also provides an engaging context for improving ocean literacy, understanding how the ocean influences our lives, and how we influence the ocean. Widespread ocean literacy is increasingly vital as we confront issues such as ocean health and climate change.

Note that many of the topics discussed above apply to more than one reason to explore. Methane hydrates, for example, are relevant to climate change as a potential source of a greenhouse gas that could accelerate trends toward warmer temperatures. Similarly, pH changes discussed under ocean health are also linked to climate change since increased dissolved carbon dioxide in the ocean is the result of increased carbon dioxide in the atmosphere that may be partially responsible for observed changes in Earth's climate. The same issues are also relevant to drugs from the sea, since warmer temperatures and changes in ocean circulation patterns are among the stressors that threaten some of the marine organisms that produce pharmacologically-active substances.

The key point is that the ocean processes do not operate in isolation; they interact and affect each other in ways that we are just beginning to understand. We separate these topics as individual examples of reasons to explore, and for improved clarity in an introductory discussion; but it is important to realize that the ocean is an integrated system—individual organisms and processes always interact with many others, and the whole is much more complex than the sum of the parts.

Learning Procedure

This lesson is designed as a student investigation into the question: Why do we explore the ocean? It is possible to make this lesson an individual student assignment, but a group of students will probably produce a more dynamic exchange of ideas. The basic lesson design is as follows: Assign the guidance questions below to groups of three or four students. Then have each group construct ocean exploration learning shapes as part of its investigation, and use these shapes to reinforce concepts resulting from student research. Finally, use oral reports from these groups as the basis for a full class discussion. The primary curriculum topic of the lesson is Earth science. It is targeted to grade levels 7–8, but suggested adaptations for grades 5–6 and 9–12 are provided following the Learning Procedure section.

1. To prepare for this lesson,
   - Review introductory information on the NOAA Ship *Okeanos Explorer* at *http://oceanexplorer.noaa.gov/okeanos/welcome.html*
   - Review video presentations "Introduction to NOAA Ship *Okeanos Explorer*" (by John McDonough) and "Deep Ocean Exploration: New Discoveries and Implications for Our Warming Planet (by Steve R. Hammond) – from the *Okeanos Explorer* Education Page (*http://oceanexplorer.noaa.gov/okeanos/edu/welcome.html*) click on "Resources and Links," then scroll down to the link for these presentations.
   - (Optional) Download some images from sources provided in the sidebar at right for use during discussions.
   - (Optional) Additional information about the history of ocean exploration is available at *http://oceanexplorer.noaa.gov/history/history.html*.

2. Briefly introduce the NOAA Ship *Okeanos Explorer*, emphasizing that this is the first Federal vessel specifically dedicated to exploring Earth's largely unknown ocean. Be sure students understand the concept of telepresence, and that telepresence technology will make it possible for people (including students in classrooms) to participate in these explorations from locations thousands of miles away.

3. Tell students that their assignment is to answer the question, "Why do we explore the ocean?" Each student or student group should prepare an oral report that addresses the following questions:
   (1) "We know more about the dead seas of Mars than our own ocean." (Jean-Michel Cousteau). How can this be true? And even if it is, so what? Isn't the deep ocean more or less the same, wherever you go?
   (2) Historically, what are some reasons for human exploration?
   (3) Today, are there any other reasons to explore Earth's ocean?
   (4) If time permits, you may also want to have students address the question, "Who are today's ocean explorers?" and refer them to the Ocean Explorer OceanAGE Careers Web page (*http://oceanexplorer.noaa.gov/edu/oceanage/welcome.html*).

   - The following links to Web pages for Ocean Explorer expeditions provide examples of some benefits that can result from ocean exploration:

     Energy:
     – *http://oceanexplorer.noaa.gov/explorations/03windows/welcome.html*
     – *http://oceanexplorer.noaa.gov/explorations/07mexico/welcome.html*

     Human Health:
     – *http://oceanexplorer.noaa.gov/explorations/03bio/welcome.html*

Key Images and Video Resources

2003 Medicines from the Deep Sea Expedition
(Drugs from the sea):
http://oceanexplorer.noaa.gov/explorations/03bio/logs/photolog/photolog.html

2003 Windows to the Deep Expedition
(Methane, cold-seep communities):
http://oceanexplorer.noaa.gov/explorations/03windows/logs/photolog/photolog.html

2005 GalAPAGoS: Where Ridge Meets Hotspot Expedition (Hydrothermal vent communities):
http://oceanexplorer.noaa.gov/explorations/05galapagos/logs/photolog/photolog.html

2006 Davidson Seamount: Exploring Ancient Coral Gardens Expedition
(Deepwater corals and other species):
http://oceanexplorer.noaa.gov/explorations/06davidson/logs/photolog/photolog.html

2006 Expedition to the Deep Slope
(Seep communities):
http://oceanexplorer.noaa.gov/explorations/06mexico/logs/photolog/photolog.html

2006 Ring of Fire Expedition
(Underwater volcanoes, carbon dioxide venting):
http://oceanexplorer.noaa.gov/explorations/06fire/logs/photolog/photolog.html

New Zealand American Submarine Ring of Fire 2007 Expedition
(Underwater volcanoes, exploration technology):
http://oceanexplorer.noaa.gov/explorations/07fire/logs/photolog/photolog.html

Lophelia II 2008 Deepwater Coral Expedition – Reefs, Rigs and Wrecks
(Deepwater communities):
http://oceanexplorer.noaa.gov/explorations/08lophelia/logs/photolog/photolog.html

During preliminary operations near Guam, Indonesian scientist Dr. Michael Purwoadi makes the first 'call' using telepresence from the NOAA Ship *Okeanos Explorer* to colleagues in the newly established Jakarta Exploration Command Center. Image credit: NOAA OER.

Coral reefs around the world are showing signs of severe stress; yet, the reefs on the coast of Bonaire are amazingly healthy. The Bonaire 2008 Expedition used autonomous underwater vehicles to help find some of the reasons. Image credit: Bonaire 2008 Expedition.
http://oceanexplorer.noaa.gov/explorations/08bonaire/logs/summary/media/elkhorn_coral.html

Swimmers recovering Deep Submergence Vehicle *Alvin* after a dive on Manning Seamount off the Carolina coast during the 2003 Windows to the Deep Expedition. Image credit: C. Martinez, NOAA
http://oceanexplorer.noaa.gov/technology/subs/alvin/media/alvin_recovery_water_600.jpg

As the oil and gas industry continues to search for energy reserves in deep waters of the Gulf of Mexico, it is critical to know more about deepwater organisms so that sensitive biological habitats may be protected. The *Lophelia* II 2008 Deepwater Coral Expedition: Reefs, Rigs, and Wrecks explored new deepwater coral communities at natural and man-made sites in the deep Gulf of Mexico. In Green Canyon, deepwater corals *Lophelia pertusa* create habitat for a number of other species. Image credit: Chuck Fisher.
http://oceanexplorer.noaa.gov/explorations/08lophelia/logs/sept24/media/green_canyon_lophelia_600.jpg

Ocean Health:
– *http://oceanexplorer.noaa.gov/explorations/08bonaire/welcome.html*
Climate Change:
– *http://oceanexplorer.noaa.gov/explorations/06arctic/welcome.html*
– *http://oceanexplorer.noaa.gov/explorations/02arctic/welcome.html*

4. Have each group make an oral presentation of their findings. When all groups have reported, facilitate a class discussion of these results. Key points for guidance questions should include:

(1) "We know more about the dead seas of Mars than our own ocean." (Jean-Michel Cousteau). How can this be true? And even if it is, so what? Isn't the deep ocean more or less the same, wherever you go?
Key Points: Considering the difficulty of photographing large areas of the ocean floor, as well as the three-dimensional nature of ocean habitats, it is easy to see how we might know more about the surface of Mars. While many people think that the deep ocean is more or less homogenous over large areas, recent discoveries of hydrothermal vents, deep-sea cold seeps, underwater volcanoes, seamounts, and other features suggest that there is much more variety than was once supposed. Images from "Key Image and Video Resources" (see sidebar on page 14) may enhance discussions.

(2) Historically, what are some reasons for human exploration?
Key Points: Students may suggest a considerable variety of motives, including to gain knowledge about the world, obtain economic benefits, increase political power, spread religious doctrines, advance science and technology, and keeping pace with other nations. Simple curiosity and/or the challenge of the unknown are also valid suggestions, though often these are accompanied by more pragmatic considerations as well.

(3) Today, are there any other reasons to explore Earth's ocean?
Key Points: Ocean exploration contributes directly to issues and needs that are widely acknowledged to be national priorities, including:

- ***Climate Change*** – The ocean has a major influence on Earth's climate; but we don't even know, let alone understand, all of the processes involved in the interactions between the ocean and climate, because most of the ocean is unknown. You may want to show images that document the decline in polar sea ice and/or glaciers *(http://www.nasa.gov/centers/goddard/images/content/94364main_STILLsea_ice_yearly.1979.tif; http://www.nasa.gov/images/content/190554main_AMSR_E_09_14_2007_r1.1536.tif;* and *http://nsidc.org/data/glacier_photo/repeat_photography.html).*

- ***Energy*** – Methane hydrates are an example of potential alternative sources of energy. The U.S. Geological Survey estimates that methane hydrates may contain roughly twice the carbon contained in all reserves of coal, oil, and conventional natural gas combined. Students should also realize that in addition to discovering new energy sources, ocean exploration is also concerned with protecting unique and sensitive environments where these resources are found.

- ***Human Health*** – Animals in deep-sea habitats have been found to be promising sources for powerful new antibiotic, anti-cancer and anti-inflammatory drugs. Expeditions to the unexplored ocean almost always discover species that are new to science, creating a high probability of finding important new natural products.

- ***Ocean Health*** – Rapid changes in Earth's climate, pollution, and overfishing are having serious negative impacts on some ocean ecosystems. Mention the potential impact of rising temperatures on tropical species that are already near their upper thermal tolerance limit, such as corals. Be sure students understand that corals are also subject to a variety of other stresses, and the combined stress from multiple sources amplifies the impacts of climate change. If it is not mentioned by students, introduce the effect of increased atmospheric carbon dioxide on ocean pH. A simple demonstration of the impact of dissolved carbon dioxide on pH can be found in Diving Deeper on page 41. Be sure students understand that while there is some disagreement about the connection between climatic temperature increase and carbon dioxide from human activity, the increase in atmospheric CO_2 and decline in ocean pH are not theoretical; these changes have been confirmed by actual measurements.

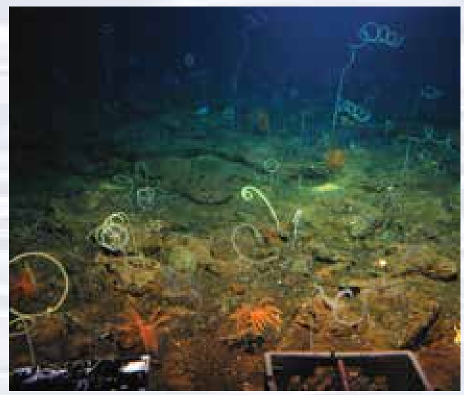
- ***Research*** – Expeditions to the unexplored ocean can help focus research into critical geographic and subject areas that are likely to produce tangible benefits. Telepresence technology aboard the *Okeanos Explorer* allows many scientists to participate at a fraction of the cost of traditional expeditions, as well as opportunities for students and the general public to have a first-hand look at the processes of scientific exploration.

- ***Technological Innovation*** – The challenges of working in the extremely hostile environments of the deep ocean are an ongoing stimulus for technology innovation and development.

- ***Science Education and Ocean Literacy*** – Ocean exploration can help inspire new generations of youth to seek careers in science, technology, engineering, and mathematics, and offers vivid examples of how concepts of biology, physical science, and Earth science are useful in the real world. Similarly, the challenges of exploring the deep ocean can provide the basis for problem-solving instruction in technology and engineering. Ocean exploration also provides an engaging context for improving ocean literacy, understanding how the ocean influences our lives, and how we influence the ocean. Widespread ocean literacy is increasingly vital as we confront issues such as ocean health and climate change.

5. **Ocean Exploration Learning Shapes and the Ocean Exploration Bowl Game** – Inspired by the *Okeanos Explorer's* satellite dome, these are geometric solids constructed by students to provide three-dimensional surfaces for displaying concepts, images, and other information. Many curricula require students to communicate ideas to other groups, and Learning Shapes provide a novel and versatile tool that can enhance communication activities. Learning Shapes can be constructed in many sizes, shapes, and colors using a variety of materials (stiff paper such as card stock is inexpensive, versatile, and widely available). In addition to their use as a learning and communication tool, constructing Learning Shapes also provides a basis for potential cross-curricular activities with Language Arts and Mathematics, and helps develop engineering skills including

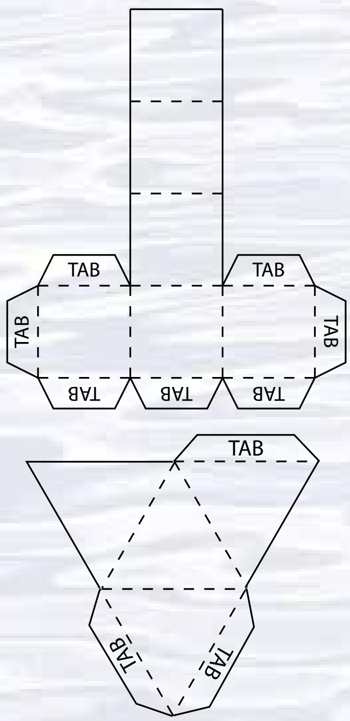
Carbon dioxide bubbles from a volcanic pit on the Submarine Ring of Fire Expedition can affect water acidity in nearby communities. The overall effect of volcanic gases on the acidity of the ocean is not known. Image credit: NOAA.
http://www.noaanews.noaa.gov/stories2006/images/undersea-volcano-sulfur-cloud-bubbles.jpg



Life abounds around a vent field near Volcano 19 in the southwest Pacific Ocean. Until recently, these deep-sea communities were entirely unknown. Image credit: NOAA/NURP.
http://www.noaanews.noaa.gov/stories2005/images/ventfield-lifew2005.jpg

Ocean explorers study sea ice ecosystems in the Arctic Ocean. Image credit: Emory Kristof.
http://oceanexplorer.noaa.gov/explorations/02arctic/logs/hirez/22_diver_hirez.jpg

Figure 1: Simple Learning Shapes



Learning Shapes are fun to make! Image credit: Mel Goodwin.

layout and design, material selection, modeling, and prototyping. The simplest Learning Shapes are tetrahedrons and cubes, which provide four and six surfaces respectively and can be constructed as illustrated in Figure 1. There are numerous books and Web sites that describe how to construct various polygons.

To reinforce concepts resulting from student investigations, students construct Learning Shapes to summarize modern reasons for ocean exploration (*i.e.*, climate change, energy, human health, ocean health, research, technological innovation and science education), and will use their creations to play a competitive "Ocean Exploration Bowl" game.

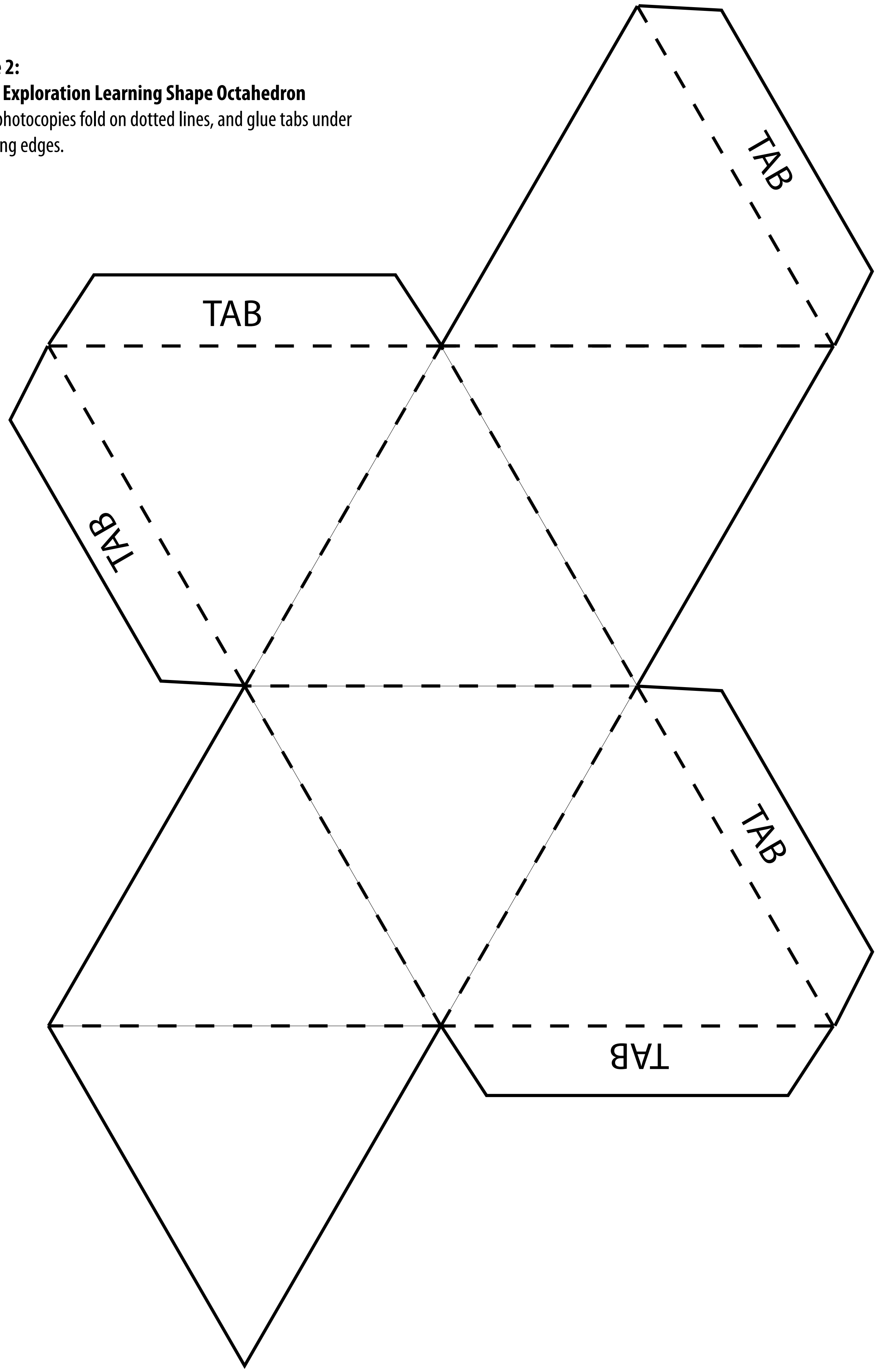
a. Each student group should construct four octahedrons using the pattern illustrated in Figure 2 (page 18). If larger Learning Shapes are desired, the pattern can be copied onto tabloid-size paper or cover stock with an enlarging photocopier.

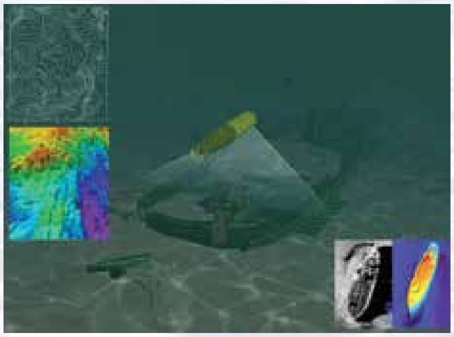
b. Students should attach images or text to the eight faces of the Learning Shapes as follows:
- One Learning Shape should have images attached to seven faces that illustrate the seven modern reasons for ocean exploration discussed above. So one face will have an image representing climate change, another face will have an image that represents energy, and so on. The remaining face should have an image of the *Okeanos Explorer*. Since this eighth face is used as a neutral image, it could be completely blank, but using an image of America's Ship for Ocean Exploration makes the Learning Shape much more interesting!
- One of the Learning Shapes should have text on seven faces that provide a descriptive title for one of the modern reasons for ocean exploration. So there should be one face that says "Energy," another that says "Ocean Health," and so on. The eighth face should have an image of the *Okeanos Explorer*, or other neutral image.
- The two remaining Learning Shapes should also have one neutral face containing an image of the *Okeanos Explorer*. The other seven faces should contain brief text describing a single fact about one of the seven modern reasons for ocean exploration, with a different reason represented on each of the seven faces. So one of the shapes might have a face that says "Methane hydrates are a potential energy source found in the deep ocean" (representing energy as a reason for exploration), another face that says "Deep-sea animals can be promising sources of new drugs" (representing human health as a reason for exploration), and so on.

Note: It is easier to attach images and text before Learning Shapes are fully assembled. Cut out and pre-fold the Shapes, but attach images and/or text before gluing the tabs into place. For sample Learning Shapes, see To Boldly Go Addendum http://oceanexplorer.noaa.gov/okeanos/edu/leadersguide/media/toboldlygo_addendum.pdf.

When all four Learning Shapes are completed, it should be possible to orient the shapes so that the upper face of one shape shows a picture representing one of the modern reasons for ocean exploration, the upper face of another shape shows a descriptive title stating the reason in words, and the upper faces of the remaining two shapes shows facts relevant to that reason. It should also be possible to orient the four shapes so that the upper face shows a "neutral" image that is not specifically related to a specific reason to explore the ocean.

Figure 2:
Ocean Exploration Learning Shape Octahedron
Using photocopies fold on dotted lines, and glue tabs under matching edges.





Ocean exploration requires ongoing technological innovation. Situational Awareness is one such innovation used in Autonomous Underwater Vehicles (AUVs) to provide the ability to sense their surroundings and avoid obstacles. Image credit: NOAA.
http://oceanexplorer.noaa.gov/explorations/08auvfest/background/hires/auv_concept_hires.jpg

NOAA's Ocean Explorer Gallery offers images of unusual organisms from the deep ocean that are ideal for Ocean Exploration Learning Shapes, such as this spiny crab, deepwater anemone, and Shaefer's anglerfish. Image credit: NOAA.
http://oceanexplorer.noaa.gov/explorations/04fire/logs/hirez/spinycrab_hirez.jpg
http://oceanexplorer.noaa.gov/explorations/02quest/logs/jun16/media/anemone.html
http://oceanexplorer.noaa.gov/explorations/04etta/logs/hires/bubba_mouth_hires.jpg

c. Now it's time to play "Ocean Exploration Bowl!" The object of this game is for student groups to correctly associate, in the shortest possible time, descriptive titles and relevant facts with an image representing a reason for exploration. Groups compete one at a time, and when all groups have competed, one round has been completed. When a group has finished, ask members of other groups to verify that the selected title and facts correctly match the image. Students have to pay attention to make this verification, and because play proceeds rapidly from group to group, there is minimal down time during which students may become distracted.

Assign two students to act as timekeepers. Since groups compete one at a time, timekeepers can be members of other competing groups. Provide each timekeeper with a stopwatch. Have one group arrange their four Learning Shapes on a desk or table so that the image of *Okeanos Explorer* (or other neutral image) shows on the upper face of each Learning Shape.

You (the educator) should pick up the Learning Shape that has images attached, hold it out of students' sight, and orient the Learning Shape so that one of the images representing a reason for ocean exploration is facing the palm of your hand. Put the Learning Shape back onto the table, and say "Boldly Go!" as you remove your hand. The timekeepers should start their stopwatches as soon as you say "Boldly Go!", and students in the group should orient the remaining three cubes as quickly as possible so that the appropriate descriptive title and two relevant facts are facing upward. As soon as they have done this, the group should say "Discovery!" which is the signal for the timekeepers to stop their stopwatches. Have group members state their reason for ocean exploration, and the relevant facts. Record the average from the two stopwatches on a score sheet for the competing group.

Repeat this process for the remaining groups. At least three rounds should be completed to cover all seven reasons and a good selection of relevant facts. When the winning group has been determined (by the shortest average time over all rounds), award prizes such as small bags of seaweed crackers, or other ocean-related items. Be sure every group receives something, but it's fine if the winner's share is larger!

If time is short, you may want to have groups construct only the first Learning Shape with images, then have group members state as many relevant facts as possible when a particular image is turned face up. This eliminates the need for timekeepers, but you should probably have several rounds since student research is likely to yield more facts for some reasons than others.

Adaptations for Other Grade Levels

Considerations for Grades 5-6 – Some students may not be familiar with hydrothermal vents, deep-sea cold seeps, underwater volcanoes, and seamounts that have been relatively recently discovered, so be sure to have images of these habitats available to show after receiving students' comments on the Cousteau quotation. Similarly, students may not be aware of the potential for new medicines or alternative energy sources from deep-sea ecosystems. Depending upon their existing knowledge, you may want to focus primarily upon these potentials as contemporary reasons for ocean exploration, since the relationship between deep-ocean processes and climate change may be difficult to understand at this grade level. In addition, students may be intrigued by how little is known about the deep ocean, and may feel that this is sufficient justification for exploration. Be sure students understand that the *Okeanos Explorer* is the first U.S. ship to be dedicated specifically to exploring the largely unknown ocean.

Considerations for Grades 9-12 – Ocean acidification, pH, buffers, carbon dioxide sources and sinks, methane hydrates, deep-sea medicines, and deep-ocean habitats (hydrothermal vents, deep-sea cold seeps, underwater volcanoes, and seamounts) can all be explored in greater detail. Consider assigning these topics to individual student groups prior to beginning a discussion focused on ocean exploration. When groups have completed their reports, lead a discussion to address the Guidance Questions and invite appropriate groups to present relevant information from their reports in the context of "why explore."

The BRIDGE Connection

www.vims.edu/bridge/ – In the navigation menu on the left side of the Web page, click "Ocean Science Topics," then "Human Activities," then "Technology" for links to information and activities involved with ocean exploration, including satellites, underwater robots, and deep-sea medicines.

The "Me" Connection

Have students write a brief essay about what ocean life might be like in the second half of the 21st century, and how ocean exploration might affect that future.

Connections to Other Subjects

English/Language Arts, Mathematics, Social Studies

Assessment

Written reports may be required as part of Learning Procedure Step 3. These reports, discussions and/or the Ocean Exploration Bowl game provide a basis for assessment.

Multimedia Discovery Missions

http://www.oceanexplorer.noaa.gov/edu/learning/welcome.html Click on the links to Lessons 3, 5, 12, 13, and 15 for interactive multimedia presentations and Learning Activities on Deep-Sea Corals, Chemosynthesis and Hydrothermal Vent Life, Food, Water, and Medicine from the Sea, Ocean Pollution, and Seamounts.

Lesson Plans in Volume 1

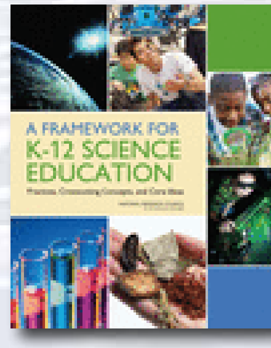
As these lessons were originally developed for Online Professional Development they are accessible online at *http://oceanexplorer.noaa.gov/okeanos/edu/welcome.html*.

Other Resources

See page 217 for Other Resources.

Next Generation Science Standards

Lesson plans developed for Volume 1 are correlated with *Ocean Literacy Essential Principles and Fundamental Concepts* as indicated in the back of this book. Additionally, a separate online document illustrates individual lesson support for the Performance Expectations and three dimensions of the Next Generation Science Standards and associated Common Core State Standards for Mathematics and for English Language Arts & Literacy. This information is provided to educators as a context or point of departure for addressing particular standards and does not necessarily mean that any lesson fully develops a particular standard, principle or concept. Please see: *http://oceanexplorer.noaa.gov/okeanos/edu/collection/wdwe_ngss.pdf*.



The Next Generation Science Standards

The Next Generation Science Standards integrate three dimensions within each standard: Science and Engineering Practices, Disciplinary Core Ideas, and Crosscutting Concepts. The standards are written as student performance expectations and each combines Science and Engineering Practices, Disciplinary Core Ideas, and Crosscutting Concepts as described in *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (National Research Council, 2012). While specific performance expectations may emphasize only a few of the practice categories, teachers are encouraged to utilize several practices in any instruction. Similarly, only a few crosscutting concepts may be emphasized, but this is not intended to limit instruction.

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:
oceanexeducation@noaa.gov

For More Information

Paula Keener, Director, Education Programs
NOAA Office of Ocean Exploration and Research
Hollings Marine Laboratory
331 Fort Johnson Road, Charleston SC 29412
843.762.8818 843.762.8737 (fax)
paula.keener-chavis@noaa.gov

Acknowledgments

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

Diving Deeper: Additional Information about Key Topics

This section provides additional details and discussion of selected topics mentioned in "Background Information."

Overview of Some Key Data Concerning Global Climate Change

Since the middle of the 1800's, Earth's average temperature has warmed by about 1°F. This doesn't sound like much of a change, but it is important to realize that Earth's average temperature is now warmer than it has been at any time since at least 1400 AD. We say "at least" because 1400 AD is as far back as scientists have good estimates of temperatures. Other evidence suggests that Earth's temperature is warmer now than it has been in many thousands of years, maybe nearly 100,000 years. It is also important to remember that most averages include numbers that are higher and lower than the "average" value. So the warming in some areas can be much higher than 1°F, while other areas may actually be cooler. Debate continues about the causes of climate change and the relative importance of long-term climate cycles, greenhouse gases, and other factors; but it is clear that:

- Mountain glaciers are melting;
- Polar ice is decreasing;
- Springtime snow cover has been reduced;
- Ground temperature has been increasing in many areas; and
- Sea level has risen by several inches in the last 100 years.

You may have heard statements such as "Earth's temperature has been dropping for the last ten years." These statements are based on the fact that 1998 was abnormally hot due to the strongest El Nino event in the last century. However, the 2000's were the warmest decade on record and the average global temperature in 2010 tied 2005 as the warmest year since reliable records began in 1880. In the State of the Climate in 2009 report (Arndt, Baringer, and Johnson, 2010), an international team of climate scientists concluded, "Each of the last three decades was warmer than all earlier decades in the instrumental record and each set a new and statistically significant record." Several years following 1998 were indeed cooler than 1998, but the long-term trend still shows continued warming. There are many factors that affect global temperatures in a single year, and it is not surprising that one year might be cooler than the preceding year. But the global warming trend is a matter of decades, not just one or two years. The long-term trend is still clear: Seven of the eight warmest years on record have occurred since 2001, and the ten warmest years on record have all occurred since 1995.

Within the world scientific community, there is a broad consensus that:

- Global warming is unequivocal and primarily human-induced.
- Climate changes are underway in the United States and are projected to grow.
- Widespread climate-related impacts are occurring now and are expected to increase.
- Climate change will stress water resources.
- Crop and livestock production will be increasingly challenged.
- Coastal areas are at increasing risk from sea-level rise and storm surge.
- Risks to human health will increase.
- Climate change will interact with many social and environmental stresses.
- Thresholds will be crossed, leading to large changes in climate and ecosystems.
- Future climate change and its impacts depend on choices made today.

(source: Karl, Melillo, and Peterson, 2009).

The scientific consensus on these points is supported by a huge amount of data from many places on Earth. Following is a brief review of a few key points.

Cause of the Observed Warming

Earth's climate is affected by a number of factors, including changes in Earth's orbit, solar variability, volcanoes, and the greenhouse effect. But the only factor that coincides with the warming trend of the last century is the observed increase in greenhouse gases, particularly carbon dioxide. There is no credible scientific debate about this: Since the start of the Industrial Revolution, atmospheric carbon dioxide concentrations have increased from 280 parts per million (ppm) to 380 ppm. Today, the global concentration of carbon dioxide is significantly higher than the natural range over the last 800,000 years of 170 – 300 ppm.

Cause of Increasing Atmospheric Carbon Dioxide

There is also no scientific debate about the source of increased atmospheric carbon dioxide. Humans burning fossil fuels release billions of tons of carbon into the atmosphere every year, and the quantity of fuels burned has been increasing for over 150 years (see, for example, *http://cdiac.ornl.gov/trends/emis/tre_glob.html*).

What about volcanoes? Scientists estimate that volcanoes (including underwater volcanoes) emit 145-255 million tons of carbon dioxide into the atmosphere each year. Emissions of carbon dioxide from human activities are estimated at about 30 billion tons per year. So, the amount of carbon dioxide from human activities is more than 100 times greater than the amount of carbon dioxide emitted by volcanoes (*http://volcano.oregonstate.edu/education/gases/man.html*). Further, if volcanoes had a significant impact, we should see "spikes" on graphs of atmospheric carbon dioxide every time a volcano erupts; but such spikes are not present on these graphs.

What about increases in atmospheric carbon dioxide that happened during pre-human times? It is true that carbon dioxide rose and fell by over 100 ppm at various times in Earth's history, but these rises took place over 5,000 to 20,000 years; the present increase of 100 ppm has happened in only 150 years. Additional evidence implicating human activities comes from isotope analyses of the carbon and oxygen atoms that make up atmospheric carbon dioxide molecules. These analyses show that the oxygen atoms in some of these molecules are much younger than the carbon atoms in the same molecule. Older carbon could only come from fossil fuel deposits, and the only way these deposits could become airborne is through combustion. Note that the amount of methane released by natural seepage as described below is much less than the amount of carbon released by combustion of fossil fuel, so natural seepage cannot account for the presence of older carbon.

Effect of Continued Increase in Atmospheric Carbon Dioxide

Global Temperature Increase

If atmospheric carbon dioxide concentrations continue to increase and nothing is done to reduce carbon dioxide emissions, global temperatures are projected to increase by 1.1° to 6.4°C (2° to 11.5°F) by 2100 (Meehl, *et al.*, 2007). So, the minimum expected temperature increase under these conditions is nearly three times twice the increase that has already been observed. The actual increase could be much greater, depending upon the influence of feedbacks. For example, decreasing ice and snow in polar regions means that less solar radiation will be reflected away from Earth's surface. This would result in more radiation being absorbed at the surface, and increased warming.

A methane hydrate mound on the seafloor; bubbles show that methane is continuously leaking out of features like this. If bottom waters warmed, this entire feature may be destabilized and leak methane at a higher rate. Image credit: NOAA
http://oceanexplorer.noaa.gov/explorations/10chile/background/methane/media/methane4.html

Methane Hydrates

Warmer temperatures in the Arctic could also trigger another feedback process. Methane hydrates are a type of ice that contains methane molecules surrounded by a cage of frozen water molecules. Most methane hydrates are believed to exist in ocean sediments, but some are also found in high latitude soils called permafrost as well as in tropical wetlands. Increasing temperatures may cause methane hydrates to melt and release methane gas to the atmosphere. Since methane is a powerful greenhouse gas, and decomposes to form carbon dioxide, increased atmospheric methane could result in an increased greenhouse effect and additional warming of Earth's climate. Brook *et al.* (2008) report that a sudden, rapid release of methane is very unlikely to occur within 100 years; but it is very likely that warming will increase the rate of chronic methane emission from these sources, and that this additional methane could increase the rate of global temperature rise.

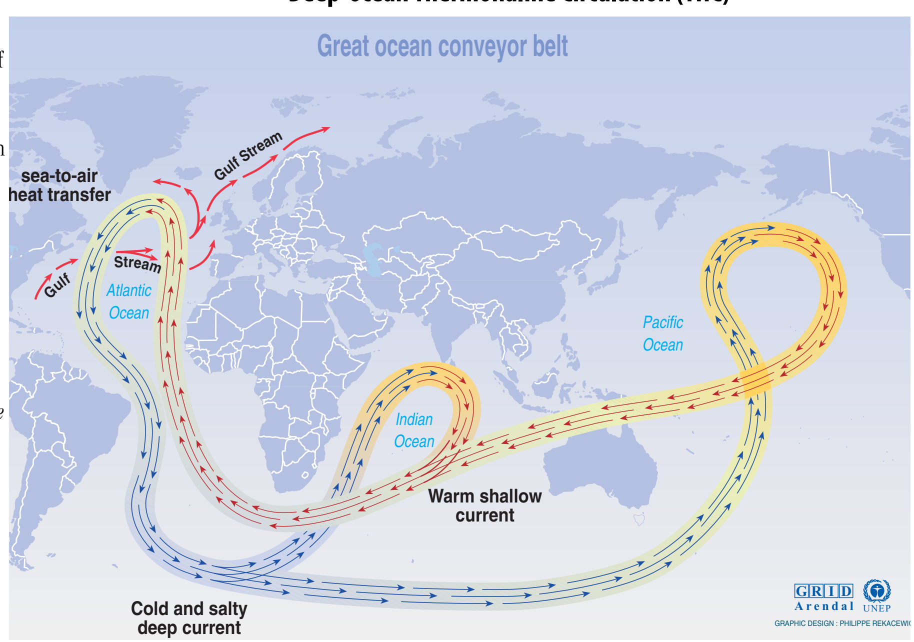
Ocean Temperature

A warmer atmosphere could also mean warmer temperatures in Earth's ocean. Since the solubility of carbon dioxide decreases as temperature rises, warmer temperatures could decrease carbon dioxide absorption by the ocean creating yet another feedback mechanism. Temperature has an opposite effect on the atmosphere's capacity for water vapor: Warmer air can hold more water vapor that evaporates from the ocean and land surface. Increased atmospheric water vapor has been observed from satellites, and is primarily due to human influences (Santer, *et al.*, 2007). Water vapor is the most important and abundant greenhouse gas, and increased atmospheric water vapor can strengthen the greenhouse effect and result in additional warming. This effect may be counterbalanced to some extent if increased atmospheric water vapor causes increased cloud cover that reduces the amount of solar radiation reaching Earth's surface.

Ocean Circulation

Global climate is strongly influenced by interactions between Earth's atmosphere and ocean, but these interactions are complex and poorly understood. While the deep-ocean might seem far removed from the atmosphere, one of the most significant climatic influences results from the deep-ocean thermohaline circulation (THC).

Deep-ocean Thermohaline Circulation (THC)



World ocean thermohaline circulation (THC) is driven primarily by the formation and sinking of deep water in the Norwegian Sea. When salinity decreases because of excess precipitation, runoff, or ice melt, the conveyor belt will weaken or even shut down. Variations in the THC may lead to climate change in Europe and also affect other areas of the global ocean.

Source: *http://www.grida.no/publications/vg/climate/page/3085.aspx*; data from *Climate Change 1995 – Impacts, adaptations and mitigation of climate change: Scientific-Technical Analyses. Contribution of Working Group 2 to the Second Assessment Report of the Intergovernmental Panel on Climate Change*. United Nations Environment Programme and World Meteorological Organization. Cambridge University Press. 1996. Cartographer/Designer: Philippe Rekacewicz, UNEP/GRID-Arendal. *http://maps.grida.no/library/files/storage/31new.pdf*

The THC is driven by changes in seawater density. Two factors affect the density of seawater: temperature (the "thermo" part) and salinity (the "haline" part). Major features of the THC include:

- In the Northeastern Atlantic Ocean, atmospheric cooling increases the density of surface waters. Decreased salinity due to freshwater influx partially offsets this increase (since reduced salinity lowers the density of seawater), but temperature has a greater effect, so there is a net increase in seawater density. The formation of sea ice may also play a role as freezing removes water but leaves salt behind causing the density of the unfrozen seawater to increase. The primary locations of dense water formation in the North Atlantic are the Greenland-Iceland-Nordic Seas and the Labrador Sea.
- The dense water sinks into the Atlantic to depths of 1,000 m and below, and flows south along the east coasts of North and South America.
- As the dense water sinks, it is replaced by warm water flowing north in the Gulf Stream and its extension, the North Atlantic Drift (note that the Gulf Stream is primarily a wind driven current, but portions of its circulation—the North Atlantic Drift—are also part of the THC).
- The deep south-flowing current combines with cold, dense waters formed near Antarctica, and flows from west to east in the Deep Circumpolar Current. Some of the mass deflects to the north to enter the Indian and Pacific Oceans.
- Some of the cold water mass is warmed as it approaches the equator, causing density to decrease. Upwelling of deep waters is difficult to observe, and is believed to occur in many places, particularly in the Southern Ocean in the region of the Antarctic Circumpolar Current.
- In the Indian Ocean, the water mass gradually warms and turns in a clockwise direction until it forms a west-moving surface current that moves around the southern tip of Africa into the South Atlantic Ocean.
- In the Pacific, the deepwater mass flows to the north on the western side of the Pacific basin. Some of the mass mixes with warmer water, warms, and dissipates in the North Pacific. The remainder of the mass continues a deep, clockwise circulation. A warm, shallow current also exists in the Pacific, which moves south and west, through the Indonesian archipelago, across the Indian Ocean, around the southern tip of Africa, and into the South Atlantic.
- Evaporation increases the salinity of the current, which flows toward the northwest, joins the Gulf Stream, and flows toward the Arctic regions where it replenishes dense sinking water to begin the cycle again.


Reduced Arctic sea ice allows more heat to be absorbed by the ocean. Image credit: NOAA.

The processes outlined above are greatly simplified. In reality, the deep-ocean THC is much more complex, and is not fully understood. Our understanding of the connections between the deep-ocean THC and Earth's ecosystems is similarly incomplete, but most scientists agree that:

- The THC affects almost all of the world's ocean (and for this reason, it is often called the "global conveyor belt");
- The THC plays an important role in transporting dissolved oxygen and nutrients from surface waters to biological communities in deep water; and
- The THC is at least partially responsible for the fact that countries in northwestern Europe (Britain and Scandinavia) are about 9°C warmer than other locations at similar latitudes.

In recent years, changes in the Arctic climate have led to growing concerns about the possible effects of these changes on the deep-ocean THC. In the past 30 years, parts of Alaska and Eurasia have warmed by about six degrees Celsius. In the last 20 years, the extent of Arctic sea ice has decreased by 5%, and in some areas, sea ice thickness has

Dry ice, a pH indicator, and water can be used in the classroom to demonstrate the acidifying effects of carbon dioxide in ocean water. For a similar demonstration using human respiration instead of dry ice, see page 41. Image credit: NOAA/CRCP

decreased by 40%. Overall, the Arctic climate is warming more rapidly than elsewhere on Earth. Reasons for this include:

- When snow and ice are present, as much as 80% of solar energy that reaches Earth's surface is reflected back into space. As snow and ice melt, surface reflectivity (called "albedo") is reduced, so more solar energy is absorbed by Earth's surface;
- Less heat is required to warm the atmosphere over the Arctic because the Arctic atmosphere is thinner than elsewhere *http://oceanexplorer.noaa.gov/explorations/06arctic/logs/leg1_summary/media/slideshow/slideshow.html*;
- With less sea ice, the heat absorbed by the ocean in summer is more easily transferred to the atmosphere in winter.

Dense water sinking in the North Atlantic Ocean is one of the principal forces that drives the circulation of the global conveyor belt. Since an increase in freshwater inflow (such as from melting ice) or warmer temperatures in these areas would weaken the processes that cause seawater density to increase, these changes could also weaken the global conveyor belt.

Ocean pH

Increasing atmospheric carbon dioxide is also having a serious effect on ocean pH. Each year, the ocean absorbs approximately 25% of the CO_2 added to the atmosphere by human activities. When CO_2 dissolves in seawater, carbonic acid is formed, which raises acidity. Ocean acidity has increased by 30% since the beginning of the Industrial Revolution, causing seawater to become corrosive to the shells and skeletons of many marine organisms as well as affecting the reproduction and physiology of others. See *Off Base,* page 205, for additional discussion and references.

Impacts of Expected Climate Change if Trends Continue

The Intergovernmental Panel on Climate Change and U.S. Global Change Research Program (the leading providers of scientific advice to global and United States of America policy makers) have produced reports on some of the impacts that are occurring as a result of climate change as well as impacts that are anticipated if present trends continue (Solomon, *et al.*, 2007; Karl, Melillo, and Peterson, 2009). These impacts include:

- Floods and droughts are likely to become more common and more intense, as rainfall becomes more concentrated into heavy events with longer, hotter dry periods in between;
- Precipitation and runoff are likely to increase in the Northeast and Midwest in winter and spring, and decrease in the West (especially the Southwest) in spring and summer;
- Water supplies stored in glaciers and snow cover are projected to decline, reducing water availability in regions supplied by meltwater from major mountain ranges, where more than one-sixth of the world population currently lives;
- Sea-level rise is expected to increase saltwater intrusion into coastal freshwater aquifers, making some unusable without desalination;
- Rising sea levels are likely to damage energy production equipment; the U.S. East Coast and Gulf Coast are particularly vulnerable because the land is relatively flat and is sinking in many places;
- Added stress from climate change will increase the risk of extinction for many plants and animals;
- Wildfires, insect outbreaks, and invasive weed species are likely to increase;

- Increasing atmospheric carbon dioxide concentration is causing an increase in ocean acidity, which reduces the ability of shellfish, corals and other sea life to build shells and skeletons out of calcium carbonate, and also interferes with reproduction in other marine organisms.

Ocean Energy Overview

Earth's ocean contains enormous energy resources in its waters, in the adjacent atmosphere, and in the mantle and crust beneath the seafloor. Ocean energy resources include non-renewable sources such as oil and gas, as well as renewable sources, such as the energy of offshore winds, waves, and ocean currents. With the exception of oil and gas, ocean energy resources have not been extensively utilized in the United States, primarily because many of the technologies are not well-developed, nor have they been economically competitive with fossil fuels and nuclear power.

Underutilized ocean energy resources, though, are receiving increasing attention as technologies improve, prices of traditional energy sources continue to increase, and political considerations become more problematic. The following overview includes energy sources that are already being used in commercial-scale projects, as well as sources for which harvest technologies are still in the early stages of development.

Note: "Ocean energy" is sometimes used as a term that includes only forms of ***renewable*** energy that may be derived from the sea. The following discussion also includes non-renewable methane hydrates, because of the enormous quantity of energy that is potentially available from these substances, and the widespread occurrence of methane hydrates in deep-sea environments.

Salinity Gradient (Osmotic) Energy

When fresh water and salt water are separated by a semipermeable membrane, water will move through the membrane into the salt solution (only water molecules can pass through a semipermeable membrane). This water movement is driven by a force called osmotic pressure, which is defined as the pressure that would have to be applied to the salt water solution to prevent the influx of water through the semipermeable membrane. Influx of fresh water will increase the volume of the salt water. If the salt water is in a closed container, the volume cannot increase because water is essentially incompressible, and the pressure in the container will rise until it equals the osmotic pressure. If the pressure in the container is released, it can be used to drive a turbine to generate electricity. This method for utilizing salinity gradient energy is called Pressure Retarded Osmosis.

Reverse Electrodialysis is another salinity gradient technique that uses a series of anion and cation exchange membranes (negatively charged ions can pass through anion exchange membranes; positively charged ions can pass through cation exchange membranes). When fresh water and salt water are separated by an anion exchange membrane, negatively charged ions will move from the salt water into the fresh water until the concentration on both sides of the membrane are equal. Similarly, when fresh water and salt water are separated by an cation exchange membrane, positively charged ions will move from the salt water into the fresh water until the concentration on both sides of the membrane are equal. A reverse electrodialysis cell is essentially a salt battery with alternating containers of fresh water and salt water separated by an alternating series of anion and cation exchange membranes. If electrodes are placed at opposite ends of the cell and connected to an electric circuit, a voltage will be produced in the circuit.

Development of salinity gradient energy technology is still in its infancy, though the potential energy is large in locations where rivers mix with salt water.

Waves have the highest energy density of any renewable energy resource. Image credit: NOAA

Waves

Enormous amounts of kinetic energy exists in the moving waves of the ocean. In fact, waves have the highest energy density of any renewable resource. Wave-power is particularly rich in areas along the western coasts of Scotland, northern Canada, southern Africa, Australia, and the northwestern coasts of the United States. Devices to capture wave energy are designed to extract energy directly from the surface motion of ocean waves or from pressure fluctuations below the surface caused by waves. Most of these devices being tested at commercial scales use one of the following technologies:

- Terminator devices are oriented perpendicular to the direction of wave travel and are analogous to a piston moving inside a cylinder. An Oscillating Water Column is a type of terminator in which water enters through a subsurface opening into a chamber with air trapped above it. Wave action causes the column of water to move up and down in the chamber, forcing the air though an opening to rotate a turbine. Another type of terminator, called an Overtopping Device, consists of an enclosed reservoir that is filled by overtopping waves. Water collected in the reservoir is released back into the ocean through an outlet system that uses the energy of the falling water to rotate a turbine.
- Point absorbers are floating structures with components that move relative to each other due to wave action (for example, a floating piston inside a fixed cylinder). The motion of the components is used to drive electromechanical or hydraulic energy converters (you can see an animation of one type of point absorber at *http://www.finavera.com/en/wavetech/aquabuoymovie*).
- Attenuators are segmented floating structures oriented parallel to the direction of the waves. As waves pass under the attenuator, the connections between segments flex and this flexing motion is transmitted to hydraulic pistons that drive electric generators inside the segments.

You can see illustrations and animations of these devices at *http://ocsenergy.anl.gov/guide/wave/index.cfm*.

Rising and falling tides can be used to generate electricity where the tidal range is at least 16 – 24 feet. Image credit: NOAA

Tidal Energy

Humans have been using the energy of ocean tides since at least the eighth century AD. The basic principle is to build a dam across an estuary or small tidal stream so that water is trapped behind the dam when the tide rises. Then when the tide falls, the trapped water can be released to that it turns a water wheel that can do work such as mill grains or turn a turbine to generate electricity. A tidal range of at least 16 - 24 feet is needed for economical electricity generation, which limits the number of locations where it is feasible to capture tidal energy in this way. One such location is the La Rance River estuary on the northern coast of France, where a tidal energy generating station has been in operation since 1966. Smaller stations have been established in Nova Scotia, Canada and Murmansk, Russia.

An alternative approach for capturing tidal energy is to place turbines in offshore tidal streams. The technology is similar to that used for capturing energy from ocean currents.

Current Energy

Ocean currents, such as the Gulf Stream, Florida Straits Current, and California Current, are driven by wind, solar heating, and density variations of large ocean water masses. These currents are relatively constant and flow in one direction only, while the velocity of tidal currents closer to shore varies constantly and their direction changes several times each day. Ocean currents contain an enormous amount of energy; for example, it has been estimated that all of Florida's electrical needs could be met by capturing less than 1% of the available energy in the Gulf Stream.

Technology to capture ocean current energy is presently in the early stages of development, and there are no commercial scale turbines producing electricity for regular distribution. Experimental projects include submerged water turbines similar to wind turbines, as well as doughnut-shaped turbines with blades resembling those seen in jet engines (see *http://ocsenergy.anl.gov/guide/current/index.cfm* for illustrations).

Thermal Energy

> *I owe all to the ocean; it produces electricity, and electricity gives heat, light, motion, and, in a word, life to the* Nautilus.
>
> *— Jules Verne, 1870*

Captain Nemo's explanation of engineering aboard the *Nautilus* in *20,000 Leagues Under the Sea* provides the first documented reference to the use of ocean chemistry to produce electricity. A decade later, French Engineer Jacques D'Arsonval suggested the possibility of using ocean temperature differences to produce electricity.

This idea is based on the fact that Earth's ocean covers slightly more than 70 percent of the Earth's surface, making the ocean Earth's largest collector and storage system for solar energy. On an average day, 60 million square kilometers (23 million square miles) of tropical seas absorb an amount of solar radiation equal in heat content to about 250 billion barrels of oil (in 2008, the world daily consumption of oil is estimated to have been 84.5 million barrels). So, harvesting even a very small fraction of the radiant energy absorbed by Earth's ocean could have a significant impact on human energy needs.

Ocean Thermal Energy Conversion (OTEC) is a technology to convert solar radiation absorbed by the ocean into electric power. The basis for this concept is that surface ocean waters receive most solar radiation and consequently are warmer than deeper waters. Where the temperature difference between surface water and deep water is about 20°C (36°F), an OTEC system can produce a significant amount of power.

D'Arsonval's original idea was to pump warm seawater through a heat exchanger to vaporize a fluid with a low boiling point (such as ammonia), and then use the expanding vapor to turn an electricity-generating turbine. Cold seawater would be pumped through a second heat exchanger to condense the vapor back into a liquid, which would be recycled through the system. This type of OTEC is called a closed-cycle system. Pilot-scale closed-cycle OTEC systems have been successful in producing electric power.

Open-cycle OTEC systems use warm seawater that boils when it is placed in a low-pressure container. The expanding steam drives an electricity-generating turbine. Cold seawater is used to condense the steam back to water. This water is almost pure fresh water, since the salt is left behind in the low-pressure container when the seawater boils. Experimental open-cycle OTEC plants have also successfully produced electric power, in some cases with energy conversion efficiencies as high as 97%. Hybrid OTEC systems combine some features of both closed-cycle and open-cycle systems: Warm seawater enters a vacuum chamber where it is evaporated into steam (similar to the open-cycle evaporation process) that is used to vaporize a low-boiling-point fluid (as in closed-cycle system) that drives a turbine to produce electricity.

Geothermal energy has been used for centuries. Most of Earth's geothermal activity occurs along the Ring of Fire, which has been investigated by Ocean Explorer expeditions since 2002. Image credit: NOAA and NSF

Another type of thermal energy comes from the earth itself. This geothermal energy is produced in Earth's core by the decay of radioactive particles. Earth's core consists of an inner mass of solid iron and an outer core of melted rock called magma. The outer core is surrounded by Earth' s crust, which is 3 - 5 miles thick under the oceans and 15 - 35 miles thick under the continents. Volcanoes occur where magma comes close to the surface of the crust. In some areas, water enters cracks in the crust, comes close to hot magma, and turns into boiling hot water or steam. The heated water may emerge at the surface of Earth's crust as a hot spring, or may erupt into the air as a geyser. Geothermally heated water has been used for centuries to heat buildings, for bathing, and for cooking, and more recently to generate electricity.

Most geothermal activity in the world occurs along the boundaries of tectonic plates encircling the Pacific Ocean, in an area called the Ring of Fire. This area has been the subject of Ocean Explorer expeditions from 2002 through 2007, which documented numerous underwater volcanoes, hydrothermal vent fields and other geothermal features, many of which were unexplored prior to these expeditions. Technology for capturing geothermal energy from these sources is in the early stages of development, but pilot projects are planned or underway in several locations including the Azores, Northern Mariana Islands, and Cascades Mountains of the Pacific Northwest; and at least one system has been proposed to directly harvest energy from deep-sea hydrothermal vents.

Solar

Energy from the sun is the primary energy source for photosynthesis, winds, waves, and deep-ocean currents. Image credit: NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010

Energy from the sun is the primary energy source for all photosynthetic ecosystems, and also drives winds, waves, and deep-ocean currents. In fact, energy from wind, waves, currents, and OTEC could be considered as indirect forms of solar energy (similarly, tidal current energy could be considered as an indirect form of gravitational energy, since tidal currents are driven by gravitational forces between Earth, its moon, and the sun). Solar energy technologies that are presently used in land-based installations may also be developed for offshore use.

Concentrating Solar Power (CSP) technology concentrates the sun's rays to produce steam to drive turbines or other devices to generate electricity. In the United States, CSP plants have been operating reliably for more than 15 years. CSP installations typically are one of three types:

- Trough systems consist of long mirrors that are curved to form parabolas with oil-filled pipes running along the long axis of the mirror at the focal point of the parabola. The mirrors focus sunlight onto the pipes and heat the oil up to 750°F. The hot oil is used to make steam that drives a steam turbine to produce electricity.
- Power towers (also called central receivers) have many large, flat mirrors that track the sun and focus its rays onto a receiver that is on top of a tall tower. The concentrated sunlight heats a fluid, which is used to make steam or is stored for later use (this allows electricity to be produced even if the sun is not

shining). Some power towers use molten salt as the fluid and heat the salt to over 1,000°F.

- Dish/engine systems use mirrored parabolic dishes (similar to a television satellite dish but about 10 times larger) to track the sun's path and focus sunlight onto a receiver, which is mounted at the focal point of the parabola. The receiver heats hydrogen or helium gas contained in thin tubes that are connected to cylinders of an engine similar to an internal combustion engine. Heated gas expands inside the cylinders and drives pistons connected to a crankshaft. The crankshaft is connected to an electric generator.

Solar photonic technologies absorb solar photons and convert part of the energy to electricity (as in a photovoltaic cell) or store part of the energy in a chemical reaction (as in the conversion of water to hydrogen and oxygen). A photovoltaic (PV) cell transfers the energy of photons to electrons in the atoms that make up the cell. The energized electrons escape from these atoms and move from the PV cell into an electrical circuit. Concentrated PV (CPV) systems use mirrors or lenses and track the sun to keep light focused on the PV cells.

The appropriate solar technology for offshore applications depends in part on the intended use of the energy to be generated. CSP technologies may be more appropriate for generating and delivering electricity to shore, while photonic technology may be more appropriate for generating electricity that will be used "on-site" and to supply energy for activities such as hydrogen production or desalinization.

You can see illustrations and animations of CSP and solar photonic devices at *http://ocsenergy.anl.gov/guide/solar/index.cfm.*

Wind

For many centuries, humans have harnessed wind power to do various types of work, from pushing ships through the ocean, to pumping water, to processing agricultural products. More recently, wind has been used to produce electricity. Most wind turbines (wind turbines produce electricity; windmills grind grain or pump water) have been located on land, but offshore wind turbines are being used in a number of countries, including Denmark and the United Kingdom where large offshore wind facilities have been installed to take advantage of consistent winds. Offshore winds tend to flow at higher speeds than onshore winds, which means that offshore wind turbines have the potential to produce more electricity than land-based installations.

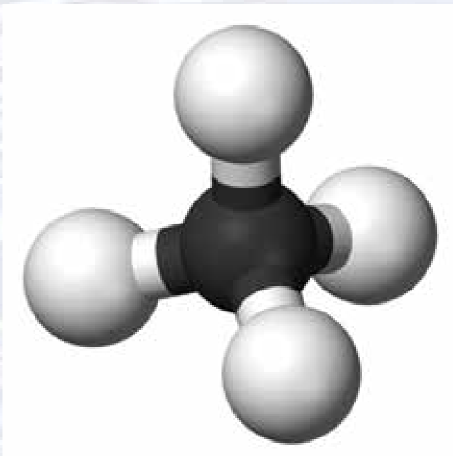
Wind and waves building during an Ocean Explorer expedition at Mississippi Canyon in the Gulf of Mexico. Image credit: University of Alabama and NOAA OE

Commercial-scale offshore wind facilities in the United States are located in waters that are much deeper than European waters where commercial wind facilities are currently sited. As a result, offshore wind turbines are larger and more complex than shore-based turbines, with features that include strengthened support towers to withstand with wind and wave forces, built-in service cranes, automatic greasing systems, pre-heating and cooling systems to maintain gear oil temperature within a narrow temperature range, and lightning protection systems.

Hybrids

There is growing interest in combining several ocean energy sources in installations called Hybrids. One of the problems with wind power, for example, is that the wind doesn't always blow at velocities needed to generate electricity (above 12 to 14 miles per hour), but is so strong at other times that turbines have to be shut down to avoid damage. Combining wind turbines with other energy sources can provide more consistent electricity output. Waves, currents, and OTEC have been proposed as potential energy sources for hybrid installations. Recent examples include:

- Eclipse Energy's Ormonde Project in the Irish Sea, which will produce energy from 30 wind turbines as well as from nearby gas fields; and
- Outer Banks Ocean Energy Corporation, which was formally chartered in September 2009 to generate electrical power from wind, wave and current resources approximately 25 miles off the coast of North Carolina.

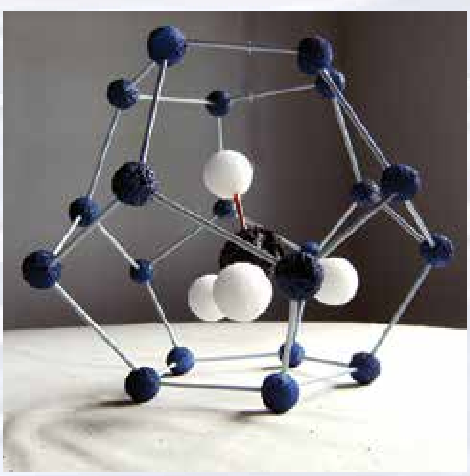


Methane is composed of one carbon atom surrounded by four hydrogen atoms. It is the simplest hydrocarbon. Image credit: INSPIRE: Chile Margin 2010.
http://oceanexplorer.noaa.gov/explorations/10chile/background/methane/media/methane1.html

Methane Hydrates and Other Hydrocarbons

Methane hydrate is a type of clathrate, in which molecules of frozen water form an open lattice that encloses molecules of methane without actually forming chemical bonds between the two compounds. Methane is produced in many environments by a group of Archaea known as methanogenic Archaeobacteria. These Archaeobacteria obtain energy by anaerobic metabolism through which they break down the organic material contained in once-living plants and animals. When this process takes place in deep-ocean sediments, methane molecules are surrounded by water molecules, and conditions of low temperature and high pressure allow stable ice-like methane hydrates to form. The U.S. Geological Survey has estimated that on a global scale, methane hydrates may contain roughly twice the carbon contained in all reserves of coal, oil, and conventional natural gas combined. Methane is a fossil fuel that could be used in many of the same ways that other fossil fuels (*e.g.*, coal and petroleum) are used (and with the same environmental impacts). According to the U.S. Department of Energy, the recoverable U.S. domestic natural gas resource is roughly 2,300 trillion cubic feet (Tcf). In the case of methane hydrates, the potentially-recoverable domestic resource base could be on the order of 5,000 Tcf.

While potential benefits as an alternative energy source are exciting, methane hydrates may also cause big problems.



Build your own model of a methane hydrate molecule! See page 125. Image credit: Mellie Lewis

Although methane hydrates remain stable in deep-sea sediments for long periods of time, as the sediments become deeper and deeper they are heated by the Earth's core. Eventually, temperature within the sediments rises to a point at which the clathrates are no longer stable and free methane gas is released (at a water depth of 2 km, this point is reached at a sediment depth of about 500 m). The pressurized gas remains trapped beneath hundreds of meters of sediments that are cemented together by still-frozen methane hydrates. If the overlying sediments are disrupted by an earthquake or underwater landslide, the pressurized methane can escape suddenly, producing a violent underwater explosion that may result in disastrous tsunamis.

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The release of large quantities of methane gas can have other consequences as well, since methane is one of the greenhouse gases. In the atmosphere, these gases allow solar radiation to pass through but absorb heat radiation that is reflected back from the Earth's surface, thus warming the atmosphere. Many scientists have suggested that increased carbon dioxide in the atmosphere produced by burning fossil fuels is causing a greenhouse effect that is gradually warming the atmosphere and the Earth's surface. A sudden release of methane from deep-sea sediments could have a similar effect, since methane has more than 30 times the heat-trapping ability of carbon dioxide.

In 1995, Australian paleoceanographer Gerald Dickens suggested that a sudden release of methane from submarine sediments during the Paleocene epoch (at the end of the Tertiary Period, about 55 million years ago) caused a greenhouse effect that raised the temperatures in the deep ocean by about six degrees Celsius. The result was the extinction of many deep-sea organisms known as the Paleocene extinction event. More recently, other scientists have suggested that similar events could have contributed to mass extinctions during the Jurassic period (183 million years ago), as well as to the sudden appearance of many new animal phyla during the Cambrian period (the "Cambrian explosion," about 520 million years ago).

Besides methane hydrates, regions such as the Gulf of Mexico produce significant quantities of petroleum that are associated with unique deep-sea ecosystems. In the Gulf of Mexico, these ecosystems are typically found in areas with rocky substrates or "hardgrounds." Most of these hardbottom areas are found in locations called cold seeps where hydrocarbons are seeping through the seafloor. Microorganisms are the connection between hardgrounds and cold seeps. When microorganisms consume hydrocarbons under anaerobic conditions, they produce bicarbonate which reacts with calcium and magnesium ions in the water and precipitates as carbonate rock. Two types of ecosystems are typically associated with deepwater hardgrounds in the Gulf of Mexico: chemosynthetic communities and deep-sea coral communities. Hydrocarbon seeps may indicate the presence of undiscovered petroleum deposits, so the presence of these ecosystems can indicate potential sites for exploratory drilling and possible development of offshore oil wells. At the same time, these are unique ecosystems whose importance is presently unknown. For more information about deep-sea ecosystems in the Gulf of Mexico, see *Lessons from the Deep: Exploring the Gulf of Mexico's Deep-Sea Ecosystems Education Materials Collection* (*http://oceanexplorer.noaa.gov/edu/guide/welcome.html*).

These small oil droplets have seeped through the sediment and adhered to the top of methane hydrate. This image was taken at a depth of less than 1,000 m in the Gulf of Mexico. Image credit: Ian MacDonald, Texas A&M-Corpus Christi
http://oceanexplorer.noaa.gov/explorations/06mexico/logs/may08/media/oil_on_methane_600.html

Interest in methane hydrates has intensified in recent years due to the fact that the United States is relying more and more on the use of natural gas to achieve economic and environmental goals and there are increasing concerns about the long-term availability of our natural gas supply. Since 2000, the National Methane Hydrate R&D Program (conducted by the U.S. Department of Energy's National Energy Technology Laboratory) has supported a wide range of projects to assess the feasibility of developing methane hydrates deposits as new source of natural gas. Key activities include efforts to ensure the safety of deepwater oil and gas exploration and production operations that require drilling through marine hydrate deposits; developing knowledge and technology to allow commercial production of methane from hydrate deposits on Alaska's North Slope by the year 2015; and a joint project with the Bureau of Ocean Energy Management, Regulation and Enforcement and NOAA to establish a permanent monitoring station on the Gulf of Mexico seafloor to monitor the stability of methane hydrates. See *http://www.netl.doe.gov/technologies/oil-gas/FutureSupply/MethaneHydrates/projects/DOEProjects/DOE-Project_toc.html* for other methane hydrate R&D projects.

Human Health Overview

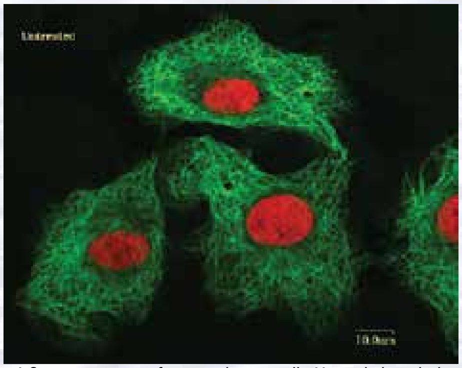
Chemicals produced by marine animals that may be useful in treating human diseases include:

Ecteinascidin – Extracted from tunicates; being tested in humans for treatment of breast and ovarian cancers and other solid tumors; acts by blocking transcription of DNA

Topsentin – Extracted from the sponges *Topsentia genitrix*, *Hexadella* sp., and *Spongosorites* sp.; anti-inflammatory agent; mode of action not certain

Lasonolide – Extracted from the sponge *Forcepia* sp.; anti-tumor agent; acts by binding with DNA

See page 175 for a simple bioassay that can be used for a wide variety of experiments and inquiries. Image credit: Mel Goodwin



A fluorescent image of untreated cancer cells. Microtubules, which form the cells' cytoskeleton, are stained green. The cell nuclei are stained red. Image credit: NOAA
http://oceanexplorer.noaa.gov/explorations/03bio/logs/sept18/media/untreated_cell.html

An image of treated cancer cells. These cells were exposed to a drug for 24 hours before being fixed and stained for viewing. The cytoskeletons are stained green; the nuclei are stained red. Image credit: NOAA
http://oceanexplorer.noaa.gov/explorations/03bio/logs/sept18/media/treated_cell.html

Harbor Branch Oceanographic Institution has more than 16,000 cultures of microbes isolated from deep- and shallow-water marine organisms. Image credit: NOAA
http://oceanexplorer.noaa.gov/explorations/03bio/background/microbiology/media/figure_01.html

Discodermalide – Extracted from deep-sea sponges belonging to the genus *Discodermia*; anti-tumor agent; acts by interfering with microtubule networks

Bryostatin – Extracted from the bryozoan *Bugula neritina*; potential treatment for leukemia and melanoma; acts as a differentiating agent, forcing cancer cells to mature and thus halting uncontrolled cell division

Pseudopterosins – Extracted from the octocoral *Pseudopterogorgia elisabethae* (sea whip); anti-inflammatory and analgesic agents that reduce swelling and skin irritation and accelerate wound healing; acts as an inhibitor of phospholipase A, which is a key enzyme in inflammatory reactions

ω-conotoxin MVIIA – Extracted from the cone snail *Conus magnus*; potent pain-killer; acts by interfering with calcium ion flux, thereby reducing the release of neurotransmitters

A striking feature of this list is that all of the organisms (except the cone snail) are sessile (non-moving) invertebrates. To date, this has been true of most marine invertebrates that produce pharmacologically-active substances. Several reasons have been suggested to explain why sessile marine animals are particularly productive of potent chemicals. One possibility is that they use these chemicals to repel predators, because they are basically "sitting ducks." Another possibility is that since many of these species are filter feeders, and consequently are exposed to all sorts of parasites and pathogens in the water, they may use powerful chemicals to repel parasites or as antibiotics against disease-causing organisms. Competition for space may explain why some of these invertebrates produce anti-cancer agents. If two species are competing for the same piece of bottom space, it would be helpful to produce a substance that would attack rapidly dividing cells of the competing organism. Since cancer cells often divide more rapidly than normal cells, the same substance might have anti-cancer properties.
For more information about drugs from the sea, visit *http://oceanexplorer.noaa.gov/explorations/03bio/welcome.html*.

Ocean Health Overview

Unless otherwise cited, the following information is from Allsopp, Page, Johnston, and Santillo (2007).

Overfishing

Global demand for seafood has grown steadily over the past century, resulting in increasingly sophisticated fishing industries that use powerful boats, freezer trawlers, acoustic fish finders, and other advanced technologies. In 2005, capture fisheries around the world harvested about 95 million tons of fish. In the same year, at least 76 percent of the populations that support those fisheries were considered fully exploited, overexploited, or depleted. In most cases, overfishing has been the primary cause for the declines, though in some cases environmental conditions have also contributed. Between 1950 and 2000, nearly one-fourth of all fisheries collapsed. Small fisheries, small fish stocks, and bottom-dwelling species were the most vulnerable. One of the best-known collapses took place in the Atlantic cod fishery, which collapsed in 1991.

In addition to the obvious impact of having fewer fishes, intensive fishing has other impacts as well:

- Selectively targeting larger, faster-growing fishes may change the genetic diversity within populations of these species and reduce their survival capabilities.
- As populations of large predators are depleted, fishing is moving farther down ocean food webs, placing increasing pressure on populations of

smaller, shorter-lived fishes and resulting in simplified food webs. These webs are less able to compensate for changes caused by climate shifts or other environmental factors.

- Overfishing herbivorous species can result in excessive growth of algae and other marine plants. This is a significant problem in coral reef ecosystems where removal of herbivorous fishes is resulting in corals being displaced by algae.
- Depletion of traditional fisheries is causing modern fishing vessels to move onto the high seas where there is little or no fisheries regulation or management.
- In addition to harvesting fishes that are valuable as food, industrial fishing is also targeting other species for conversion into fishmeal or fish oil. Since many of the latter species are low in ocean food webs, overfishing of these stocks can have serious impacts on many other species.
- Substantial numbers of seabirds, marine mammals, and sea turtles become entangled or hooked accidentally by fishing gear, causing further disruption to ocean food webs.
- Overcapacity in the world's fishing fleets (*i.e.*, too many boats, not enough fish) is causing an increase in illegal, unregulated, and unreported (IUU) fishing, which may account for as much as 20 percent of the global fishery harvest. IUU fishing includes bottom trawling and other methods that cause severe damage to marine ecosystems, and threaten marine diversity, the livelihood of local fishing communities, and the food security of coastal countries.

Because overfishing is a global problem, scientists and policymakers in many countries have begun to cooperate on a new approach to manage ocean resources. This approach has protecting entire marine ecosystems as its primary objective, and emphasizes a precautionary approach (in contrast to approaches that focus on maximum extraction of resources). A key element of this approach is establishing networks of marine protected areas that protect entire ecosystems and allow biodiversity to recover and flourish. Outside these reserves, the ecosystem approach emphasizes interaction between species, rather than focusing on individual species that are targeted for harvest. The precautionary aspect of the ecosystem approach requires those who want to use ocean resources to show that their activities will not harm the marine environment, instead of requiring resource managers to establish maximum limits for resource use. As Allsopp *et al*. (2007) point out, current approaches that favor freedom to fish and freedom **OF** the seas will need to be replaced with the new concept of freedom **FOR** the seas to continue to exist as we know them. In the U.S., programs for stewardship of living marine resources through science-based conservation and management of healthy ecosystems are overseen by NOAA Fisheries Service (see *http://www.nmfs.noaa.gov/* for more information).

As the global demand for seafood continues to increase, there has been a rapid expansion in aquaculture over the past 30 years. Aquaculture produced about 40% of all fish harvested in 2005, consumes more than a third of the worldwide production of fishmeal, and is the fastest-growing animal-food production sector in the world. Like many other intensive food-producing industries that require high inputs, large-scale aquaculture may have negative environmental impacts, such as: net food loss (when the mass of fishmeal required to grow a species is greater than the mass of food that is produced); depletion of wild stocks for seed; habitat loss; nutrient pollution; or invasive species. Aquaculture has the potential to reduce harvest pressure on natural populations. Countries that use an ecosystem approach to marine resource management may also include aquaculture as part of their overall strategy, along with measures to avoid negative impacts (see *http://aquaculture.noaa.gov/welcome.html* for more information).

Habitat Destruction

Nearshore marine habitats are susceptible to damage or destruction by coastal development, but perhaps the greatest damage for the ocean as a whole comes from bottom trawling, a fishing method that uses a weighted net that is dragged along the seafloor. The result is that almost everything is removed from the ocean floor, and the bottom is converted to mud that forms a plume behind the trawlers. Bottom trawling is analogous to clearcutting in old growth forests. Bottom trawling causes severe habitat destruction, particularly in deep-ocean coral reefs and seamounts that provide habitats for many species. Photographs of seafloor habitats off the coasts of Norway and the United Kingdom show trawl scars up to four kilometers long, some of which have destroyed reefs that were 4,500 years old. Off the Atlantic coast of Florida, an estimated 90–99 percent of reefs formed by the deepwater coral *Oculina* have been destroyed. Many countries have banned bottom trawling in some areas, but this practice is still unregulated over many parts of Earth's ocean, including areas that contain sea mounts and deepwater coral ecosystems. In 2006, NOAA Fisheries designated more than 150,000 square miles off the U.S. West Coast as Essential Fish Habitat, which prohibited destructive fishing methods. *Oculina* habitats off the coast of Florida were closed to fishing in 1984. In 2001, part of the Ocean Explorer Islands in the Stream Expedition included experimental efforts to restore some damaged areas on the *Oculina* Banks (see *http://oceanexplorer.noaa.gov/explorations/islands01/log/sep2/sep2.html* for more information).

Ecosystem-based approaches to marine resource management may include similar restoration efforts (for other examples, see *http://www.habitat.noaa.gov/rc_awards11mcoastalproject.html*).

Invasive Species

Invasive species are non-native species that have been introduced to a region, have established thriving reproductive populations, and are expanding their range. Invasive species often have no natural predators in their new environment, and can successfully compete with and possibly replace native species. Invasive species are usually introduced accidentally or deliberately by humans. A particularly dangerous example is the Mediterranean clone of *Caulerpa taxifolia*, a marine alga containing a toxin that is lethal to some species and may interfere with the eggs of some marine mammals. *C. taxifolia* was accidentally introduced into the Mediterranean by a marine aquarium, and is now forming dense mats that displace invertebrates, fish, and native algae from the seafloor. Until recently, *C. taxifolia* was a popular species in aquarium stores. The European Green Crab (*Carcinus maenas*) is another invasive species, introduced to the U.S. over 150 years ago in the ballast and heavily fouled outer hulls of wooden ships coming from Europe. These crabs feed on a variety of organisms, including clams, oysters, mussels, marine worms and small crustaceans, and are a serious potential competitor for native fish and bird species. At the turn of the century, European green crabs almost destroyed the soft clam industry of Maine and surrounding waterways, and is at least partially responsible for the decline of scallop populations on Martha's Vineyard. In California, the green crab has caused the loss of as much as 50 percent of Manila clam stocks and declines in other crab populations. Lionfish (*Pterois volitans*) are native to the Indo-Pacific from Australia north to southern Japan and south to Micronesia, but have recently been seen along the Atlantic coast of the United States and in the Caribbean; probably introduced in ballast water or from marine aquaria. Lionfish feed on smaller fishes, shrimp, and small crabs. Venomous spines in the dorsal and pectoral fins are used to immobilize prey species, as well as to discourage potential predators. The ecological impact of invasive lionfish in the Atlantic and Caribbean is not yet known, but they may compete with many native species, including economically important species of snapper and grouper. Populations of prey species could be seriously affected as well.

Toxins, Nutrients, Marine Debris

For thousands of years, Earth's ocean has provided a convenient means for disposing of unwanted products of human activity. The ocean's impressive size, coupled with the fact that it is largely out of sight, makes it easy to assume that this practice is of no particular consequence. But there is growing evidence that thousands of different chemicals, radioactive substances, nutrients, oil, and marine debris are having a significant impact.

Although much of the debris concentrated in the "garbage patch" is composed of small bits of plastic not immediately visible to the naked eye, large items are occasionally observed. On Aug. 11, Scripps Institution of Oceanography SEAPLEX researchers encountered this large ghost net with tangled rope, net, plastic, and various biological organisms. Image credit: Scripps Institution of Oceanography.
http://oceanexplorer.noaa.gov/okeanos/explorations/ex1006/background/mantanet/media/ghost_net.html

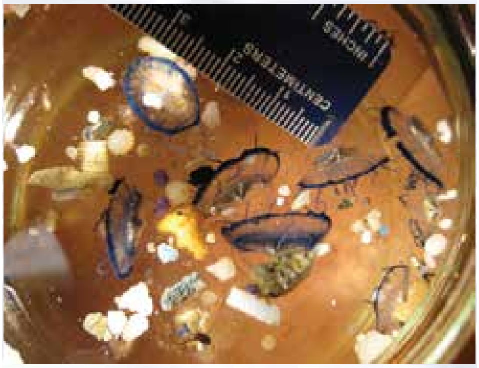
Recent concerns about chemical contamination have focused on the impact of synthetic chemicals known as persistent organic pollutants (POPs), which are toxic, long-lived, often accumulate in the tissues of fish and other animals, and may travel long distances from their point of origin. POPs include chemicals that have significant benefits to humans, such as brominated flame retardants (BFRs), that are added to plastics, resins, textiles, paints, electronics, and other products to increase their fire resistance. Global use of BFRs doubled between 1990 and 2000, and they are known to contaminate marine organisms all over the world including those in the deep oceans and remote Arctic regions. Toxic effects have not been extensively studied, but there is evidence that they can disrupt endocrine systems, nervous systems, and immune functions.

Artificial radionucleides are another class of substances that have no natural counterparts, are extremely long-lived, and are known to cause cancers and mutations. Nuclear weapons testing between 1954 and 1962 has been the largest single source of artificial radionuclides to the ocean due to fallout, but contamination continues from nuclear power facilities and nuclear reprocessing plants.

Evidence of human activity extends even hundreds of miles from shore and 2,200m below the ocean surface. Image credit: NOAA Expedition to the Deep Slope.
http://oceanexplorer.noaa.gov/explorations/06mexico/logs/hires/beercans_hires.jpg

Nutrient pollution, mainly nitrogen and phosphorous compounds, enters coastal waters via agricultural fertilizer run-off, sewage discharges, and atmospheric pollution from burning fossil fuels. Excess nutrients in coastal waters can cause massive blooms of phytoplankton and other marine plants. When these plants die, they sink to the bottom and are decomposed by microorganisms that consume oxygen. This is called eutrophication. In some cases, this decomposition process consumes almost all of the dissolved oxygen in the surrounding water. The result is the formation of vast, oxygen-depleted areas known as "dead zones." Around the world, the number of dead zones has risen every decade since the 1970s. One of the largest dead zones occurs in the northern Gulf of Mexico, and has been linked to massive increases in the use of fertilizers in the Mississippi River watershed which began in the 1950s.

Actually, dead zones aren't really dead; they often contain abundant populations of bacteria, jellyfish, and other species that can tolerate low-oxygen conditions. This replacement of populations of healthy aerobic populations with anoxia-tolerant bacteria and jellyfish has been called "the rise of slime" (Jackson, 2008). It has also been pointed out (Jackson, 2008) that dead zone ecosystems resemble ocean communities prior to the Cambrian explosion.



North Pacific Ocean Gyre collections from Scripps Institution of Oceanography scientists aboard the SEAPLEX voyage in August of 2009 revealed small jellyfish (*Velella velella*) with lots of plastic. Image credit: J. Leichter, Scripps Institution of Oceanography.

Oil spills are a well-known form of contamination as a result of the publicity that typically surrounds major spills. Less well known are much smaller spills that occur every day from ships, offshore drilling operations, and routine vessel maintenance. The amount of damage caused by an oil spill depends upon the size of the spill, type of oil involved, location of the spill, and weather conditions. Major spills have severe impacts on coastal wildlife, but long term continued exposure to low levels of oil can also have a significant effect on survival and reproduction of seabirds and marine mammals.

Marine debris is a pervasive problem affecting all of Earth's ocean, and injures and kills many different marine animals through drowning, suffocation, strangulation, starvation (through reduced feeding efficiency), injuries, and internal damage. Large quantities of marine debris are found in shipping lanes, near fishing areas, and in oceanic convergence zones. 80% of marine debris is from land-based sources; the rest comes from marine activities. Sources include tourist-related litter, debris in sewage, derelict fishing gear, and wastes from ships and boats. Plastic bags are the major type of marine debris found on the seabed, especially in coastal areas. Derelict fishing gear can continue to trap and catch fish even when it is no longer tended by fishermen. This "ghost fishing," can capture large quantities of marine organisms. Marine debris can also act as rafts, possibly carrying marine animals and plants long distances to areas where they become invasive species.

Climate Change and Ocean Health

An overview of climate change issues is provided in Diving Deeper, page 21. Major impacts on ocean health are related to increased temperature, sea level rise, and ocean acidification (which is discussed in a separate section below).

Global sea surface temperature is approximately one degree C higher now than 140 years ago. One degree may not sound like much, but the key point is the rate at which this increase has taken place. Over the past 25 years the rate of increase in sea surface temperature in all European seas has been about 10 times faster than the average rate of increase during the past century. Earth's ocean could warm by an additional one to two degrees C by the end of this century.

Many marine organisms live at temperatures close to their thermal tolerances, so even a slight warming could have serious effects on their physiological functioning and ability to survive. Coral reefs are a frequently-cited example. Shallow-water reef-building corals live primarily in tropical latitudes (less than 30 degrees north or south of the equator) where water temperatures are close to the maximum temperature that corals can tolerate. Abnormally high temperatures result in thermal stress, and many corals respond by expelling symbiotic algae (zooxanthellae) that live within the coral's soft tissues. Since the zooxanthellae are responsible for most of the corals' color, corals that have expelled their algal symbionts appear to be bleached. Zooxanthellae are important to corals' nutrition and growth, and expelling these symbionts can have significant impacts on the corals' health. In some cases, corals are able to survive a bleaching event and eventually recover; but if other types of stress are present and the stress is sustained, the corals may die.

Prior to the 1980s, coral bleaching events were isolated and appeared to be the result of short-term events such as major storms, severe tidal exposures, sedimentation, pollution, or thermal shock. Over the past 20 years, though, these events have become more widespread, and many laboratory studies have shown a direct relationship between bleaching and water temperature stress. In general, coral bleaching events often occur in areas where the sea surface temperature rises one degree C or more above the normal maximum temperature.

It is possible that corals' physiology might change to allow them to become acclimated to higher temperatures, or that populations might adapt if individual corals' ability to tolerate higher temperatures provided a survival advantage that allowed these corals to become more numerous. There is no indication, however, that either of these possibilities is actually happening. It is important to remember that the impacts of rising ocean temperatures are not confined to corals; corals happen to be very conspicuous and have been the subject of scientific research for many years, so changes are likely to be noticed. Similar impacts are almost certainly taking place in many other species that are less-studied or are presently unknown to science.

Even when individual species are able to tolerate increased temperatures, they may still be affected by changes within their food webs. For example, warmer waters in northwestern Europe have caused clams (*Macoma balthica*) to spawn earlier in the year, but blooms of phytoplankton on which the clams feed do not happen until later in the spring. Clam larvae also face increased predation from shrimp whose abundance has increased in early spring due to warmer temperatures.

Sea-level rise is caused by the expansion of sea water as it warms, as well as melting of ice on land (melting sea ice doesn't increase sea level, as you can demonstrate with ice cubes in a glass of water). For at least 2,000 years prior to 1900, sea-level changed very little. During the last century, however, sea-level rose by roughly 20 cm (8 inches) and is expected to continue rising for at least several decades. The amount of additional rise will depend largely on how much melting occurs at the polar ice caps. Even if greenhouse gas concentrations were stabilized immediately, sea level will continue to rise from thermal expansion, and ice sheets will continue to melt. Increased sea level will have significant impacts on low-lying coastal areas and on species whose habitats are in these areas.

Increased influx of fresh water from melting ice sheets coupled with warmer ocean temperatures may also cause changes in ocean currents, that are driven by temperature and salinity differences between large masses of seawater. Potential changes to the deep-ocean thermohaline circulation ("The Great Ocean Conveyor Belt") are described on page 23.

Some of the most rapid warming is taking place in Earth's polar regions. Continued loss of sea ice is expected to have negative impacts on species that depend upon the sea ice habitat, such as fishes, birds, seals, whales, and polar bears. These are discussed in *The Good, The Bad and The Arctic*, a lesson plan from the Ocean Explorer 2005 Hidden Ocean Expedition (*http://oceanexplorer.noaa.gov/explorations/05arctic/background/edu/media/arctic05_goodandbad.pdf*).

Ocean Acidification

Ocean acidification is "the other carbon dioxide problem," additional to the problem of carbon dioxide as a greenhouse gas. For many years, carbon dioxide in Earth's atmosphere has been increasing. Regardless of the reasons for this increase and the possible connection with climate change, dissolved carbon dioxide in the ocean has increased along with atmospheric CO_2. More dissolved carbon dioxide means a lower ocean pH. This, in turn, leads to a decrease in carbonate ions that are essential to the process of calcification through which many organisms produce shells and other skeletal structures. Corals, shellfish, echinoderms, and many marine plankton build body parts through calcification. Pteropods are planktonic snails that are an important component of food chains in high-latitude regions, and have been shown to have pitted or partially dissolved shells in waters where carbonate ions are depleted. On June 5, 2008, NOAA Oceanographer Richard A. Feely told the U.S. House of Representatives Subcommittee on Energy and Environment that the ocean currently absorbs 22 million tons of carbon dioxide daily, and that scientists estimate the pH of ocean surface waters has fallen by about 0.11 units from an average of about 8.21 to 8.10 since the beginning of the industrial revolution. Feely also said that if carbon dioxide emissions continue according to predictions, the surface water pH will decrease to about 7.8 – 7.9 by the end of the century. "To put this in historical perspective, the resulting surface ocean pH would be lower than it has been for more than 20 million years," he said.

Ocean acidification is a result of increased CO_2 emissions, and is not directly related to climate change. There are many uncertainties about the causes, extent, and impacts of global climate change; but these do not apply to ocean acidification which can be observed happening right now and is highly predictable into the future. Measures to reduce global temperatures or the concentration of other greenhouse gases will have no effect on ocean acidification. Only a reduction in atmospheric CO_2 concentrations will affect the acidification problem.

Research is just beginning on the impacts of ocean acidification on marine organisms and ecosystems (more than 60% of the research papers on this subject have been published since 2004). Impacts have been observed in many species, however, and range from interference with calcification processes to reduced resistance to other environmental stresses such as increasing temperatures and pollution.

Where Do We Go From Here?

Ocean Health issues revolve around two points:

1) Earth's ocean is about systems; everything is connected.
2) Human activities have global impacts on Earth's ocean.

It's very easy to be overwhelmed by the magnitude of ocean health problems, and just assume we can do nothing. The reality is that these problems did not arise through a single, deliberate action. They are the result of numerous individual actions that took place without any consideration for their collective impacts on Earth's ecosystems. And another reality is that effective solutions to these problems will not occur in a single, global action, but rather will involve numerous individual actions that by themselves seem insignificant, but collectively can have global impacts. Individually, we are all insignificant on a global scale. Collectively, we have global impacts. The root cause of many ocean health problems is the cumulative impact of individual actions; and many solutions to these problems also depend upon the cumulative impact of individual actions.

What Do pH Numbers Mean?

An "acid" is commonly defined as a chemical that releases hydrogen ions (abbreviated H^+). The pH (which stands for "power of hydrogen") of a solution is defined as the negative logarithm of the hydrogen ion concentration in moles per liter. So,

$$\mathbf{pH = -\log [H^+]}$$

where brackets are understood to mean "concentration."

The logarithm of a number x is the power to which another number called the "base" must be raised to produce x. So, the logarithm of 1000 to the base 10 is 3 because 10 raised to the power of 3 is equal to 1000. Where pH is concerned, the base is always 10. If a solution has a hydrogen ion concentration of 1 x 10^{-7} moles/liter, the logarithm of this concentration is -7, and the pH is 7. The pH scale ranges from 0 to 14, which corresponds to a hydrogen ion concentration range of 1.0 mole/liter to 1 x 10^{-14} mole/liter. A pH of 7 is considered neutral. A pH below 7 (higher hydrogen ion concentration) is acidic; a pH above 7 (lower hydrogen ion concentration) is basic. A decrease of 0.1 pH unit may not seem like much, until we remember that this is a logarithm. So a pH of 8.2 corresponds to a hydrogen ion concentration of:

1 x $10^{-8.2}$ moles/liter = 0.00000000631 moles/liter
(10 raised to the -8.2 power)

and a pH of 8.1 corresponds to a hydrogen ion concentration of:

1 x 10-8.1 moles/liter = 0.00000000794 moles/liter

so a drop of 0.1 pH unit represents a 25.8% increase in the concentration of hydrogen ions.

Note that while the term "ocean acidification" is commonly used, the ocean is not expected to actually become acidic (which would mean that the pH was below 7.0). "Acidification" in this case only means that the pH is declining.

The Carbonate Buffer System

pH is a measure of acidity, which is the concentration of hydrogen ions; increasing hydrogen ions causes increased acidity. A pH of 7 is considered neutral; a pH below 7 is acidic; a pH above 7 is basic. Dissolved chemicals cause seawater to act as a pH buffer; that is, seawater tends to resist changes in pH. This Carbonate Buffer System is described by the following equation:

The Carbonate Buffer System Equation

CO_2	+	H_2O	$\leftrightarrow$	H_2CO_3	$\leftrightarrow$	H^+	+	HCO_3^-	$\leftrightarrow$	$2H^+$	+	CO_3^{2-}
carbon dioxide		water		carbonic acid		hydrogen ion		bicarbonate ion		2 hydrogen ions		carbonate ion

This equation shows that carbon dioxide dissolves in seawater to form carbonic acid, a weak acid. Most of the carbonic acid normally dissociates to form hydrogen ions, bicarbonate ions, and carbonate ions. Carbon dioxide, carbonic acid, bicarbonate ions, and carbonate ions are all present in normal seawater, although not in the same concentrations (about 87% of inorganic carbon is bicarbonate, about 12% is carbonate, and carbonic acid and carbon dioxide combined are about 1%). When these chemicals are in equilibrium, the pH of seawater is about 8.1 – 8.3 (slightly basic). More dissolved carbon dioxide causes an increase in hydrogen ions and a lower ocean pH. But the pH change in seawater is less than if the same amount of carbon dioxide were dissolved in fresh water because the carbonate buffer system in seawater removes some of the added hydrogen ions from solution.

In addition to the reactions described in the carbonate buffer system equation, other reactions also take place between carbon dioxide, carbonic acid, bicarbonate ions, and carbonate ions. One of these other reactions takes place between carbon dioxide, water, and carbonate ions:

CO_2 carbon dioxide	+	H_2O water	+	CO_3^{2-} carbonate ion	↔	2 HCO_3^- 2 bicarbonate ions

So, adding carbon dioxide to the ocean system can also cause a decrease in carbonate ions; and carbonate ions are essential to the process of calcification through which many organisms produce shells and other skeletal structures.

Demonstrating the Effect of Dissolved Carbon Dioxide on pH

Increased atmospheric carbon dioxide has a demonstrable effect on ocean pH. A simple demonstration of the impact of dissolved carbon dioxide on pH can be found below. While there is some disagreement about the connection between climatic temperature increase and carbon dioxide from human activity, the increase in atmospheric CO_2 and decline in ocean pH are not theoretical; these changes have been confirmed by actual measurements. The following demonstration illustrates this concept.

Educators are urged to try the following procedures in advance of demonstrating before an audience. It is possible that enough atmospheric carbon dioxide may dissolve in distilled water to lower the pH so that the solution will turn yellow as soon as the indicator solution is introduced. If this happens, adjust the starting pH to slightly above neutral by adding a small pinch of baking soda to the distilled water before introducing the indicator solution.

Materials

- Drinking straw
- 100 ml of distilled water
- 100 ml of seawater (natural or artificial)
- Glass jar or beaker, about 200 ml capacity
- Bromothymol Blue Indicator Solution, 0.04% aqueous

Procedure

Step 1. Pour approximately 100 ml of distilled or tap water into a clean, transparent container. Add 15 drops of bromothymol blue indicator solution.

Step 2. Pour approximately 100 ml of seawater (artificial or natural) into a second clean, transparent container. Add 15 drops of bromothymol blue indicator solution.

Step 3. Blow steadily through a drinking straw into the water in the first container, and record the time required for the color to change from blue to yellow-green.

Step 4. Repeat Step 3 with the water in the second container. Note that it is possible to blow through two straws simultaneously, and if this is done there is no need to record elapsed time.

Step 5. Discuss the following:

- Blowing through the straw bubbles carbon dioxide through the liquid in the containers.
- Carbon dioxide dissolves in water to form a weak acid (carbonic acid).
- Bromothymol blue is blue in basic solutions, and yellow in acidic solutions. The color change happens in the approximate range of pH 6.0-7.6.
- A buffer is a solution that tends to resist changes in pH.

Ask students to apply one or more of these facts to explain the results of the demonstration. Do these results suggest that seawater may act as a buffer?

Notes:

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

Section 2:
Key Topic – Ocean Exploration

Journey to the Unknown
(adapted from the 2002 Galapagos Rift Expedition)

Focus
Ocean Exploration

Grade Level
5-6 (Life Science/Earth Science)

Focus Question
What information can you use to determine where you are in an unknown area?

Learning Objectives
- Students will experience the excitement of discovery and problem-solving to learn what organisms could live in extreme environments in the deep ocean.
- Students will understand the importance of ocean exploration.

Materials
- NOAA and Woods Hole Oceanographic Institution photos of deep-sea animals (*http://oceanexplorer.noaa.gov/gallery/gallery.html* and *http://shiva.whoi.edu/ims/login.jsp;jsessionid=3bg7feo4j35* respectively). Other useful deep-sea animal pictures can be found at *http://extremescience.com/life-in-the-deep.htm*, *http://tqjunior.thinkquest.org/4106*, and *http://www.ocean.udel.edu/deepsea/gallery/gallery.html*
- Octocoral photos (*http://oceanexplorer.noaa.gov/gallery/livingocean/livingocean_coral.html*)
- One or more photos of remotely operated vehicles (*http://oceanexplorer.noaa.gov/technology/subs/rov/rov.html*) for each student group
- One pint Ziploc bag of sand, one for each student group
- One pint Ziploc bag of mud, one for each student group
- (Optional) Hands-On Activity Guides: *How to Posterize Images*, and *LED Ultraviolet Illuminator Construction Guide*, one for each student or student group
- (Optional) *Student Data Sheet* – 1 per student for use with Extension #3

Audiovisual Materials
- None

Teaching Time
Two 45-minute class periods

Ocean Exploration and Research

Seating Arrangement

Groups of three or four students

Maximum Number of Students

30

Key Words and Concepts

Explore
Technology
Submersible
Biodiversity

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.

"We know more about the dead seas of Mars than our own ocean."
– Jean Michel Cousteau

Our current estimation is that 95% of Earth's ocean is unexplored. At first, this may be hard to believe, particularly if we look at recent satellite maps of Earth's ocean floor. These maps seem to show seafloor features in considerable detail. But satellites can't see below the ocean's surface. The "images" of these features are estimates based on the height of the ocean's surface, which varies because the pull of gravity is affected by seafloor features. And if we consider the scale of these maps, it is easy to see how some things might be missed. To show our planet's entire ocean, a typical wall map has a scale of about 1 cm = 300 km. At that scale, the dot made by a 0.5 mm pencil represents an area of over 60 square miles! The fact is, most of the ocean floor has never been seen by human eyes.

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 our largely unknown ocean for the purposes of discovery and the advancement of knowledge. To fulfill its mission, the *Okeanos Explorer* has specialized capabilities for finding new and unusual features in unexplored parts of Earth's ocean, and for gathering key information that will support more detailed investigations by subsequent expeditions. These capabilities include:

- Underwater mapping using multibeam sonar capable of producing high-resolution maps of the seafloor to depths of 6,000 meters;
- Underwater robots (remotely operated vehicles, or ROVs) that can investigate anomalies as deep as 6,000 meters; and
- Advanced broadband satellite communication and telepresence.

Capability for broadband telecommunications provides the foundation for telepresence: technologies that allow people to observe and interact with events at a remote location. This allows live images to be transmitted from the seafloor to scientists ashore, classrooms, newsrooms and living rooms, and opens new educational opportunities, which are a major part of *Okeanos Explorer's* mission for advancement of knowledge. In addition, telepresence makes it possible for shipboard equipment to be controlled by scientists in shore-based Exploration Command Centers. In this way, scientific expertise

A spectacular photo of the NOAA Ship *Okeanos Explorer* Control Room while ROV operations are underway. Image credit: NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.

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*

can be brought to the exploration team as soon as discoveries are made, and at a fraction of the cost of traditional oceanographic expeditions.

Learning Procedure

1. To prepare for this lesson review introductory information on the NOAA Ship *Okeanos Explorer* at *http://oceanexplorer.noaa.gov/okeanos/welcome.html*. You may also want to consider having students complete some or all of the lesson, *To Boldly Go....*

2. If you have not previously done so, briefly introduce the NOAA Ship *Okeanos Explorer*, emphasizing that this is the first Federal vessel specifically dedicated to exploring Earth's largely unknown ocean. Include a short discussion of reasons that ocean exploration is important.

3. Tell students to close their eyes, and say that they are part of an expedition to an unexplored region of Earth's ocean.

4. Read the following imaginary series of events that might take place in the *Okeanos Explorer's* Control Room or in an Exploration Command Center, but do not mention either of these locations at this point:
   a. You are a scientist on a mission. You are seated in a control room with several other scientists and technicians. Several large video monitors are on the wall in front of you.
   b. One of the monitors shows an image of a sun-lit ocean, just a few feet above the surface. A technician sitting in a chair next to you says "Here we go," as she moves a large joystick slightly. As you watch, the sea surface seems to rise up. There is a sudden splash in front of the lens and the monitor now shows rays of sunlight shining through the blue ocean water.
   c. Every minute or so, the pilot with the joystick calls out a number. As the numbers increase, the scene on the monitor grows steadily darker. By the time the pilot says "Fifty meters," the monitor is almost completely black.
   d. The pilot touches a switch and beams of light shine out into the darkness. She continues to call out larger and larger numbers. Strange animals appear in the path of the lights, then quickly disappear. Time passes, but no one wants to look away from the monitor because they might miss something amazing. The scientists keep up a running conversation about what they see, and their words are recorded along with the video images.
   e. Suddenly the scene on the monitor changes as the pilot says "Two thousand meters." You see a horizontal surface that must be the ocean bottom. Large branching objects seem to be growing out of the seafloor. You ask the pilot to collect a few samples of these. A mechanical claw attached to a metal arm appears on the monitor, tightens onto one of the branching objects, and then pulls the object back toward the video camera. The claw and the sample disappear, and the pilot says, "OK, it's in the basket."
   f. Another scientist notices things moving in the mud, and asks the pilot to collect more samples. As the camera moves around, you can see that the ocean floor is covered with animals, tracks, and holes.
   g. After collecting more samples, the pilot says, "Let's watch for a few minutes with the lights off." The monitor is completely black for what seems like a long time, but then a glowing object flashes across the screen. "WHAT WAS THAT???" There is another flash of light, and it almost seems to be following the first object. Several scientists are busily speaking into their microphones to record every detail of something they have never seen before.

Dr. Amy Baco-Taylor, Deep-sea biologist.
Image credit: Tyler Fox.
http://oceanexplorer.noaa.gov/edu/oceanage/04baco_taylor/welcome.html

Hugo Marrero, Submersible Pilot, Harbor Branch Oceanographic Institute.
http://oceanexplorer.noaa.gov/edu/oceanage/06marrero/welcome.html

Dr. Roy Cullimore, Microbiologist.
Image credit: Jeremy Weirich.
http://oceanexplorer.noaa.gov/edu/oceanage/04cullimore/welcome.html

Who Are Today's Ocean Explorers? [OceanAGE]

Ocean exploration requires new ways of thinking and close collaboration among biologists, chemists, climatologists, computer programmers, educators, engineers, geologists, meteorologists, physicists, anthropologists, and many other fields of expertise. Through the Ocean Explorer OceanAGE Careers Web page *http://oceanexplorer.noaa.gov/edu/oceanage/welcome.html*, marine explorers provide students with first-hand knowledge of exciting careers through live interviews, profiles, and mission logs. Career profiles include:

- Deep-sea Biologist – Amy Baco-Taylor
- Fish Ecologist – Peter Auster
- Geophysicist – Bob Embley
- Marine Ecologist – Peter Etnoyer
- Marine Geoarchaeologist – Beverly Goodman
- Marine Mammal Biologist – Kristin Laidre
- Microbiologist – Roy Cullimore
- Natural Products Biologist – Shirley Pomponi
- NOAA Corps Officer – Brian Kennedy
- Oceanographer – Robert Ballard
- Submersible Pilot – Hugo Marrero

h. Finally, the pilot begins calling out numbers again, but this time each number is smaller than the one before. Everyone has been in the control room for hours, but they can't wait to begin analyzing the samples from part of the Earth that has never been seen before.

5. Have students open their eyes and have a discussion about where they think that they have been and why. If necessary, stimulate the discussion by asking some or all of the following:
   - Were you excited?
   - Where were you?
   - Where did the video images on the monitor come from?
   - Why was it dark?
   - What were the glowing objects?
   - What were the branching objects?
   - What were the things moving in the mud?
   - Do you think that scientists get excited when they are making discoveries?

6. Tell students that you are going to provide them with some materials to help them try to determine where they went on their imaginary voyage. Give each table copies of several photos of deep-sea creatures, a picture of a remotely operated vehicle, a Ziploc bag full of sand and one of mud. (Do not explain the materials yet). Tell the students to think about the things that they saw and heard, including the pilot's words. Give them 10-15 minutes to explore, discuss, and ask questions.

7. As a class, have students discuss their ideas, answering questions, and challenging ideas. Then tell them that they were on an imaginary mission in a control room for the NOAA Ship *Okeanos Explorer*. Explain that one of the important capabilities of the ship is telepresence, which allows people to observe and interact with events at remote locations. Telepresence technologies allow live images to be transmitted from the seafloor to scientists ashore, classrooms, newsrooms and living rooms, and are a major part of the *Okeanos Explorer's* mission for advancement of knowledge. Telepresence also makes it possible for shipboard equipment to be controlled by scientists in shore-based Exploration Command Centers. In this way, scientific expertise can be brought to the exploration team as soon as discoveries are made, and at a fraction of the cost of traditional oceanographic expeditions. So, their imaginary mission might have taken place aboard the *Okeanos Explorer*, but it could also have happened thousands of miles away in an Exploration Command Center.

8. (Optional) Posterize images of deep-sea creatures, and construct an ultraviolet LED poster illuminator (See Student Handouts).

The BRIDGE Connection

www.vims.edu/bridge/ – Scroll over "Lesson Plans," then "5th Grade" for resources and activities related to ocean exploration.

The "Me" Connection

Have a discussion of products from the sea, and the potential to discover new species, new medicines, and new ways of transferring energy. (Use *www.obia.com* and *www.coralreefalliance.org/aboutcoralreefs* Web sites from Resources section.)

A benthic fish called a Sea Robin. This fish has several sets of modified fins - some modified for perching on the seafloor, and 'wing-like' fins for swimming. Image captured by the *Little Hercules* ROV at 279 meters depth on a site referred to as 'Zona Senja' on August 2, 2010. Image credit: NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/hires/batfish_hires.jpg

A deep-sea chimaera. Chimaeras are most closely related to sharks, although their evolutionary lineage branched off from sharks nearly 400 million years ago, and they have remained an isolated group ever since. Like sharks, chimaeras are cartilaginous and have no real bones. The lateral lines running across this chimaera are mechano-receptors that detect pressure waves (just like ears). The dotted-looking lines on the frontal portion of the face (near the mouth) are ampullae de Lorenzini and they detect perturbations in electrical fields generated by living organisms. Image credit: NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/hires/chimaera_hires.jpg

Connections to Other Subjects

Biology, English/Language Arts, Mathematics

Assessment

Have students write a log entry with illustrations about what was seen on the deep-sea dive. Ask them to include the newly-learned vocabulary terms in their entry.

Extensions

1. Follow events aboard the *Okeanos Explorer* at *http://oceanexplorer.noaa.gov/okeanos/welcome.html*.
2. Research the Internet to find more species that live at depths of 2,000 meters and beyond. Have students make posters using the information about particular animals and share the posters with classmates. If students use fluorescent paints or markers to color their posters, you may also want to construct one or more ultraviolet illuminators as directed in the *LED Ultraviolet Illuminator Construction Guide*, page 50.
3. Conduct a simulated deep-ocean bottom exploration on the playground or other outside location. Have students pretend that they are exploring it for the first time. Ecological surveys often make use of frames called "quadrats" that enclose a known area. Quadrats may be made of wood, plastic, or other materials, and are usually square (although they can be any shape as long as the enclosed area is known). Several quadrats are spaced over the area to be surveyed; the exact number of quadrats usually depends upon the time and personnel available to complete the survey. Students can make quadrats with meter sticks taped together to form squares, or hula hoops to form circular quadrats. Have students draw their entire quadrat and record observations of both living and nonliving components on the *Student Data Sheet*, page 53.

Multimedia Discovery Missions

http://www.montereyinstitute.org/noaa/ Click on the links to Lessons 3, 6, 11, and 12 for interactive multimedia presentations and Learning Activities on Deep-Sea Corals, Deep-Sea Benthos, Energy from the Oceans, and Food, Water, and Medicine from the Sea.

Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

(All of the following Lesson Plans are targeted toward Grades 5-6)

A Piece of Cake (from the Cayman Islands Twilight Zone 2007 Expedition)
http://oceanexplorer.noaa.gov/explorations/07twilightzone/background/edu/media/cake.pdf

Focus: Spatial heterogeneity in deepwater coral communities (Life Science)
Students will explain what a habitat is, describe at least three functions or benefits that habitats provide, and describe some habitats that are typical of deepwater hard bottom communities. Students will also explain how organisms, such as deepwater corals and sponges, add to the variety of habitats in areas such as the Cayman Islands.

Deep Gardens (from the Cayman Islands Twilight Zone 2007 Expedition)
http://oceanexplorer.noaa.gov/explorations/07twilightzone/background/edu/media/deepgardens.pdf

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

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

Let's Make a Tubeworm! (from the 2002 Gulf of Mexico Expedition)
http://oceanexplorer.noaa.gov/explorations/02mexico/background/edu/media/gom_tube_gr56.pdf

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

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

Chemists with No Backbones (from the 2003 Deep Sea Medicines Expedition)
http://oceanexplorer.noaa.gov/explorations/03bio/background/edu/media/meds_chemnobackbones.pdf

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

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

Keep Away (from the 2006 Expedition to the Deep Slope)
http://oceanexplorer.noaa.gov/explorations/06mexico/background/edu/gom_06_keepaway.pdf

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

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

What's In That Cake? (from the 2006 Expedition to the Deep Slope)
http://oceanexplorer.noaa.gov/explorations/06mexico/background/edu/gom_06_cake.pdf

Focus: Exploration of deep-sea habitats (Life Science)

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

Other Resources

See page 217 for Other Resources.

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:
oceanexeducation@noaa.gov

For More Information

Paula Keener, Director, Education Programs
NOAA Office of Ocean Exploration and Research
Hollings Marine Laboratory
331 Fort Johnson Road, Charleston SC 29412
843.762.8818   843.762.8737 (fax)
paula.keener-chavis@noaa.gov

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This lesson was adapted by Mel Goodwin, PhD, Marine Biologist and Science Writer, Charleston, SC from a lesson by Robin Rutherford and Jane Settle, Porter Gaud School, Charleston, SC for NOAA. Design/layout: Coastal Images Graphic Design, Charleston, SC. If reproducing this lesson, please cite NOAA as the source, and provide the following URL:
http://oceanexplorer.noaa.gov

Next Generation Science Standards

Lesson plans developed for Volume 1 are correlated with *Ocean Literacy Essential Principles and Fundamental Concepts* as indicated in the back of this book. Additionally, a separate online document illustrates individual lesson support for the Performance Expectations and three dimensions of the Next Generation Science Standards and associated Common Core State Standards for Mathematics and for English Language Arts & Literacy. This information is provided to educators as a context or point of departure for addressing particular standards and does not necessarily mean that any lesson fully develops a particular standard, principle or concept. Please see: *http://oceanexplorer.noaa.gov/okeanos/edu/collection/wdwe_ngss.pdf.*

1

http://oceanexplorer.noaa.gov/explorations/03mex/logs/sept25/media/dsc_0055_100.jpg

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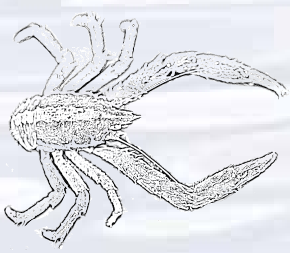

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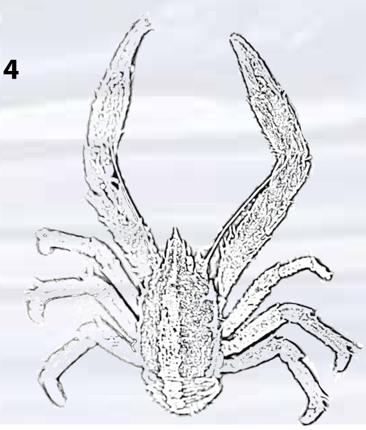


How to Posterize Images

There are many techniques and software programs that convert photographic images to simpler outlines or images that contain fewer colors. Here is a simple technique using Adobe Illustrator® that produces outline images that can be colored with markers, crayons, or pencils.

1. Select an image. In general, higher resolution images will produce more detailed outlines, but may take longer to process. This is an image of a three-toothed squat lobster (*Munidopsis tridentata*) from the Ocean Explorer Gallery (*http://oceanexplorer.noaa.gov/gallery/gallery.html*).

2. Open the image in Adobe Illustrator®, and select the image with the solid arrow tool. Scroll over "Sketch" in the "Effect" drop-down menu, then select "Photocopy." Adjust the "Detail" and "Darkness" controls until you like the image, then click "OK." Note: You may need to adjust the magnification box in the lower left corner so you can see the entire image. Select "Fit on Screen" from the pop-up window that appears when you click the magnification box.

3. If you want to remove unwanted portions of the image, click on "Live Trace" in the "Object" drop-down menu, then "Make and Expand" (if you don't like the result, choose "Tracing Options" from the "Live Trace" menu and experiment with the presets to find one you like). When the tracing is complete, use the open arrow tool and eraser tool to remove unwanted material. Take your time, save often, and use the magnification tool to zoom in when necessary.

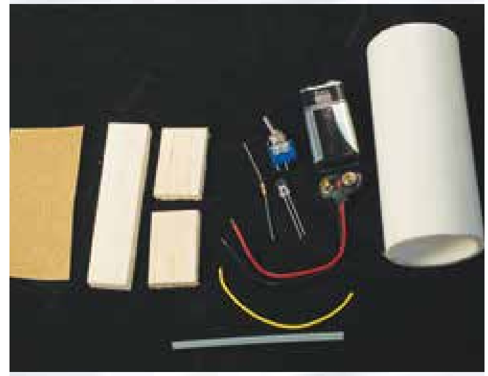
4. Rotate your image to the desired orientation, and you are ready to color! If you use fluorescent markers or crayons, you can use the Ultraviolet Illuminator for dramatic effects in a darkened room. This is especially useful to illustrate bioluminescence, which was studied during the Bioluminescence 2009: Living Light on the Deep-Sea Floor, Operation Deep Scope 2005, and Operation Deep Scope 2004 Expeditions (*http://oceanexplorer.noaa.gov/explorations/09bioluminescence/welcome.html*, *http://oceanexplorer.noaa.gov/explorations/05deepscope/welcome.html* and *http://oceanexplorer.noaa.gov/explorations/04deepscope/welcome.html*, respectively).

LED Ultraviolet Illuminator Construction Guide

Materials

- 1 Piece balsa or bass wood, 3-1/2" x 1" x 3/8" thick
- 2 Pieces balsa or bass wood, 1-5/8" x 1" x 1/4" thick
- 1 Toggle switch, SPST (Radio Shack Part No. 275-0612, or equivalent)
- 1 Resistor, 330 ohms, 1/4 watt (Radio Shack Part No. 271-1315, or equivalent)
- 1 9-volt Battery
- 1 9-volt Battery snap connector (Radio Shack Part No. 270-325, or equivalent)
- 1 Ultraviolet light emitting diode (Mouser Electronics Part No. 593-VAOL5GUV8T4, or equivalent)
- 3" Length, 22 gauge insulated hookup wire
- 3" Length, heat shrink tubing, 1/8" inside diameter
- 5-1/4" Length, 1-1/2" inside diameter PVC pipe
- Small piece of medium (100 grit) sandpaper

[NOTE: Mention of trademarks or proprietary names does not imply endorsement by NOAA]



Tools

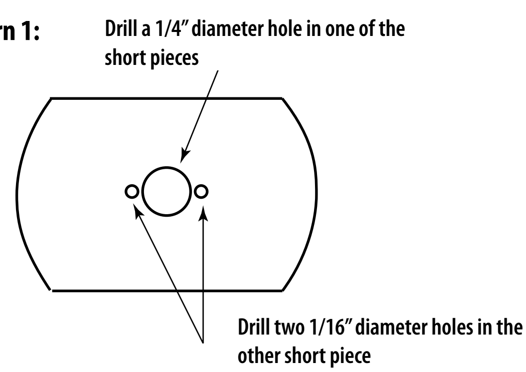
- Longnose pliers
- Wire cutters
- (Optional) Wire stripper
- Craft saw or coping saw
- Hand or electric drill
- 1/16" and 1/4" drill bits
- Hot glue gun
- Hair dryer or heat gun
- Soldering iron and rosin-core solder (do not use acid core solder in electronic circuits!)
- Safety glasses or goggles

A note about soldering: If you have never soldered before, you may want to visit *http://www.instructables.com/id/How-to-solder/*. Be sure to wear safety glasses or goggles when soldering, and work in a well-ventilated space (you can set up a small fan if necessary to blow away soldering fumes).

Construction Procedure

1. Use a craft saw or coping saw to cut the two short pieces of wood according to Pattern 1. These pieces should fit snugly inside the PVC pipe. Adjust the fit with sandpaper if necessary.

Pattern 1:



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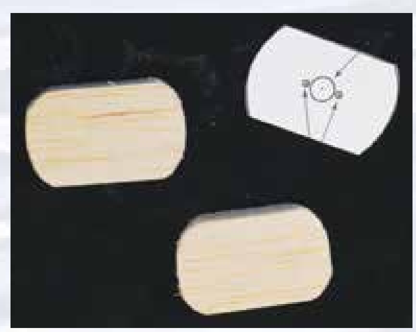

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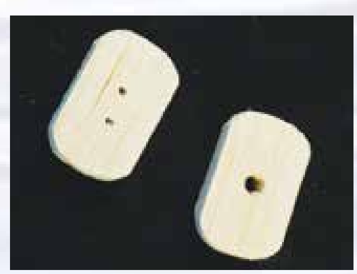


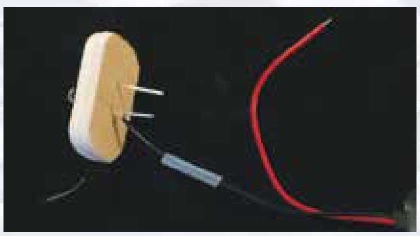
3

4a

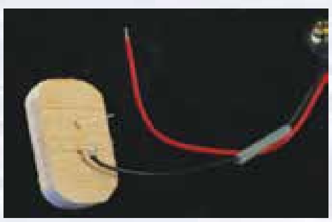
4b

5a

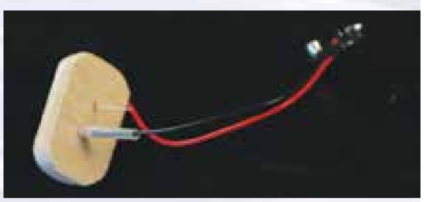
5b



6a



6b



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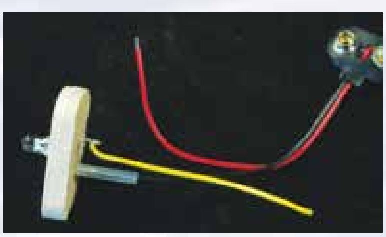
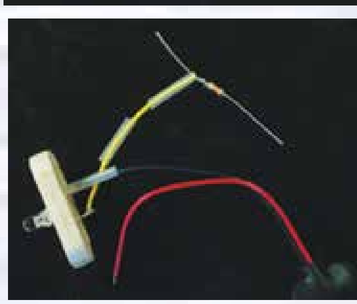


8a



2. Drill two 1/16" diameter holes in one of the short wood pieces in the locations indicated on Pattern 1. Drill one 1/4" hole in the other short wood piece as indicated on the pattern (Figure 2).

3. Mount the toggle switch on the short piece of wood with the 1/4" hole. The switch comes with two hex nuts, a flat washer, and a lockwasher. Remove all of the hardware and insert the threaded portion of the switch through the hole. You may have to press the body of the switch slightly into the balsa wood to expose enough thread to start one of the hex nuts. Tighten the nut two or three turns, then remove the nut, install the flat washer, and re-install the nut. Tighten several turns until the switch is securely mounted (Figure 3). NOTE: The photograph shows the switch in the "Off" position. Be sure your switch stays in this position until all steps are completed. This is a good time to mark "Off" on the wood near the switch handle.

4. Bend the wire leads of the LED as shown so that the leads will fit through the 1/16" holes in the other short piece of wood (Figure 4a). Put a small dab of hot glue on the wood between the holes, and hold the LED in place until the glue sets (Figure 4b).

5. Notice that the base of the LED is flattened on one side (FIgure 5a). The lead that is closest to the flattened site is the cathode of the LED which connects to the negative side of the battery. Remove about 1/2" of insulation from the black lead of the 9-volt battery snap connector. Twist the strands together, then put a 3/4" piece of heat shrink tubing over the black lead. Now, wrap the bare wire around the cathode lead from the LED about 1/4" from where it emerges from the piece of wood (a pair of longnose pliers can be helpful for this step) (Figure 5b).

6. Solder the connection by holding the heated soldering iron against the twisted wires, then touching the solder to the opposite side of the connection (don't touch the solder to the soldering iron, because the wires being soldered must be hot enough to melt the solder; otherwise the joint will be weak) (Figure 6a). Trim the excess lead coming from the LED and slide the heat shrink tubing over the joint (Figure 6b).

7. Remove about 1/2" of insulation from one end of the piece of hookup wire. Twist the strands together, then wrap the bare wire around the other lead from the LED and solder the connection. Trim the excess lead coming from the LED (Figure 7).

8. Remove about 1/2" of insulation from the other end of the hookup wire and twist the strands together. Put two 3/4" pieces of heat shrink tubing over the wire, then wrap the bare wire around one lead of the resistor about 1/4" from where it emerges from the resistor body. Solder the connection. Trim the excess lead coming from the resistor. Slide the heat shrink tubing over the joint with the LED and the joint with the resistor (FIgure 8).

9. Put a 3/4" piece of heatshrink tubing over the other lead of the resistor. Bend the end of the lead into a U-shaped hook, and slide the hook through one terminal of the toggle switch. Crimp the hook tightly onto the switch terminal, then solder the connection (Figure 9).

10. Remove about 1/4" of insulation from the red lead of the 9-volt battery snap connector, and twist the strands together. Bend the end of the lead into a U-shaped hook, and slide the hook through the other terminal of the toggle switch. Crimp the hook tightly onto the switch terminal, then solder the connection (FIgure 10).

11. Heat all pieces of heat shrink tubing so that they shrink around the wires and connections they are covering.

12. Using hot melt glue, glue the 9-volt battery near the center of the long piece of wood (Figure 12).

13. Bend the long lead of the resistor as shown so that it will fit over the battery (FIgure 13a), then glue the short pieces of wood to the ends of the long piece of wood using hot melt glue (FIgure 13b).

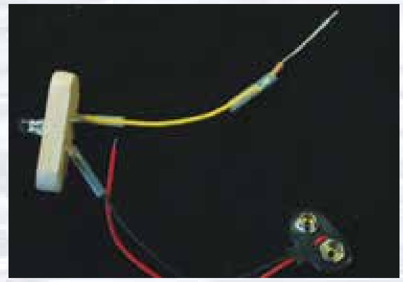
14. Check to be sure the switch is in the "Off" position (see Step 3). Attach the snap connector to the battery, and slide the assembly into the PVC pipe so that the piece of wood with the switch is flush with one end of the pipe. If necessary, use a small amount of hot glue to hold the assembly inside the pipe (Figure 14). Your Ultraviolet Illuminator is finished! Test your illuminator by turning the switch on in a darkened room. Remember: NEVER LOOK DIRECTLY AT A SOURCE OF ULTRAVIOLET LIGHT!

Notes About Components

A light emitting diode (LED) is a device that acts as a one-way gate to electric current, and that under some conditions will emit light. A diode is made with two small blocks of two different silicon compounds. The two blocks are held together by an encapsulating material, and a wire lead is attached to each block. One block is called the anode and the other is called the cathode. When the anode is more positive than the cathode, an electric current will flow through the diode. In an LED, this current flow causes light to be emitted. LEDs emit only one color of light, which depends upon the specific chemistry of the silicon compounds.

A resistor is an electrical device that resists the flow of electric current. The unit for resistance measurement is the "ohm." Resistors may have a single fixed resistance, or may be variable. Photoresistors and thermistors are variable resistors whose resistance changes with exposure to light and heat respectively. The resistor used in the Ultraviolet Illuminator is a fixed resistor made with a mixture of carbon and a glue-like binder.

8b



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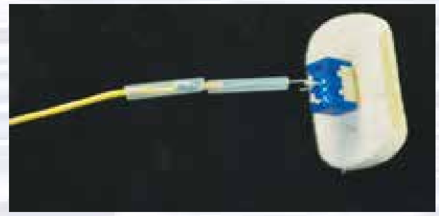

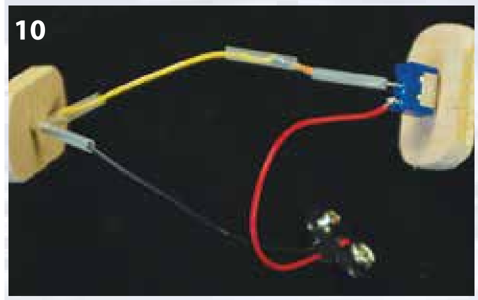

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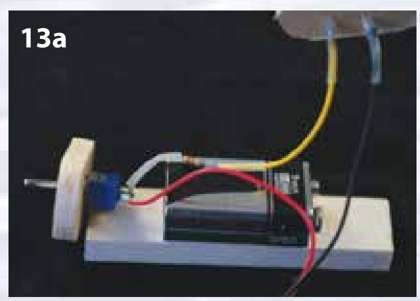
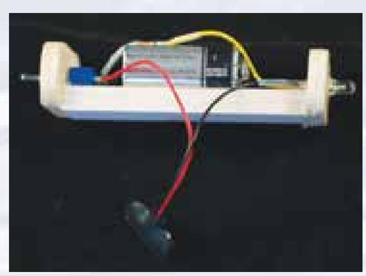


13b



14

Student Data Sheet for Quadrat Exploration

(See Extension #3, page 47)

Quadrat No.________

Animals		Plants		Burrows & Mounds		
Description	No.	Description	No.	Description	No.	Soil Description

Going Deeper: Many scientists, including those that explore the deep ocean, use quadrats as tools for quantifying organisms. Do you think this is a good method? Why or why not?

____

____

____

____

____

____

____

Notes:

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

Section 2:
Key Topic – Ocean Exploration

Come On Down!

(adapted from the 2002 Submarine Ring of Fire Expedition and the *Lophelia* II 2009: Deepwater Coral Expedition: Reefs, Rigs and Wrecks)

Focus
Ocean Exploration

Grade Level
7-8 (Physical Science)

Focus Question
What are some physical science principles that affect the operation of deep-sea submersibles?

Learning Objectives
- Students will research the development and use of research vessels/vehicles used for deep-ocean exploration.
- Students will calculate the density of objects by determining the mass and volume.
- Students will explain the concept of neutral buoyancy, perform calculations related to neutral buoyancy, describe why it may be difficult to maintain neutral buoyancy in the ocean, and discuss some strategies for overcoming these difficulties.

The *Little Hercules* ROV shines its lights on deep-sea life at approximately 1500 meters depth offshore Kona, Hawaii. Image taken by OER's camera platform during ROV shakedown operations aboard NOAA Ship *Okeanos Explorer* on March 22, 2010. Image credit: NOAA Office of Ocean Exploration and Research.
http://oceanexplorer.noaa.gov/okeanos/media/slideshow/gallery/ex03222010/hires/hercules_light.jpg

Materials
- Copies of *Underwater Robot Capability Survey*; one copy for each student group
- Copies of *Density and Buoyancy Investigation Guide*; one copy for each student group
- 100 ml graduated cylinder; one for each student group
- Sink or large containers for waste water
- Faucet or large container of water with a spigot or siphon to allow controlled dispensing
- Small objects that will fit into the 100 ml graduated cylinders, such as washers or nuts, small pieces of wood, rocks, pieces of modeling clay, corks, or similar objects; each student group should have a collection of at least four objects including some that will sink and others that will float
- Triple beam balance; one balance may be shared by several groups
- Stiff wire approximately 3 inches long or a straightened paper clip; one for each student group

Audiovisual Materials
- Chalkboard, marker board, or overhead projector
- (Optional) Video or computer projection equipment to show images of submersibles

Ocean Exploration and Research

Teaching Time
Two 45-minute class periods

Seating Arrangement
Groups of two to four students

Maximum Number of Students
32

Key Words and Concepts
Density
Buoyancy
Submersible
Volume
Mass

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.

> ***"We know more about the dead seas of Mars than our own ocean."***
> *– Jean Michel Cousteau*

Our current estimation is that 95% of Earth's ocean is unexplored. At first, this may be hard to believe, particularly if we look at recent satellite maps of Earth's ocean floor. These maps seem to show seafloor features in considerable detail. But satellites can't see below the ocean's surface. The "images" of these features are estimates based on the height of the ocean's surface, which varies because the pull of gravity is affected by seafloor features. And if we consider the scale of these maps, it is easy to see how some things might be missed. To show our planet's entire ocean, a typical wall map has a scale of about 1 cm = 300 km. At that scale, the dot made by a 0.5 mm pencil represents an area of over 60 square miles! The fact is, most of the ocean floor has never been seen by human eyes.

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 our largely unknown ocean for the purposes of discovery and the advancement of knowledge. To fulfill its mission, the *Okeanos Explorer* has specialized capabilities for finding new and unusual features in unexplored parts of Earth's ocean, and for gathering key information that will support more detailed investigations by subsequent expeditions. These capabilities include:

- Underwater mapping using multibeam sonar capable of producing high-resolution maps of the seafloor to depths of 6,000 meters;
- Underwater robots (remotely operated vehicles, or ROVs) that can investigate anomalies as deep as 6,000 meters; and
- Advanced broadband satellite communication and telepresence.

Capability for broadband telecommunications provides the foundation for telepresence: technologies that allow people to observe and interact with events at a remote location. This allows live images to be transmitted from the seafloor to scientists ashore,

A spectacular photo of the NOAA Ship *Okeanos Explorer* Control Room while ROV operations are underway. Image credit: NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.

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*

classrooms, newsrooms and living rooms, and opens new educational opportunities, which are a major part of *Okeanos Explorer's* mission for advancement of knowledge. In addition, telepresence makes it possible for shipboard equipment to be controlled by scientists in shore-based Exploration Command Centers. In this way, scientific expertise can be brought to the exploration team as soon as discoveries are made, and at a fraction of the cost of traditional oceanographic expeditions.

Some of the most exciting discoveries in modern ocean exploration have been made with the assistance of underwater robots. In this lesson, students will determine the density and buoyancy of various objects, and will use their knowledge of buoyancy principles to calculate the floatation that is theoretically needed to achieve neutral buoyancy; a characteristic that is often required for manned and unmanned submersibles.

Learning Procedure

[NOTE: Like all technologies in active use, ROVs are under constant improvement, development and replacement. Consequently, some of the underwater robots referenced in this lesson may no longer be in active service when students undertake this investigation. This does not constitute an obstacle to achieving the Learning Objectives of this lesson, but may require some additional research as Web sites are updated to reflect changes in underwater robotic technology.]

1. To prepare for this lesson:
   a. Review introductory information on the NOAA Ship *Okeanos Explorer* at *http://oceanexplorer.noaa.gov/okeanos/welcome.html*. You may also want to consider having students complete some or all of the lesson, *To Boldly Go….*
   b. Review the Ocean Explorer Web pages on underwater robotic vehicles, indexed at *http://oceanexplorer.noaa.gov/technology/subs/subs.html* and the essay on ROV *Little Hercules* at *http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/rov/rov.html*.
   c. Review procedures described in the *Density and Buoyancy Investigation Guide* (page 65), and prepare materials needed by student groups to complete this activity.
   d. If your students use Lego® robotics or Vernier® calculator-based laboratory materials, you may want to consider alternative procedures described on the *Using Electronic Force Sensors to Measure Buoyancy* information sheet.
   e. Depending upon available time, you may also want to have students complete the activity described in Step 5 of the lesson, *I, Robot, Can Do That!* (*http://oceanexplorer.noaa.gov/explorations/05lostcity/background/edu/media/lostcity05_i_robot.pdf*). In this activity, students identify which of the robots they have studied are best suited to a series of underwater missions.

2. If you have not previously done so, introduce the NOAA Ship *Okeanos Explorer*, emphasizing that this is the first Federal vessel specifically dedicated to exploring Earth's largely unknown ocean. Lead a discussion of reasons that ocean exploration is important, and briefly review the major technological capabilities of the ship. Say that robotic submersibles are a key component of many ocean exploration expeditions, and tell students that their assignment is to investigate some of these robots. Assign one of the following robots to each student group, and provide each group with a copy of *Underwater Robot Capability Survey*:
   Autonomous Benthic Explorer (ABE)

Little Hercules
Remotely Operated Platform for Ocean Science (ROPOS)
General Purpose Remotely Operated Vehicles (ROVs)
RCV-150
Tiburon

You may want to direct students to the Ocean Explorer Web pages on underwater robotic vehicles (see 1b. above). If students do not have access to the internet, provide copies of the relevant materials to each group.

3. Have each student group present a brief oral report of the capabilities of their assigned robot. The following points should be included:

Autonomous Benthic Explorer (ABE)

- Capable of operating to depths up to 5,000 meters
- Autonomous vehicle; no tether to support ship
- Tools: video cameras, conductivity and temperature sensors, depth recorder, magnetometer, sonar, wax core sampler, navigation system
- Developed to monitor underwater areas over a long period of time
- Follows instructions programmed prior to launch; data are not available until robot is recovered
- Operates independently during missions, but requires technicians and engineers for maintenance, as well as data managers to retrieve information stored in computer memory
- NOTE: ABE was lost during the INSPIRE: Chile Margin 2010 Expedition; see *http://oceanexplorer.noaa.gov/explorations/10chile/logs/mar7a/mar7a.html*

Remotely Operated Platform for Ocean Science (ROPOS)

- Capable of operating to depths up to 5,000 meters
- 5,500 m of electrical-optical cable tether
- Tools: two digital video cameras; two manipulator arms that can be fitted with different sampling tools (stainless steel jaws, manipulator feedback sensors, rope cutters, snap hooks, core tubes); variable-speed suction sampler and rotating sampling tray; sonar; telemetry system
- Can also be outfitted with up to eight custom-designed tools such as a hot-fluid sampler; chemical scanner; tubeworm stainer; rock-coring drill; rock-cutting chainsaw; laser-illuminated, range gated camera; and downward-looking digital scanning sonar
- Wide variety of observation tools provides scientists with exceptional flexibility so they can quickly respond to new and unexpected discoveries
- A "typical" dive requires at least four people (and sometimes more): the "Hot Seat" scientist, pilot, manipulator operator, and data/event logger

General Purpose Remotely Operated Vehicles (ROVs)

- Depth capability varies
- Operated by one or more persons aboard a surface vessel
- Linked to the ship by a group of cables that carry electrical signals back and forth between the operator and the vehicle
- Tools: most are equipped with at least a video camera and lights
- Additional equipment may include a still camera, a manipulator or cutting arm, water samplers, and instruments that measure water clarity, light penetration, and temperature
- Also used for educational programs at aquaria and to link to scientific expeditions live via the internet

The ABE autonomous underwater vehicle (free-swimming robot). ABE (full name: Autonomous Benthic Explorer) has been used on multiple expeditions to find new hydrothermal vents in the deep ocean all over the world, from New Zealand to South Africa and from Brazil to Ecuador. Photo credit: Christopher German.
http://oceanexplorer.noaa.gov/explorations/10chile/background/exploration/media/exploration1.html

Epitaph for ABE:
Under the wide and restless sea,
Lies my grave, now let me be;
Glad did I work and now I rest,
Now by deadlines no longer stressed.
And I lay me down with a will.

This be the verse you grave for me;
"Here lies ABE where it longed to be;
Home is the sailor, home to the sea,
Here it rests, now let it be."
~ Al Bradley (after Robert Louis Stevenson)

ROPOS being deployed for deepwater operations inside its steel cage.
http://oceanexplorer.noaa.gov/technology/subs/ropos/media/roposfirstdive.html

Left-to-Right: Dave Wright, Tom Kok, and Brian Bingham look up for a moment while operating the ROV. Every day presents the pilot, co-pilot, and navigator with new and unforeseen challenges. Image credit: C. Verplanck, NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.

Okeanos Explorer crew launch the vehicle during test dives off Hawaii. Image credit: NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/hires/launch_hires.jpg

The control room stations for the ROV *Tiburon* used on the 2006 Davidson Seamount Expedition. From left to right, the stations are: Co-pilot, Pilot, Science, Annotation, and Navigation. Image credit: NOAA/MBARI 2006. For more information, please visit
http://oceanexplorer.noaa.gov/explorations/06davidson/logs/feb02/feb02.html
http://oceanexplorer.noaa.gov/explorations/06davidson/logs/feb02/media/control_room.html

- Range in size from that of a bread box to a small truck
- Often kept aboard vessels doing submersible operations for safety, and so the ROV can take the place of the submersible when it cannot be used because of weather or maintenance problems
- Can also be used to investigate questionable dive sites before a sub is deployed to reduce risk to the subs and their pilots

Little Hercules
- Capable of operating to depths of 4,000 meters
- Provided first and only images of John Kennedy's PT boat, PT-109
- Operated by pilots via a fiberoptic multiplexer system
- Equipped with ultra-short baseline tracking system (USBL)
- Tools:
  - Full color imaging sonar
  - Conductivity-Temperature-Depth sensor
  - Two color CCD cameras
  - High definition video camera
  - Depth and altitude sensors
- Mission ROV for 2010 INDEX-SATAL Expedition in Indonesia (see *http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/rov/rov.html* for more information)

Tiburon (ROV)
- Capable of operating to depths of 4,000 meters
- Controlled from a special control room on board its tender vessel, the R/V *Western Flyer*
- Tether contains electrical wires and fiber-optic strands
- Electrical thrusters and manipulators, rather than hydraulic systems, allow vehicle to move quietly through the water, causing less disturbance to animals being observed
- Variable buoyancy system allows the vehicle to float motionless in the water without the constant use of the thrusters
- Lower half of the vehicle is a modular toolsled, which can be exchanged with other toolsleds to carry out specific missions: benthic (or bottom) toolsled has an extra manipulator arm and extensive sample-carrying space for geological and biological samples; "midwater" toolsled used to explore the biology of open ocean creatures; rock coring toolsled has been used to take oriented rock cores from the seafloor.

RCV-150
- Capable of operating to depths of 914 m
- Tethered to support ship via a double armored electro-optical umbilical
- Tools: color video camera, 1500 watts of lighting, micro conductivity/temperature/depth sensor, sonar, manipulator with a six-inch cutoff wheel
- Controlled by a single pilot from a control console located in the tracking room of the support ship
- Small size compared to a submersible allows ROV to have high maneuverability; can get close to the bottom and allow the cameras to peer under ledges and into nooks and crannies
- Primary data collected is video
- Has been used to conduct surveys of bottomfish in Hawai'i

4. Give each student group a copy of the *Density and Buoyancy Investigation Guide* and a collection of objects whose density and buoyancy are to be determined. If necessary, explain how to use the balance, where students are to obtain water, and how they should dispose of wastewater.

5. Lead a discussion of students' results. In Part A of the *Investigation Guide*, students should realize that they need to know mass and volume to find the density of an object. Since the volume of many substances changes in response to temperature, it is also true that the density of an object also depends upon temperature. But temperature changes usually have very small effects on density compared to the effects of changing mass and volume. Students should also observe that objects that float have lower densities than objects that sink.

   In Part B, students should realize that increasing the volume of an object will increase the volume and weight of fluid displaced when the object is immersed, and thus will increase the buoyant force acting on the object.

   Most science standards do not expect elementary students to distinguish between mass and weight, but middle school (Grades 6-8) students are expected to make this distinction. These concepts can be easily confused when dealing with density and buoyancy, because when students use a balance to determine mass they are actually measuring weight (mass multiplied by the force of gravity). This works out because the balance is calibrated to take gravity into account, but under zero gravity conditions the balance would not give an accurate estimate of mass. So if we want to calculate the buoyant force acting on an object based on the weight of displaced fluid, we have to use units of weight such as pounds. If we want to use metric units of force (Newtons) we have to multiply the mass of the displaced fluid (in kg) by the acceleration of gravity (about 9.81 m/sec^2). Since these metric units, as well as the concepts of gravitational acceleration, are usually taught in higher grade levels, we do not have students calculate actual buoyant force in this lesson. But if students discuss buoyant force in terms of grams or kilograms, it is important to remind them that these are units of mass and that buoyancy involves units of weight.

   These considerations are not a problem for the *Apply* portion of Part B, because the mass of the robot and mass of water displaced by the float are both acted upon by the same acceleration due to gravity (9.81 m/sec^2). To make the robot neutrally buoyant, the volume of water displaced by the float must have a mass that is equal the mass of the robot (400 kg). Since the density of water is 1,000 kg/m^3, the volume of water that has a mass of 400 kg is:

   $$400 \text{ kg} \div 1{,}000 \text{ kg/m}^3 = 0.4 \text{ m}^3$$

   To calculate the diameter of a cylinder that is 750 cm long that has a volume of 0.4 m^3, first calculate the radius of a 750 cm long cyclinder that has this volume:

   $$\pi \bullet r^2 \bullet L = 0.4 \text{ m}^3$$
   $$\pi \bullet r^2 \bullet 0.75 \text{ m} = 0.4 \text{ m}^3$$
   $$\pi \bullet r^2 = 0.4 \text{ m}^3 \div 0.75 \text{ m}$$
   $$\pi \bullet r^2 = 0.533 \text{ m}^2$$
   $$r^2 = 0.170 \text{ m}^2$$
   $$r = 0.412 \text{ m}$$

So, the diameter of the cylinder is

$$D = 2r = 2\ (0.412\ \text{m}) = 0.824\ \text{m}$$

Discuss some of the factors that might make it difficult to maintain neutral buoyancy. Temperature could have a relatively minor effect as discussed above. Pressure would be a much more serious consideration, since at depths of 400 m to 1,500 m, for example, the pressure would be roughly 40 to 150 times greater than surface pressure. This presents serious design considerations, since there would be a large pressure difference between the inside and outside of the cylinder if the cylinder contained air at normal atmospheric pressure. Even a slight compression of a floatation cylinder could change its volume so that it would no longer provide neutral buoyancy.

Salinity also affects buoyancy, and some of your students have probably found that it is easier to float in seawater than in freshwater. The reason, of course, is that the density of seawater is greater than freshwater (at the same temperature); so the weight of seawater displaced by an object will be greater than the weight of freshwater displaced by the same object, and the resulting buoyant force is greater in seawater. Salinity often varies at different locations in the water column. Again, even slight variations can be enough to upset neutral buoyancy in an underwater floatation system.

Several strategies can be used to compensate for buoyancy changes. One way to do this is to change the volume of a float by adding or removing air; SCUBA divers use this strategy to adjust their buoyancy by adding or removing air to their buoyancy compensator. Another approach is to provide more floatation than is necessary for neutral buoyancy, then add weight to the system; usually by pumping water in or out of an enclosed space. Ballast tanks on submarines are based on this strategy.

The BRIDGE Connection

www.vims.edu/bridge/ – In the "Site Navigation" menu on the left, click "Ocean Science Topics," then "Human Activities," then "Technology" for links to resources about submersibles, ROVs, and other technologies used in underwater exploration.

The "Me" Connection

Have students write a brief essay describing how robots are (or may be) of personal benefit.

Connections to Other Subjects

English/Language Arts, Life Science, Mathematics

Assessment

Reports and discussions in Steps 3 and 4 provide opportunities for assessment.

Extensions

1. Follow events aboard the *Okeanos Explorer* at *http://oceanexplorer.noaa.gov/okeanos/welcome.html*.
2. Build your own underwater robot! See books by Harry Bohm under "Resources."

Multimedia Discovery Missions

http://www.montereyinstitute.org/noaa/ Click on the links to Lessons 3, 6, 11, and 12 for interactive multimedia presentations and Learning Activities on Deep-Sea Corals, Deep-Sea Benthos, Energy from the Oceans, and Food, Water, and Medicine from the Sea.

Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

Call to Arms (Grades 5-6)
(from the 2008 Deepwater Coral Expedition: Reefs, Rigs, and Wrecks)
http://oceanexplorer.noaa.gov/explorations/08lophelia/background/edu/media/calltoarms.pdf
Focus: Robotic Analogues for Human Structures (Physical Science/Life Science)
Students will describe the types of motion found in the human arm, and describe four common robotic arm designs that mimic some or all of these functions.

I, Robot, Can Do That! (Grades 7-8)
(from the Thunder Bay Sinkholes 2008 Expedition)
http://oceanexplorer.noaa.gov/explorations/08thunderbay/background/edu/media/robot.pdf
Focus: Underwater Robotic Vehicles for Scientific Exploration (Physical Science/Life Science)
Students will describe and contrast at least three types of underwater robots used for scientific explorations, discuss the advantages and disadvantages of using underwater robots in scientific explorations, and identify robotic vehicles best suited to carry out certain tasks.

The Robot Explorer (Grades 9-12) (from the 2009 Bermuda Caves Expedition)
http://oceanexplorer.noaa.gov/explorations/09bermuda/background/edu/media/09robot.pdf
Focus: Remotely operated vehicles for exploring anchialine caves (Physics/Earth Science/Technology)
Students will discuss remotely operated vehicles and onboard systems used for exploring anchialine caves, and will explain the design and construction process for a simple robot explorer.

My Wet Robot (Grades 9-12) (from the PHAEDRA 2006 Expedition)
http://oceanexplorer.noaa.gov/explorations/06greece/background/edu/media/wet_robot.pdf
Focus: Underwater Robotic Vehicles (Physical Science)
Students will discuss the advantages and disadvantages of using underwater robots in scientific explorations, identify key design requirements for a robotic vehicle that is capable of carrying out specific exploration tasks, describe practical approaches to meet identified design requirements, and (optionally) construct a robotic vehicle capable of carrying out an assigned task.

The Roving Robotic Chemist (Grades 9-12)
(from the PHAEDRA 2006 Expedition)
http://oceanexplorer.noaa.gov/explorations/06greece/background/edu/media/robot_chemist.pdf
Focus: Mass Spectrometry (Chemistry)

Students will explain the basic principles underlying mass spectrometry, discuss the advantages of in-situ mass spectrometry, explain the concept of dynamic re-tasking as it applies to an autonomous underwater vehicle, and develop and justify a sampling strategy that could be incorporated into a program to guide an AUV searching for chemical clues to specific geologic features.

Where's My 'Bot? (Grades 9-12) (from the Bonaire 2008: Exploring Coral Reef Sustainability with New Technologies Expedition)
http://oceanexplorer.noaa.gov/explorations/08bonaire/background/edu/media/wheresbot.pdf
Focus: Marine Navigation (Earth Science/Mathematics)
Students will estimate geographic position based on speed and direction of travel, and integrate these calculations with GPS data to estimate the set and drift of currents.

The Robot Archaeologist (Grades 9-12) (from the AUVfest 2008 Expedition)
http://oceanexplorer.noaa.gov/explorations/08auvfest/background/edu/media/robot.pdf
Focus: Marine Archaeology/Marine Navigation (Earth Science/Mathematics)
Students will design an archaeological survey strategy for an autonomous underwater vehicle (AUV); calculate expected position of the AUV based on speed and direction of travel; and calculate course correction required to compensate for the set and drift of currents.

Other Resources

See page 217 for Other Resources.

Next Generation Science Standards

Lesson plans developed for Volume 1 are correlated with *Ocean Literacy Essential Principles and Fundamental Concepts* as indicated in the back of this book. Additionally, a separate online document illustrates individual lesson support for the Performance Expectations and three dimensions of the Next Generation Science Standards and associated Common Core State Standards for Mathematics and for English Language Arts & Literacy. This information is provided to educators as a context or point of departure for addressing particular standards and does not necessarily mean that any lesson fully develops a particular standard, principle or concept. Please see: *http://oceanexplorer.noaa.gov/okeanos/edu/collection/wdwe_ngss.pdf.*

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:
oceanexeducation@noaa.gov

For More Information

Paula Keener, Director, Education Programs
NOAA Office of Ocean Exploration and Research
Hollings Marine Laboratory
331 Fort Johnson Road, Charleston SC 29412
843.762.8818   843.762.8737 (fax)
paula.keener-chavis@noaa.gov

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Underwater Robot Capability Survey

Name of Robotic Vehicle

Maximum Operating Depth

Tethered or Autonomous

Minimum Number of Crew Required for Operation

Tools

Special Capabilities or Advantages

Other Details

Density and Buoyancy Investigation Guide

A. Density

Background

Density is a physical property of matter that is related to an object's mass (the amount of material in the object) and volume (the object's physical size). You know that a handful of styrofoam weighs much less than a handful of rocks. This is because the density of the styrofoam is less than the density of the rocks. Density is usually defined as "mass per unit volume," and the density of an object or substance is stated in "grams per cubic centimeter."

Inquire

Your task is to measure the density of objects in the collection provided by your teacher. What two properties of each object do you need to know to find the object's density?

Measure the mass of each object using a balance as directed by your teacher. Record these measurements on the data sheet.

Now measure the volume of each object. The easiest way to do this is to immerse the object in water in a graduated cylinder and measure the increase in water volume. Put water into a graduated cylinder so the cylinder is about half full. Record the volume of the water on the data sheet in the "Volume Without Object" column. Drop the object into the cylinder and record the new volume on the data sheet in the "Volume With Object" column. If the object floats, you will need to push it down with a piece of stiff wire until the object is completely submerged. Subtract "Volume Without Object" from "Volume With Object" and record the result in the "Object Volume" column.

Calculate the density of each object by dividing the mass by the volume, and record the results on the data sheet in the "Density" column. Hint: One milliliter is the same as one cubic centimeter.

Record the buoyancy of the object in the last column.

What do you notice about the density of objects that sink compared to objects that float?

B. Buoyancy

Background

Read the following explanation of Archimedes' Principle:
The idea of buoyancy was summed up by a Greek mathematician named Archimedes: any object, wholly or partly immersed in a fluid, is buoyed up by a force equal to the weight of the fluid displaced by the object. Today, this definition is called Archimedes' Principle. Archimedes is considered one of the three greatest mathematicians of all time (the other two are Newton and Gauss). Archimedes was born in 287 B.C., in Syracuse, Greece. He was a master at mathematics and spent most of his time thinking about new problems to solve.

Many of these problems came from Hiero, the king of Syracuse. Archimedes came up with his famous principle while trying to solve this problem: The king ordered a gold crown and gave the goldsmith the exact amount of metal to make it. When Hiero received it, the crown had the correct weight but the king suspected that some silver had been substituted for the gold. He did not know how to prove it, so he asked Archimedes for help.

One day while thinking this over, Archimedes went for a bath and water overflowed the tub. He recognized that there was a relationship between the amount of water that overflowed the tub and the amount of his body that was submerged. This observation gave him the means to find the volume of an irregularly shaped object, such as the king's crown. With this information, Archimedes could find out how much a volume of gold equal to the volume of the crown would weigh. If the weight of the same volume of gold turned out to be the same as the weight of the crown, then he would know that the crown was made of gold. But if the weight of the same volume of gold was different from the weight of the crown, then he would know that the crown was not pure gold after all.

Archimedes had solved the problem! He was so excited that he ran naked through the streets of Syracuse shouting "I have found it!". As it turned out, the crown was not pure gold, so the goldsmith was brought to justice and Archimedes never took another bath...(just kidding!).

(from *Discover Your World with NOAA: An Activity Book*; *http://celebrating200years.noaa.gov/edufun/book/welcome.html*)

Inquire

If the volume of an object increases but the mass of the object does not change, how does this affect the buoyant force acting on the object when it is immersed in a fluid?

Apply

Underwater robots usually are designed to be able to achieve neutral buoyancy (they do not sink or float, but stay suspended in the middle of the water) while they are performing various tasks. One way to adjust buoyancy is to pump water in or out of floatation cylinders that are attached to the frame of the robot. This changes the volume of air that is contained inside the cylinders, and therefore changes their buoyancy.

Suppose you have an underwater robot that has a mass of 400 kg in fresh water without any extra floatation. What is the minimum diameter of a cylinder that is 750 cm long that will provide enough floatation to make the robot neutrally buoyant? Assume that the cylinder is made from a material that is weightless in water.

Hints:

(a) The formula for the volume of a cylinder is $\pi \bullet r^2 \bullet L$, where r is the radius of the cylinder and L is the length of the cylinder.

(b) One cubic meter of fresh water has a mass of 1,000 kilograms at 5° C

Why might it be difficult to maintain neutral buoyancy, even if the floatation cylinder had the correct dimensions? What strategies could be used to overcome these difficulties?

Density and Buoyancy Investigation Data Sheet

Object	Mass	Volume	Volume	Object	Density	Buoyancy
	(g)	Without Object (ml)	With Object (ml)	Volume (ml)	(g/cm3)	S = sinks F = Floats N = Neutral

Using Electronic Force Sensors to Measure Buoyancy

Electronic force sensors can be adapted to measure buoyancy. Incorporating this approach to measurements in Part A of the *Density and Buoyancy Investigation Guide* provides additional opportunities for hands-on student problem-solving, as well as experience with using calculators or computers for data logging and analysis.

Vernier Software and Technology (*http://www.vernier.com*) offers a dual-range sensor that can be used as a replacement for a hand-held spring scale, and attaches to graphing calculators as well as interfaces that allow sensor readings to be stored and analyzed by personal computers. The sensor may be mounted on a ring stand and used to measure the weight of objects attached to a hook built into the sensor. If these objects are immersed in a container of water, the change in weight provides a measure of buoyancy.

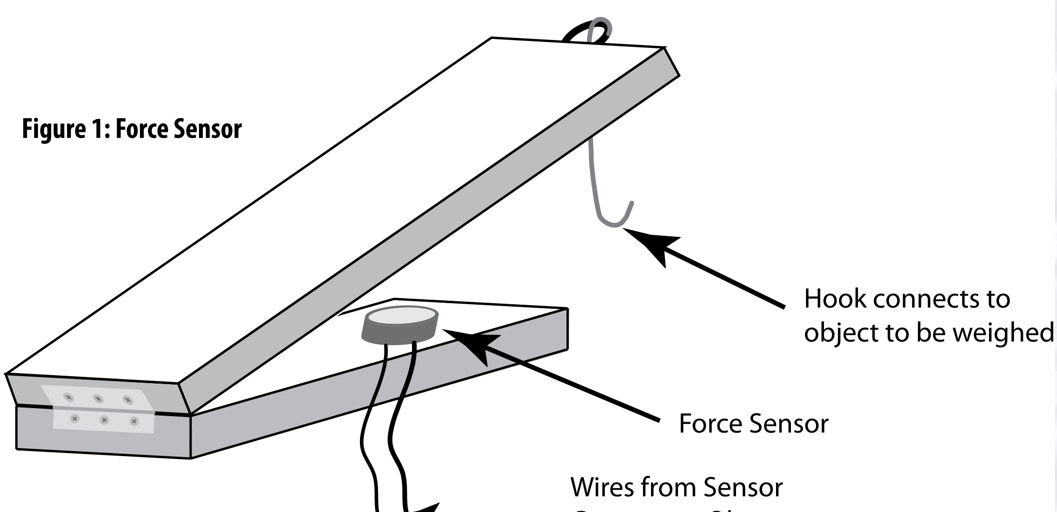
Adapters are available to allow the Lego Mindstorms® RCX and NXT microcontroller bricks to accept Vernier and other third-party sensors that can provide data to personal computers via RoboLab® software (*http://www.vernier.com/engineering/lego-nxt/*). Since many middle schools participate in First Lego League competitions, students may already be familiar with procedures for acquiring data using these microcontrollers and software.

Less expensive force sensors are also available. FlexiForce® sensors, for example, are very thin printed circuits that can be used to measure force between two surfaces. Since these sensors are essentially variable resistors whose resistance decreases as force is applied, the change in resistance can be read with an inexpensive ohmmeter. By calibrating the sensor with objects whose weight is known, a graph can be constructed that converts sensor resistance into units of force (see *http://www.tekscan.com/pdfs/FlexiforceUserManual.pdf* for details). To use this type of sensor for buoyancy measurements, it is necessary to devise a way for the object being tested to apply pressure to the sensor. One solution is illustrated in Figure 1, but students will probably create many others as well.

A variety of Web pages provide directions for constructing simple force sensors from very inexpensive materials (*e.g.*, *http://www.instructables.com/id/How-to-Make-Bi-Directional-Flex-Sensors/*). Many of these also are devices whose resistance changes as they are subjected to pressure or flexing, and are based on plastic or cloth materials that include substances that make these materials conductive to electricity. The plastic bags used in the electronics industry to ship static-sensitive components are one example, and are readily available at little or no cost. Offering students the option of constructing their own sensors provides additional opportunities for creativity and problem-solving.

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

Figure 1: Force Sensor



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

Section 2: Key Topic – Ocean Exploration

Calling All Explorers

(adapted from the 2002 Submarine Ring of Fire Expedition)

Focus

Recent explorers of deep-sea environments

Grade Level

9-12 (Life Science/Earth Science)

Focus Question

What are the skills and motivations of modern ocean explorers?

Learning Objectives

- Students will describe what it means to be an explorer, both modern and historic.
- Students will explain the importance of curiosity, exploration, and the ability to document what one studies.
- Students will discuss the importance of ocean exploration.

Materials

- Copies of *Part I: Ocean Explorers Web Quest Guide;* one for each student group
- Copies of *Part II: Individual Explorers Reflections Sheet*; one for each student
- Materials for Optional Activity (see Learning Procedure, Step 5):
  - Copies of *Create a Geocache*; one copy for each student group
  - GPS receivers; one for each student group is ideal, but it is possible to complete the activity with fewer units or even just one (see Learning Procedure, Step 1)

Audiovisual Materials

- (Optional) Video or computer projection equipment for viewing interviews with ocean explorers

Teaching Time

Four or five 45-minute class periods, plus time for student research. If Background Information is read aloud and discussed with students, an extra 20 minutes of introductory time is needed before the lesson is begun.

Seating Arrangement

Part I: Groups of two to four students
Part II: Classroom style

Maximum Number of Students

32

Ocean Exploration and Research

Key Words and Concepts

Okeanos Explorer
Exploration
Documentation
Biodiversity
Extreme environments

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.

> ***"We know more about the dead seas of Mars than our own ocean."***
> *– Jean Michel Cousteau*

Our current estimation is that 95% of Earth's ocean is unexplored. At first, this may be hard to believe, particularly if we look at recent satellite maps of Earth's ocean floor. These maps seem to show seafloor features in considerable detail. But satellites can't see below the ocean's surface. The "images" of these features are estimates based on the height of the ocean's surface, which varies because the pull of gravity is affected by seafloor features. And if we consider the scale of these maps, it is easy to see how some things might be missed. To show our planet's entire ocean, a typical wall map has a scale of about 1 cm = 300 km. At that scale, the dot made by a 0.5 mm pencil represents an area of over 60 square miles! The fact is, most of the ocean floor has never been seen by human eyes.

Historically, explorers have been driven by a variety of motives. For some, the primary reason to explore was to expand their knowledge of the world. For others, economic interests provided powerful incentives, and many expeditions have launched on missions such as finding a sea route to access the spices of Asia; or quests for gold, silver, and precious stones. Political power and the desire to control large empires motivated other explorations, as did the desire to spread religious doctrines. In the case of space exploration, additional reasons have been offered, including understanding our place in the cosmos, gaining knowledge about the origins of our solar system and about human origins, providing advancements in science and technology, providing opportunities for international collaboration, and keeping pace with other nations involved in developing space technology. The first ocean exploration for the specific purpose of scientific research is often considered to be the voyage of HMS *Challenger*, conducted between 1872-1876 (visit *http://oceanexplorer.noaa.gov/explorations/03mountains/background/challenger/challenger.html* and *http://www.coexploration.org/hmschallenger/html/AbouttheProject.htm* for more information about the *Challenger* Expedition and comparisons with modern oceanographic exploration).

The science and ship crew of the HMS *Challenger* in 1874. The original crew of 216 had dwindled to 144 by the end of the long expedition. Image credit: NOAA.

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 our largely unknown ocean for the purposes of discovery and the advancement of knowledge. To fulfill its mission, the *Okeanos Explorer* has specialized capabilities for finding new and unusual features in unexplored parts of Earth's ocean, and for gathering key information that will support more detailed investigations by subsequent expeditions. These capabilities include:

A spectacular photo of the NOAA Ship *Okeanos Explorer* Control Room while ROV operations are underway. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.

During preliminary operations near Guam, Indonesian scientist Dr. Michael Purwoadi makes the first 'call' using telepresence from the NOAA Ship *Okeanos Explorer* to colleagues in the newly-established Jakarta Exploration Command Center. Image courtesy of NOAA OER.

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 Ocean Exploration and Research Program

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*

- Underwater mapping using multibeam sonar capable of producing high-resolution maps of the seafloor to depths of 6000 meters;
- Underwater robots (remotely operated vehicles, or ROVs) that can investigate anomalies as deep as 6,000 meters; and
- Advanced broadband satellite communication and telepresence.

Capability for broadband telecommunications provides the foundation for telepresence: technologies that allow people to observe and interact with events at a remote location. This allows live images to be transmitted from the seafloor to scientists ashore, classrooms, newsrooms and living rooms, and opens new educational opportunities, which are a major part of *Okeanos Explorer's* mission for advancement of knowledge. In addition, telepresence makes it possible for shipboard equipment to be controlled by scientists in shore-based Exploration Command Centers. In this way, scientific expertise can be brought to the exploration team as soon as discoveries are made, and at a fraction of the cost of traditional oceanographic expeditions.

Curiosity, desire for knowledge, and quest for adventure continue to motivate modern explorers. But today, there are additional reasons to explore Earth's ocean, including:

- **Climate Change** – The ocean has a major influence on weather and climate, but we know very little about deep-ocean processes that affect climate.
- **Energy** – Ocean exploration contributes to the discovery of new energy sources, as well as protecting unique and sensitive environments where these resources are found.
- **Human Health** – Expeditions to the unexplored ocean almost always discover species that are new to science, and many animals in deep-sea habitats have been found to be promising sources for powerful new antibiotic, anti-cancer and anti-inflammatory drugs.
- **Ocean Health** – Many ocean ecosystems are threatened by pollution, overexploitation, acidification and rising temperatures. Ocean exploration can improve understanding of these threats and ways to improve ocean health.
- **Research** – Expeditions to the unexplored ocean can help focus research into critical areas that are likely to produce tangible benefits.
- **Innovation** – Exploring Earth's ocean requires new technologies, sensors and tools, and the need to work in extremely hostile environments is an ongoing stimulus for innovation.
- **Ocean Literacy** – Ocean exploration can help inspire new generations of youth to seek careers in science, and offers vivid examples of how concepts of biology, physical science, and Earth science are useful in the real world.

Recent technological developments have made the oceans more visible than they have ever been before. With these new "technological eyes," new species, new ecosystems, and new metabolic processes have been discovered. With the commissioning of the NOAA Ship *Okeanos Explorer*, a new era of ocean exploration has been launched by our Nation. In the years ahead, ocean explorers are certain to find many more fascinating discoveries about our Ocean Planet—and our intrinsic connections to it. In this lesson, students will learn more about modern ocean explorers: who they are, what they do, and why they are drawn to explore Earth's ocean.

Learning Procedure

1. To prepare for this lesson:
   - Review introductory information on the NOAA Ship *Okeanos Explorer* at *http://oceanexplorer.noaa.gov/okeanos/welcome.html*. You may also want to consider

having students complete some or all of the lesson, *To Boldly Go…*.

- Review questions on student handouts for Parts I and II, and decide whether to show portions of ocean explorer interviews during class discussions (Step 4).
- Review procedures for optional geocaching activity (Step 5). Determine how many GPS units will be available for student use (many students may have access to suitable units at home; if only a few units are available, these can be shared by having groups complete their assignments on different days). In most cases, items needed to construct geocaches can be provided by the students. To avoid inappropriate items, each group will be required to have their geocache approved before it is hidden.
- If you want your students to explore the Global Positioning System in greater depth, see the "Your Expedition of Discovery" lesson plan from the *Lophelia* II 2009: Deepwater Coral Expedition: Reefs, Rigs, and Wrecks (*http://oceanexplorer.noaa.gov/explorations/09lophelia/background/edu/media/09yourexped.pdf*).

2. If you have not previously done so, briefly introduce the NOAA Ship *Okeanos Explorer*, emphasizing that this is the first Federal vessel specifically dedicated to exploring Earth's largely unknown ocean. Lead a discussion of reasons why ocean exploration is important, and what kinds of people students believe might be involved with modern ocean exploration. Tell students that their assignment is to find out about some modern ocean explorers. Provide each student group with a copy of *Part I: Ocean Explorers Web Quest Guide*.

3. When students have completed Part I, provide individual students with a copy of *Part II: Individual Explorers Reflections Sheet*.

4. Lead a class discussion of students' answers and reflections for Parts I and II.

5. Optional Activity: Your Own Expedition of Discovery -- Most students will be familiar with the concept of the Global Positioning System (GPS), but may not fully understand how the system works. The "Your Expedition of Discovery" lesson (*http://oceanexplorer.noaa.gov/explorations/09lophelia/background/edu/media/09yourexped.pdf*) provides a brief review of GPS, as well as the process of using latitude and longitude to describe a specific location on Earth. You may want to discuss this information with students prior to completing the rest of the activity.

   Give each student group a copy of *Create a Geocache*, and remind students that they are to submit their geocache plan for approval BEFORE beginning the field portion of their assignment. If there are not enough GPS receivers for each group to have their own, tell students how the available units will be scheduled among the groups. Be sure each group has at least one student who is familiar with the operation of the GPS receiver that group will be using.

   Review students' geocache plans. Be sure their proposed sites are not in dangerous areas and that students have appropriate permission to use the sites. An easy way to avoid these issues is to confine the sites to approved portions of the school grounds, but this makes the geocaching "expeditions" somewhat less adventurous.

   Provide each student group with the latitude and longitude of a geocache created by one of the other groups. Remind students about schedules (if any) for using the GPS receivers, and when they are to have their "Geocaching Discovery Expeditions" completed.

Have students discuss their experiences while searching for their assigned geocache, particularly any difficulties they encountered in navigating to a specific geographic location. Since student groups remove the geocaches when (and if) they are found, these geocache locations should not be registered with the official Global GPS Cache Hunt Site.

The BRIDGE Connection

www.vims.edu/bridge/ – Scroll over "Ocean Science Topics," "Human Activities," then "Heritage" for links to resources about the history of ocean exploration.

The "Me" Connection

a. All of Part II: Individual Exploration represents "Me" Connections
b. Visit *http://cfa-www.harvard.edu/space_geodesy/ATLAS/applications.html* for a worksheet that asks students to design a system that incorporates GPS receivers, and encourages students to consider how GPS might be integrated into their daily lives (a component of Project ATLAS (Assisted Transnational Learning using Artificial Satellites), a multidisciplinary, international educational outreach project in which students in the age range of 12—14 years from around the world use satellite and Internet technologies to learn about the world in which they live.

Connections to Other Subjects

English/Language Arts, Physical Earth, Life Sciences, Art/Design

Assessment

Written reports and class discussions provide opportunities for assessment.

Extensions

1. Ask students to investigate career opportunities as ocean explorers, ocean scientists, and others whose careers support ocean science and exploration.
2. Visit *http://celebrating200years.noaa.gov/edufun/book/SurveyMarkHunting.pdf* for another geocaching activity involving survey marks, and an introduction to geodesy (the science of measuring the size and shape of the Earth and accurately locating points on the Earth's surface).
3. Have students find out about "Travel Bugs" (see *http://www.geocaching.com/track*).

Other Resources

See page 217 for Other Resources.

Next Generation Science Standards

Lesson plans developed for Volume 1 are correlated with *Ocean Literacy Essential Principles and Fundamental Concepts* as indicated in the back of this book. Additionally, a separate online document illustrates individual lesson support for the Performance Expectations and three dimensions of the Next Generation Science Standards and associated Common Core State Standards for Mathematics and for English Language Arts & Literacy. This information is provided to educators as a context or point of departure for addressing particular standards and does not necessarily mean that any lesson fully develops a particular standard, principle or concept. Please see: *http://oceanexplorer.noaa.gov/okeanos/edu/collection/wdwe_ngss.pdf.*

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:
oceanexeducation@noaa.gov

For More Information

Paula Keener, Director, Education Programs
NOAA Office of Ocean Exploration and Research
Hollings Marine Laboratory
331 Fort Johnson Road, Charleston SC 29412
843.762.8818 843.762.8737 (fax)
paula.keener-chavis@noaa.gov

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Part I – Ocean Explorers Web Quest Guide

Welcome, Ocean Explorers! Please proceed to the following Web site:
http://oceanexplorer.noaa.gov/explorations/explorations.html

1. List three places in the deep sea visited by ocean explorers within the past three years.
2. Now proceed to this Web site: *http://oceanexplorer.noaa.gov/edu/oceanage/welcome.html.*
   There are many individuals studying the deep sea or involved with work done there. List at least five, and describe their fields of research or work they have done.
3. Describe what your day might be like if you were a marine mammal biologist.
4. In some ways, deep-sea explorers of modern times are similar to historic explorers. They are brave, curious men and women who are at the cutting edge of their field of interest. They are very unique individuals. One of the senior scientists interviewed on the OceanAGE Web page explains the difference between a submarine and a submersible. Find her name and record what she says about this difference.
5. What is the name of the fish ecologist who wanted to be an astronaut until he realized that the ocean was virtually unexplored and the other-worldly creatures that he wanted to see and study were living right here at home?
6. How do you think that exploring the deep sea is similar to exploring outer space?
7. Which ocean explorer traces his interest in ocean science to a vacation with his parents to the Florida Keys when he was five or six and encountered a manatee?
8. There is a big world waiting for you to explore it, and the technology to do so gets better every day. Yesterday's discoveries are today's necessities. Which explorer looks for marine plants and animals that produce chemicals that can be developed into drugs to treat human diseases?
9. As we learn more about Earth's ocean, we realize that even though the ocean is vast, its resources are limited and need protection. Which marine ecologist looks for "sweet spots" in the ocean, places where life is rich and abundant, and then works with governments and nonprofit organizations to secure protection of those resources for future generations?
10. Which ocean explorer was an insect dietician and sonar operator aboard a U.S. Navy submarine before becoming chief electronics technician aboard the NOAA Ship *Okeanos Explorer*?

    Congratulations, Explorers! You have successfully navigated the Deep Sea Explorer Web Quest! Now you are ready for some quiet reflection on what you learned with your colleagues.

Tell your teacher that you are ready to begin Part II: Individual Exploration!

Part II – Individual Explorers Reflections Sheet

1. Reflect and write about differences and similarities between explorers of the past and modern day explorers. What types of hardships do both have in common?

2. Name some places that have been explored in modern times.

3. Name places that were explored during the early history of humans.

4. Name a place that you have explored. What was unique about it that you think another visitor to that site would not have noticed?

5. Name a place that you would like to explore. What do you think you would find there? Why?

6. Why is it important to document your explorations? What is your favorite way to remember your own adventures?

7. List a few of your science and exploration role models (alive or historic) and why they inspire you. On a sheet of notebook paper or on the computer, compose a letter to one of your science and exploration role models. Write something you would want them to know about you and why you consider them an inspiration.

Teacher Answer Key for Part I – Ocean Explorers Web Quest Guide

Welcome, Ocean Explorers! Please proceed to the following Web site:
http://oceanexplorer.noaa.gov/explorations/explorations.html

1. Answers will vary. Possible answers include:
   Gulf of Mexico, Chile, Bermuda, Florida, Arctic, Bahamas, Thunder Bay, Rhode Island, Bonaire, Celebes Sea, Cayman Islands, Kermadec Arc

2. Answers will vary. Possible answers include:
   Dr. Peter Auster, Dr. Amy Baco-Taylor, Dr. Robert Ballard, Dr. Roy Cullimore, Dr. Bob Embley, Dr. Peter Etnoyer, Dr. Randy Keller, Dr. Deborah Kelley, Dr. Kristin Laidre, Mr. John McDonough, Mr. Hugo Marrero, Ms. Catalina Martinez, Dr. Charles Mazel, Dr. Shirley Pomponi, Dr. John K. Reed, Dr. Timothy Shank, Dr. Bob Embley, Dr. Edith Widder

3. Answers will vary. Students will probably take information from the interviews with Dr. Kristin Laidre.

4. Dr. Edith Widder says that the difference between a submarine and a submersible is a submarine has enough power to leave port and come back to port under its own power. A submersible has very limited power reserves so it needs a mother ship that can launch it and recover it.

5. Dr. Peter Auster

6. Answers will vary. Some include:
   Humans would need special equipment to survive and explore there.
   Humans know very little about both places.
   Humans get very excited about the prospect of finding life in both places.

7. Mr. Brian Kennedy

8. Dr. Shirley Pomponi

9. Dr. Peter Etnoyer

10. Mr. Richard Conway

Teacher Answer Key for
Part II – Individual Explorers Reflections Sheet

1. Answers will vary.

   Some Similarities:
   - Funding for both usually comes from an outside source. Explorers do not usually "own" most of the equipment, but the equipment is usually "cutting edge" for the time it is used by the explorers.
   - Exploration is undertaken by brave, curious individuals.
   - Often explorers seek resources that can be obtained from a newly-discovered site (raw materials, medicines, etc.)

   Some Differences:
   - Today, it is common for different countries to work together on exploratory projects; whereas in the past, many countries wanted to explore for the sake of conquering a particular region.
   - Today, it is not uncommon for men and women to explore together; whereas many of the past explorers were men.

   Hardships may include:
   - Funding for their explorations
   - Broken equipment while they are in the field
   - Lack of maps and directions
   - Discomfort while they are exploring extreme environments for long periods of time
   - Finding like-minded individuals to explore with them

2. Answers will vary, but may include: the deep ocean, space, the Arctic, the Antarctic, the Western coast of the United States, etc.

3. Answers will vary, but may include: navigation around the continents, rivers, new passages from one country to another, etc.

4. Answers will vary.

5. Answers will vary.

6. Answers will vary, and may include:
   - To learn from the past, to remember places and people that we meet, so that others can learn from our work, etc.
   - Students may keep journals, scrapbooks, boxes of memories, etc.

7. Answers will vary.

Create a Geocache

Geocaches are hidden containers, usually concealed outdoors, that are the objects of a high-tech treasure hunting game played throughout the world by people equipped with GPS devices. The basic idea is to locate geocaches and then share your experiences online. There are more than 800,000 active geocaches around the world, and a dedicated Web site (*http://www.geocaching.com*) to assist geocaching enthusiasts. For this activity, you will create a geocache for another student group to find, and test your own GPS skills by searching for a geocache created by one of the other groups.

1. **Planning**–Four things are essential to create a geocache:
   - An appropriate container;
   - An appropriate location in which to hide the container;
   - Something to put into the container; and
   - A GPS receiver so you can accurately record the exact location in which your geocache is hidden.

   Typical geocache containers include water bottles, screw-top plastic storage jars, watertight boxes used on boats to protect cameras and cell phones, and ammunition boxes. It's usually a good idea to put the contents of the cache inside a zip-top plastic bag, just in case the container leaks. Label the container with the word "Geocache" and the name of your school, just in case someone finds it who is not part of your class.

   The most important features of a suitable geocache site are that you have permission to use the site for your geocache, and that the site is not located in a dangerous area.

   What you put inside your geocache is up to you (within obvious limits). Most caches include a logbook and pencil so that finders can record their presence. This doesn't make much sense for this activity, however, since found geocaches will be brought back to your class. Other typical items are a welcome note, small toys, games, or playing cards.

   Be sure you understand how to use the GPS receiver before you head out to hide your geocache.
2. **Approval**–Write a brief description of your geocache, including type of container, what the cache will contain, and where it will be hidden. Be sure that you have permission to use the proposed site. Submit the plan to your teacher for approval.
3. **Assembly**–Put your geocache together according to your approved plan.
4. **Into the Field!** –Take your geocache to the location approved by your teacher, and hide it. Take careful notes about the specific location and use your GPS receiver to find the latitude and longitude of the site. Be sure to record latitude and longitude to at least 3 decimal places. If your GPS receiver uses minutes and seconds instead of decimal degrees, record latitude and longitude to at least 0.1 seconds.

   Write the latitude and longitude of your geocache on an index card, along with any clues you think will help to find the geocache. Remember that the idea is to hide the geocache well enough so someone isn't likely to discover it by accident, but not so well that it can't be found at all!
5. **Join a Geocaching Discovery Expedition** Your teacher will give you an index card from another student group that contains the latitude and longitude of a geocache they created, and may also contain some other clues to help you find it. Obtain any last minute instructions from your teacher, double-check that you know how to use your GPS receiver, then launch your expedition to find the geocache!

   Tip: Make a simple sketch map to help keep you oriented as you search. When you start, find your latitude and longitude using your GPS receiver, then make a mark near the center of a piece of paper and write your latitude and longitude near the mark. This is your starting point. Now draw a vertical arrow to show the direction of north. Rotate the paper so that the arrow points toward north. Now compare your starting location with the latitude and longitude of the geocache you are trying to discover. Assuming you are in North America, if the latitude of the geocache is greater than the latitude of your starting location, you need to go farther north. If the latitude of the geocache is less than the latitude of your starting location, you need to go farther south. Similarly, if the longitude of the geocache is greater than the longitude of your starting location, you need to go farther west, and if the longitude of the geocache is less than the longitude of your starting location, you need to go farther east. You can repeat this process whenever you are uncertain about which way to go.

   Keep track of how long it takes you to discover your assigned geocache. When you have found it, bring it back to class for further discussion.

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

Section 3: Key Topic – Climate Change

The Methane Circus

Focus
Methane hydrates, climate change, and the Cambrian Explosion

Grade Level
5-6 (Life Science/Earth Science)

Focus Question
How might methane hydrates have been involved with the Cambrian Explosion?

Learning Objectives
- Students will describe the overall events that occurred during the Cambrian Explosion.
- Students will explain how methane hydrates may contribute to global warming.
- Students will describe the reasoning behind hypotheses that link methane hydrates with the Cambrian explosion.

Materials
- Copies of *Cambrian Explosion Investigation Guide*, one for each student group
- (Optional) Materials for making model fossils
  - Copies of *Model Fossil Construction Guide*, one for each student group
  - Oven-bake modeling clay
  - Dowel, rolling pin or other cylindrical object for rolling out clay
  - Flat-sided toothpicks and a spatula
  - Aluminum baking pan (approximately 4 – 5 inch diameter)
  - Tile grout, plaster, or other water-based filler that sets hard
  - Scissors
  - Latex paint (see Steps 9 and 10 for colors)
  - Brushes
  - Paper towels
  - Corrugated cardboard or poster board
  - Oven (see modeling clay instructions for specific directions)

Audiovisual Materials
- None

Teaching Time
Two or three 45-minute class periods plus time for student research

Ocean Exploration and Research

Seating Arrangement

Groups of four to six students

Maximum Number of Students

32

Key Words and Concepts

Methane hydrate
Cambrian Explosion
Burgess Shale
Fossil
Continental drift

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.

> *"They are grubby little creatures of a sea floor 530 million years old, but we greet them with awe because they are the Old Ones, and they are trying to tell us something."*
>
> *Stephen Jay Gould*

Methane is produced in many environments by a group of Archaea known as the methanogenic Archaea. These Archaea obtain energy by anaerobic metabolism through which they break down the organic material contained in once-living plants and animals. When this process takes place in deep-ocean sediments, methane molecules are surrounded by water molecules, and conditions of low temperature and high pressure allow stable ice-like methane hydrates to form. Scientists are interested in methane hydrates for several reasons. A major interest is the possibility of methane hydrates as an energy source. The U.S. Geological Survey has estimated that on a global scale, methane hydrates may contain roughly twice the carbon contained in all reserves of coal, oil, and conventional natural gas combined. In addition to their potential importance as an energy source, scientists have found that methane hydrates are associated with unusual and possibly unique biological communities. In September, 2001, the Ocean Exploration Deep East expedition explored the crest of the Blake Ridge at a depth of 2,154 m, and found methane hydrate-associated communities containing previously-unknown species that may be sources of beneficial pharmaceutical materials and other useful natural products.

Methane hydrate looks like ice, but as the "ice" melts it releases methane gas which can be a fuel source. Image credit: Gary Klinkhammer, OSU-COAS

While such potential benefits are exciting, methane hydrates may also cause big problems. Although methane hydrates remain stable in deep-sea sediments for long periods of time, as the sediments become deeper and deeper they are heated by the Earth's core. Eventually, temperature within the sediments rises to a point at which the clathrates are no longer stable and free methane gas is released (at a water depth of 2 km, this point is reached at a sediment depth of about 500 m). The pressurized gas remains trapped beneath hundreds of meters of sediments that are cemented together by still-frozen methane hydrates. If the overlying sediments are disrupted by an earthquake or underwater landslide, the pressurized methane can escape suddenly, producing a violent underwater explosion that may result in disastrous tsunamis.

Iceworms *(Hesiocaeca methanicola)* infest a piece of orange methane hydrate at 540 m depth in the Gulf of Mexico. During the Paleocene epoch, lower sea levels could have led to huge releases of methane from frozen hydrates and contributed to global warming. Today, methane hydrates may be growing unstable due to warmer ocean temperatures. Image credit: Ian MacDonald. *http://oceanexplorer.noaa.gov/explorations/06mexico/background/plan/media/iceworms_600.jpg*

The release of large quantities of methane gas can have other consequences as well. Methane is one of the greenhouse gases. In the atmosphere, these gases allow solar radiation to pass through but absorb heat radiation that is radiated back from the Earth's surface, thus warming the atmosphere. A sudden release of methane from deep-sea sediments could increase this greenhouse effect, causing Earth's surface to become significantly warmer.

Methane-induced greenhouse warming has been linked to one of the most striking events in Earth's geologic history. In the summer of 1909, Charles Walcott, head of the Smithsonian Institution, made an amazing discovery in a small limestone quarry 8,000 feet above sea level in the Canadian Rockies: beautifully preserved fossil remains of hundreds of animals that had never been seen before. The Burgess Shale, as the quarry came to be called, turned out to be the record of the "Cambrian Explosion;" a period of geologic history 542 - 488 million years ago during which life on Earth became much more diverse. Many different multicellular animals appeared, including most of the major groups alive today, such as mollusks, arthropods, echinoderms, corals, sponges, and chordates. For the first time, many animals had hard outer skeletons, which eventually became fossilized. Prior to the Cambrian Period, most living organisms were small or microscopic with soft bodies that usually do not form recognizable fossils. In addition to the ancestors of familiar groups, many other animals appeared during the Cambrian Explosion that do not resemble any animals living today.

In 2003, Joseph Kirschvink and Timothy Raub theorized that the Cambrian Explosion might be linked to methane hydrates. According to their hypothesis, Archaea in pre-Cambrian times produced large amounts of methane from decaying organisms in Earth's tropical regions. Methane-rich sediments from tropical areas were carried into polar regions by continental drift. Colder conditions favored methane hydrate formation which created a cap under which methane gas was trapped as the Archaea continued their work. Eventually, continental drift returned the capped methane deposits back toward tropical latitudes where warmer conditions caused methane hydrates to become unstable. Periodically, large volumes of trapped methane were released into the sea and then into the atmosphere resulting in a greenhouse effect and rapid warming. Warmer temperatures stimulated invertebrate metabolism, resulting in rapid evolution of new species. In the words of Kirschvink and Raub, "A methane 'fuse' ignited the Cambrian Evolutionary Explosion."

This activity guides a student investigation into how methane hydrates may have been involved with the Cambrian Explosion, and into some of the animals that appeared during that event.

Learning Procedure

1. To prepare for this lesson:
   - Review introductory information on the NOAA Ship *Okeanos Explorer* at *http://oceanexplorer.noaa.gov/okeanos/welcome.html*. You may also want to consider having students complete some or all of the lesson, *To Boldly Go*. . . .
   - Visit the Smithsonian Institution's Cambrian Explosion Web page (*http://paleobiology.si.edu/burgess/cambrianWorld.html*) and review information about the Burgess Shale Fauna and The Age of Trilobites.
   - Review questions on the *Cambrian Explosion Investigation Guide*.
   - Review procedures on the *Model Fossil Construction Guide*, and gather necessary materials.

2. If you have not previously done so, briefly introduce the NOAA Ship *Okeanos Explorer*, emphasizing that this is the first Federal vessel specifically dedicated to exploring Earth's largely unknown ocean. Lead a discussion of reasons that ocean exploration is important, which should include further understanding of climate change.

   Briefly describe methane hydrates. You may want to use a model of a methane hydrate molecule as part of this discussion (the *Animals of the Fire Ice* lesson includes directions for making this kind of model).

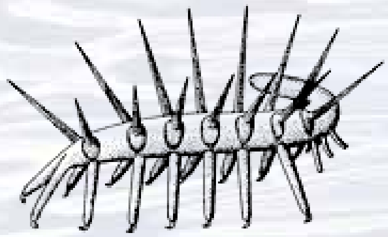
   Tell students that they are going to investigate the possible connections between methane hydrates, global warming, and a dramatic event in the history of life on Earth that took place about 530 million years ago. Assign each student group one of the following animals from the Burgess Shale:

Thaumaptilon	*Canadaspis*	*Olenoides*
Aysheaia	*Perspicaris*	*Naraoia*
Sidneyia	*Waptia*	*Opabinia*
Pikaia	*Leanchoillia*	*Amiskwia*
Canadia	*Hallucigenia*	*Anomalocaris*
Choia	*Haplophrentis*	*Wiwaxia*
Ottoia	*Marrella*	

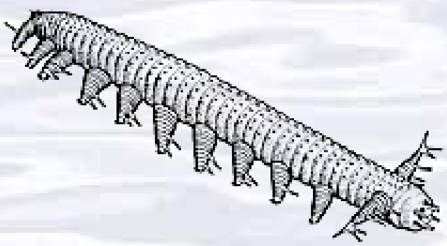
   Provide each student group with a copy of the *Cambrian Explosion Investigation Guide*. You may want to provide the link to the Smithsonian Institution's Burgess Shale Fossil Specimens Web page (*http://paleobiology.si.edu/burgess/burgessSpecimens.html*).

3. Lead a discussion of students' responses to questions on the *Guide*, and have each group present information about their assigned animal.
   a. The Cambrian Explosion was a geologic period 542 - 488 million years ago during which a great diversity of multicellular animals appeared. Most of the major animal phyla alive today appeared during this period, as well as other animals that do not resemble any animals living today.
   b. The Burgess Shale is a rock formation in the Canadian Rockies that contains fossils of many animals that appeared during the Cambrian Explosion. These fossils are unusually well-preserved and show fine details of soft parts as well as shells and similar hard structures. While many of the Burgess Shale fossils appear to be early ancestors of modern animals, others do not seem related to any living forms and reasons for their disappearance are not known.
   c. Methane hydrates are molecules of methane gas surrounded by a lattice of frozen water molecules, and are formed under conditions of high pressure and cold temperature in the deep ocean (methane hydrates are also found in some areas of arctic permafrost).
   d. Methane is a greenhouse gas. If methane hydrates become unstable due to high temperatures or mechanical disruption (*e.g.*, earthquakes) large quantities of methane gas can be released to the atmosphere where they intensify the greenhouse effect. Heat that would otherwise be radiated into space is retained by the greenhouse effect, and the result is higher temperatures in the atmosphere and on Earth's surface.
   e. In addition to the Kirschvink/Raub theory discussed above,
      - Increasing concentrations of oxygen in Earth's atmosphere and ocean may have allowed larger animals to develop;

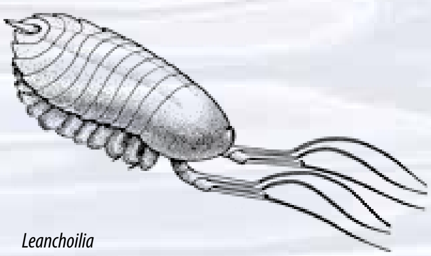
Sample illustrations from the Smithsonian Institution's Web site



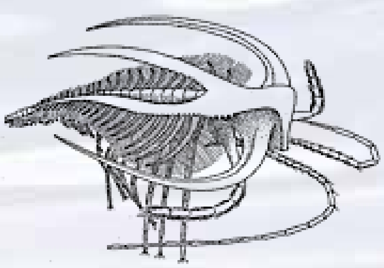
Hallucigenia



Aysheaia



Leanchoilia



Marrella

http://paleobiology.si.edu/burgess/burgessSpecimens.html

- A mass extinction event preceding the Cambrian Period may have eliminated competing organisms and allowed new species to evolve and become successful;
- The appearance of predation as a means of obtaining food might have created new ecological roles for new species, as well as making shells and other forms of armor an evolutionary advantage; more animals with more hard parts would have increased the likelihood that recognizable fossils could be formed.

Notes on Burgess Shale fauna

[*All images and pronunciations can be found on the Smithsonian Institution's Burgess Shale Fossil Specimens Web page* (*http://paleobiology.si.edu/burgess/burgessSpecimens.html*)]

Thaumaptilon – a sea pen, similar to sea pen species alive today; the animal resembles a leaf, attached to the seafloor by a structure called a hold-fast; relatively large for Cambrian animals, up to eight inches long; modern sea pens are colonial soft corals, and the surface of *Thaumaptilon* is covered on one side by tiny spots that may have been individual coral polyps; probably fed on plankton and particulate material. Phylum: Cnidaria

Aysheaia – nicknamed "velvet worm;" ten pairs of stubby tapered appendages; spines and grasping arms near the head; largest specimens are slightly over two inches long; thought to be a parasite living on sponges or a sponge predator, since *Aysheaia* fossils are often found with sponge remains. Phylum: Onychophora

Sidneyia – segmented body and tail resembling modern arthropods; two to five inches long; probably a predatory bottom-feeder that consumed molluscs, small crustaceans, and trilobites. Phylum: Arthropoda

Pikaia – elongated, flattened body with a central notochord and expanded tail fin; average length about one and one-half inches; probably swam eel-like near the seafloor, possibly feeding on particulate material. Phylum: Chordata

Canadia – worm-like; short appendages covered with stiff bristles could be used for swimming or walking; one to two inches long; its gut could be turned inside out to form a feeding organ; may have been a carnivore or scavenger. Phylum: Annelida

Choia – small, thin disc-shaped sponge with spines radiating from the middle of the body; about one inch in diameter; filter-feeder. Phylum: Porifera

Ottoia – a burrowing worm similar to modern priapulid worms; one to six inches long; carnivorous predator, possibly cannibalistic. Phylum: Priapulida

Canadaspis – crustacean-like with segmented body, walking legs, and head appendages; about one inch long; bottom-feeder. Phylum: Arthropoda

Perspicaris – a bivalved arthropod, with two sides of the carapace joined by a hinged joint along the back; about one inch long; feeding habits uncertain, may have been a swimmer or a bottom feeder. Phylum: Arthropoda

Waptia – a bivalved arthropod; about three inches long; capable of swimming but probably was a sediment feeder. Phylum: Arthropoda

Leanchoillia – an arthropod with conspicuous head appendages; often described as blind, but recent reports suggest that delicate (and consequently, rarely preserved) stalked eyes were present as well as light sensitive ocelli that are inconspicuous in most specimens; about two inches long; possibly carnivorous. Phylum: Arthropoda

Hallucigenia – elongated body with paired appendages on the lower surface and sharp spines along the back; slightly more than one inch long; probably a scavenger. Phylum: possibly Onychophora

Haplophrentis – long, flat-bottomed, conical shell with a small lid (operculum) closing the front end, and two curved appendages sticking out sideways at the front; one-tenth to one and one-quarter inches long; fed on organic material in bottom mud. Phylum: possibly Mollusca

Marrella – heart-shaped arthropod, with two pairs of large spines curved from the head back over the body; 20 body segments with long, thin appendages; two pairs of antennae on head; one-tenth to three-quarters inch long; possibly carnivorous and/or particulate feeder. Phylum: Arthropoda

Olenoides – a trilobite with smooth head shield, thorax with seven segments, and short tail; long, curved antennae; legs with spines used for grasping prey; up to four inches long; carnivorous predator and scavenger. Phylum: Arthropoda

Naraoia – A trilobite with two body shields covering the head and thorax; up to one and one-half inch long; carnivorous predator and scavenger. Phylum: Arthropoda

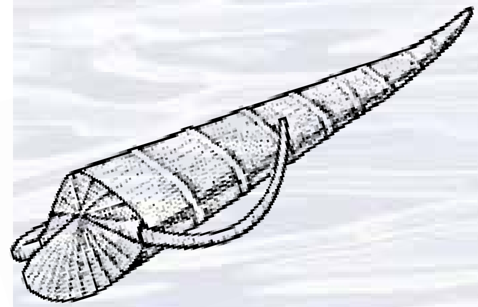
Opabinia – segmented animal with five eyes, and a long, flexible feeding organ with grasping spines; lobe-shaped appendages on the side of each segment; possibly carnivorous; up to four inches long including the feeding organ. Phylum: unknown

Amiskwia – elongated swimming animal; head with two prominent tentacles; body with stubby side fins; flattened tail; up to one inch long; feeding habits unknown. Phylum: unknown

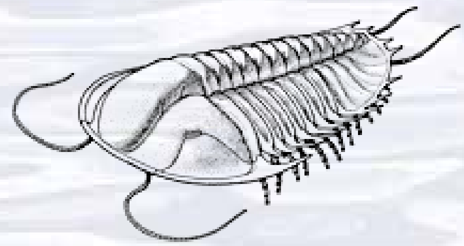
Anomalocaris – the T-rex of the Burgess Shale; large eyes, muscular swimming lobes on each side of a flattened body; large grasping limbs in front for holding prey; mouth like a garbage disposal on underside surrounded by sharp teeth; up to three feet long, some specimens from China up to six feet long; carnivorous. Phylum: unknown

Wiwaxia – oval-shaped body, upper surface covered with hard plates; two rows of long spines along the back; mouth with two rows of teeth on bottom

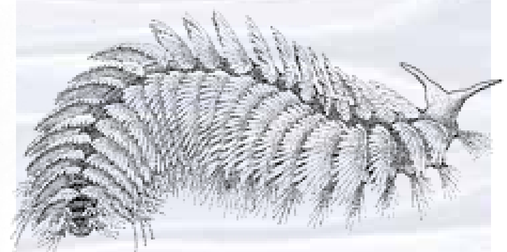
Sample illustrations from the Smithsonian Institution's Web site



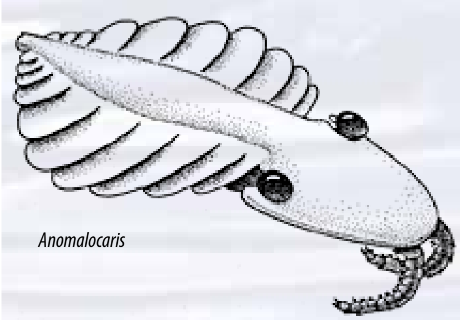
Haplophrentis



Olenoides



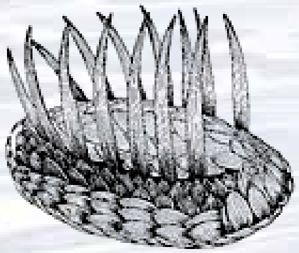
Canadia



Anomalocaris

http://paleobiology.si.edu/burgess/burgessSpecimens.html

Sample illustrations from the Smithsonian Institution's Web site



Wiwaxia

http://paleobiology.si.edu/burgess/burgessSpecimens.html

Methane gas hydrate forming below a rock overhang at the seafloor on the Blake Ridge diapir. This image, taken from the DSV *Alvin* during the NOAA/OER Deep East Expedition in 2001, marked the first discovery of gas hydrate at the seafloor on the Blake Ridge. Methane bubbling out of the seafloor below this overhang quickly "freezes," forming this downward hanging hydrate deposit, dubbed the "inverted snowcone." Image credit: NOAA.
http://oceanexplorer.noaa.gov/explorations/03windows/background/plan/media/hydrate2.html

This mother polar bear and two cubs were spotted leaping between ice floes early in the cruise. Image credit: NOAA.
http://oceanexplorer.noaa.gov/explorations/02arctic/logs/aug25/media/bears_three.html

surface; up to two inches long; bottom feeder, possibly carnivorous. Phylum: unknown

4. (Optional) Have your students construct a model fossil of their assigned animal, following directions on the *Model Fossil Construction Guide*.

The BRIDGE Connection

www.vims.edu/bridge/ – Enter "paleontology" in the Search box for links to resources about geology and paleontology.

The "Me" Connection

Read the quotation from Stephen Jay Gould at the beginning of the Background section. Have students write a short essay on what the "Old Ones" might be trying to tell us.

Connections to Other Subjects

English/Language Arts, Fine Arts

Assessment

Students' responses to *Investigation Guide* questions and class discussions provide opportunities for evaluation.

Extensions

1. Follow events aboard the *Okeanos Explorer* at *http://oceanexplorer.noaa.gov/okeanos/welcome.html*.
2. Have students research other events in the history of life on Earth that have been linked to methane hydrates.

Other Relevant Lesson Plans from the Ocean Exploration Program

(All of the following Lesson Plans are targeted toward Grades 5-6)

The Big Burp: A Bad Day in the Paleocene
(from the 2003 Windows to the Deep Expedition)
http://oceanexplorer.noaa.gov/explorations/03windows/background/education/media/03win_badday.pdf
Focus: Global warming and the Paleocene extinction (Earth Science)
Students will describe the overall events that occurred during the Paleocene extinction event, describe the processes that are believed to result in global warming, and infer how a global warming event could have contributed to the Paleocene extinction event.

Polar Bear Panic! (from the 2002 Arctic Exploration Expedition)
http://oceanexplorer.noaa.gov/explorations/02arctic/background/education/media/arctic_polarbears.pdf
Focus: Climate change in the Arctic Ocean (Earth Science)
Students will identify the three realms of the Arctic Ocean and describe the relationships between these realms; graphically analyze data on sea ice cover in the Arctic Ocean and recognize a trend in these data; and discuss possible causes for observed trends in Arctic sea ice and infer the potential impact of these trends on biological communities in the Arctic.

The Ocean Unicorn (from the 2006 Tracking Narwhals in Greenland Expedition)
http://oceanexplorer.noaa.gov/explorations/06arctic/background/edu/media/unicorn.pdf
Focus: Narwhals (Life Science)
Students will describe key elements of the life history and ecology of narwhals, including overall morphology, preferred habitat, geographic range, and feeding habits; and identify and explain three possible explanations for the apparent decline in the size of narwhal populations.

The 2006 Tracking Narwhals in Greenland Expedition used satellite-linked time-depth-temperature recorders to track whale movements, diving behavior, and ocean temperature structure during the fall narwhal migration from north Greenland to Baffin Bay. This information is needed to help understand how Arctic climate change may affect the deep-ocean thermohaline circulation, sometimes known as the "global conveyor belt." Image credit: Mads Peter Heide-Jorgensen.
http://oceanexplorer.noaa.gov/explorations/06arctic/background/hires/male_narwhals_hires.jpg

Other Resources

See page 217 for Other Resources.

Next Generation Science Standards

Lesson plans developed for Volume 1 are correlated with *Ocean Literacy Essential Principles and Fundamental Concepts* as indicated in the back of this book. Additionally, a separate online document illustrates individual lesson support for the Performance Expectations and three dimensions of the Next Generation Science Standards and associated Common Core State Standards for Mathematics and for English Language Arts & Literacy. This information is provided to educators as a context or point of departure for addressing particular standards and does not necessarily mean that any lesson fully develops a particular standard, principle or concept. Please see: *http://oceanexplorer.noaa.gov/okeanos/edu/collection/wdwe_ngss.pdf.*

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:
oceanexeducation@noaa.gov

For More Information

Paula Keener, Director, Education Programs
NOAA Office of Ocean Exploration and Research
Hollings Marine Laboratory
331 Fort Johnson Road, Charleston SC 29412
843.762.8818 843.762.8737 (fax)
paula.keener-chavis@noaa.gov

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Cambrian Explosion Investigation Guide

Long before dinosaurs, Earth's ocean contained strange animals that are unlike anything living today. Many of these animals first appeared during an event known as the Cambrian Explosion. Your assignment is to investigate the Cambrian Explosion, and find out more about at least one of the animals that appeared during this event. In addition to the references and resources provided by your teacher, key word searches on the Internet will produce all the information you need to answer the following questions:

1. What and when was the Cambrian Explosion?

2. What is the Burgess Shale?

3. What are methane hydrates?

4. How might methane hydrates be involved with global warming?

5. What are some theories about what might have caused the Cambrian Explosion?

The following questions refer to the animal assigned by your teacher.

6. What did your animal look like? [Hint: Use your animal's name in an image search on the Internet and copy the best picture you can find]

7. How big was your animal?

8. What did your animal probably eat?

9. To what phylum does your animal belong?

Model Fossil Construction Guide

NOTE: These directions are adapted from "Make a fossilized Dinosaur Egg;" http://www.instructables.com/id/Make_a_fossilized_Dinosaur_Egg/

Materials

- Oven-bake modeling clay
- Dowel, rolling pin or other cylindrical object for rolling out clay
- Flat-sided toothpicks and a spatula
- Aluminum baking pan (approximately 4 – 5 inch diameter)
- Tile grout, plaster, or other water-based filler that sets hard
- Scissors
- Latex paint (see Steps 9 and 10 for colors)
- Brushes
- Paper towels
- Corrugated cardboard or poster board
- Oven (see modeling clay instructions for specific directions)

Procedure

1. Find several images of your assigned animal. The Smithsonian Institution's Burgess Shale Fossil Specimens Web page (*http://paleobiology.si.edu/burgess/burgessSpecimens.html*) has line drawings as well as photographs of actual fossils. You may also want to do an Internet search for images of your animal to see other views. You want to get a good idea of what the animal probably looked like when it was alive, and then imagine how it would look if it were lying on very soft sediment. Obviously, most animals will appear differently depending upon whether they are lying on their back, side or front. Choose the most interesting view for your fossil.

2. Roll out a piece of modeling clay until you have a flat disk about 1/16-inch thick, and a diameter that is at least twice the maximum size of your animal (for example, if the maximum length of your animal is one inch, you should have a disk with a diameter of at least two inches). It's better to have a piece of clay that's too big than one that's too small. If your animal seems too small to make a good model, then make a model of the very rare GIANT form of this animal (in other words, just pretend the animal was bigger than presently known fossils suggest). If your animal is *Anomalocaris*, you will have to make a very rare DWARF fossil.

3. With a toothpick, outline the major pieces of your animal that will be visible on your fossil. Carefully cut out each piece with the flat side of a toothpick. Lift the pieces with a spatula, or one or two toothpicks for small pieces and place them on an aluminum baking pan.

4. Follow your teacher's instructions for baking the pieces of your fossil.

5. Cut a piece of corrugated cardboard or poster board so there will be at least one inch on all sides of your fossil when it is completed.

6. Mix grout, plaster, or filler according to instructions on the package so that you have a mix that is flexible but stiff enough not to run off of a flat piece of cardboard.

7. Make a puddle of grout, plaster or filler on the piece of cardboard you cut in Step 5. Arrange the pieces of your fossil on the puddle, and push them slightly down into the puddle before the material hardens.

8. When the filler is almost dry, but before it is completely hard, scrape or brush some of the filler away from the hardened clay pieces until enough of the fossil is revealed.

9. When the filler is completely dry and hard, spray or brush paint over the entire surface of your model. Gray, brown, or reddish colors are best, depending upon the type of rock that surrounds your fossil.

10. Thin a darker color of paint with some water. When the first layer of paint is completely dry, brush the thinned paint onto the model, then wipe most of it off with a paper towel. The thinned paint will fill in cracks and lower portions of your model, enhancing the contrast and making the model look old. After the model is completely dry, you can repeat this step again with other colors until you have the effect you want.

Your model fossil is finished!

Notes:

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

Section 3:
Key Topic – Climate Change

Where Have All the Glaciers Gone?

(adapted from the 2005 Hidden Ocean Expedition)

Focus

Arctic climate change

Grade Level

7-8 (Earth Science)

Focus Question

How is the climate of the Arctic region changing, and what impacts are expected from these changes?

Learning Objectives

- Students will describe how climate change is affecting sea ice, vegetation, and glaciers in the Arctic region.
- Students will explain how changes in the Arctic climate can produce global impacts, and will provide three examples of such impacts.
- Students will explain how a given impact resulting from climate change may be considered "positive" as well as "negative," and will provide at least one example of each.

Materials

- Copies of *Arctic Climate Change Investigation Guide*, one copy for each student or student group
- (Optional) Copies of *Arctic Climate Impact Assessment (ACIA) Highlights* and *Climate Change, the Arctic and the United Kingdom: Directions for Future Research*; see Learning Procedure, Step 1
- (Optional) Materials for constructing photocubes; the following quantities are for one photocube; kits of these materials are available from *http://www.chicaandjo.com/ourstore/*
  - 8 - 1.5" wooden cubes
  - 8 - 3" x 3" photos printed on thin photo-quality paper such as HP Bright White Inkjet Paper
  - 2 - 3" x 6" photos, printed on paper described above
  - 2 - 8" x 11" sheets of double-sided tape ("red liner tape")
  - Black felt tip marker
  - Scissors or paper trimmer
  - Sandpaper, 150 grit or finer

Ocean Exploration and Research

Audiovisual Materials

- None

Teaching Time

One or two 45-minute class periods, plus time for student research

Seating Arrangement

Classroom style if students are working individually, or groups of two to four students

Maximum Number of Students

No limit, if students work individually

Key Words and Concepts

Arctic Ocean
Canada Basin
Climate change
Greenhouse gas
Permafrost
Sea ice
Sea level
Sympagic
Polynya

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.

Within the world scientific community, there is a broad consensus that:

- Global warming is unequivocal and primarily human-induced.
- Climate changes are underway in the United States and are projected to grow.
- Widespread climate-related impacts are occurring now and are expected to increase.
- Climate change will stress water resources.
- Crop and livestock production will be increasingly challenged.
- Coastal areas are at increasing risk from sea-level rise and storm surge.
- Risks to human health will increase.
- Climate change will interact with many social and environmental stresses.
- Thresholds will be crossed, leading to large changes in climate and ecosystems.
- Future climate change and its impacts depend on choices made today. (Karl, Melillo, and Peterson, 2009).

The consensus on these points is supported by a huge amount of data from many places on Earth. A brief summary of some of the key data is provided in Diving Deeper, starting on Page 21; for more details, see "Other Resources," page 217.

During the 20th century, Earth's average surface temperature rose by approximately 0.6°C (1.08°F). Since 2000, the average surface temperature has increased by an additional 0.14°C (0.25°F). The word "average" is very important, because some parts of Earth (including the southeastern United States and parts of the North Atlantic) have cooled slightly during this period. The greatest warming has been observed in Eurasia and North America between latitude 40° and 70° N. While these changes may seem small, they happened much more quickly than any similar change in the last 10,000 years (U.S. Global Change Research Program. 2009).

Some confusion about the warming trend has recently been generated by assertions that Earth's temperature has been dropping for the last ten years. These statements are based on the fact that 1998 was abnormally hot due to the strongest El Nino event in the last century. The years following 1998 were indeed cooler than 1998, but the long-term trend still shows continued warming. There are many factors that affect global temperatures in a single year, and it is not surprising that one year might be cooler than the preceding year. But the global warming trend is a matter of decades, not just one or two years. The long-term trend is clear: The 1980's, 1990's and 2000's were each warmer than all earlier decades since reliable records began in 1880, and each of the last three decades set a new and statistically significant record (Arndt, Baringer, and Johnson, 2010). The average global temperatures in 2005 and 2010 were the warmest ever recorded.

These changes are particularly dramatic in the Arctic, where temperature is increasing at nearly twice the rate of increase occurring in the rest of the world. The Arctic Ocean is the most inaccessible and least-studied of all the Earth's major oceans. Its deepest parts (5,441 m; 17,850 ft), known as the Canada Basin, are particularly isolated and unexplored because until recently they were covered by ice for the entire year. To a large extent, the Canada Basin is also geographically isolated by the largest continental shelf of any ocean basin (average depth about 50 meters) bordering Eurasia and North America. The Chukchi Sea provides a connection with the Pacific Ocean via the Bering Strait, but this connection is very narrow and shallow, so most water exchange is with the Atlantic Ocean via the Greenland Sea. This isolation makes it likely that unique species have evolved in the Canada Basin.

The black and white photograph of Muir Glacier was taken on August 13, 1941; the color photograph was taken from the same vantage on August 31, 2004. Between 1941 and 2004 the glacier retreated more than 12 kilometers (seven miles) and thinned by more than 800 meters (875 yards). Ocean water has filled the valley, replacing the ice of Muir Glacier; the end of the glacier has retreated out of the field of view. The glacier's absence reveals scars where glacier ice once scraped high up against the hillside. In 2004, trees and shrubs grew thickly in the foreground, where in 1941 there was only bare rock. Image credit: National Snow and Ice Data Center, W. O. Field, B. F. Molnia.
http://nsidc.org/data/glacier_photo/repeat_photography.html

The 2002 Ocean Exploration expedition to the Arctic Ocean focused specifically on the biology and oceanography of the Canada Basin. Three distinct biological communities were explored:

- The Sea-Ice Realm, which includes plants and animals that live on, in, and just under the ice that floats on the ocean's surface;
- The Pelagic Realm, which includes organisms that live in the water column between the ocean surface and the bottom; and
- The Benthic Realm, which is composed of organisms that live on the bottom, including sponges, bivalves, crustaceans, polychaete worms, sea anemones, bryozoans, tunicates, and ascidians.

These realms are linked in many ways, and food webs in each realm interact with those of the other realms.

Sea ice provides a complex habitat for many species that are called sympagic, which means "ice-associated." The ice is riddled with a network of tunnels called brine channels that range in size from microscopic (a few thousandths of a millimeter) to more than an inch in diameter. Diatoms and algae inhabit these channels and obtain energy from sunlight to produce biological material through photosynthesis (a process called "primary production"). Bacteria, viruses, and fungi also inhabit the channels, and together with diatoms and algae provide an energy source (food) for flatworms, crustaceans, and other animals. In the spring, melting ice releases organisms and nutrients that interact with the ocean water below the ice. Large masses of algae form at the ice-seawater interface and may form filaments several meters long. On average, more than 50% of the primary production in the Arctic Ocean comes from single-celled algae that live near the ice-seawater junction.

The ice-seawater interface is critical to the polar marine ecosystem, providing an energy source for many organisms, as well as protection from predators. Arctic cod use the interface area as nursery grounds, and in turn provide an important food source for many marine mammals and birds. The ice also provides migration routes for polar bears. In the spring, the solid ice cover breaks into floes of pack ice that can transport organisms, nutrients, and pollutants over thousands of kilometers. Partial melting of sea ice during the summer months produces ponds on the ice surface called polynyas that contain their own communities of organisms. Because only 50% of this ice melts in the summer, ice floes can exist for many years and can reach a thickness of more than 2 m (6 ft).

When sea ice melts, more sunlight enters the sea, and algae grow rapidly since the sun shines for 24 hours a day during the summer. These algae provide energy for a variety of pelagic organisms, including floating crustaceans and jellyfishes called zooplankton, which are the energy source for larger pelagic animals including fishes, squids, seals, and whales. When pelagic organisms die, they settle to the ocean bottom, and become the energy source for inhabitants of the benthic realm. These animals, in turn, provide energy for bottom-feeding fishes, whales, and seals.

The 2005 Hidden Ocean Expedition focused on additional explorations of these realms. A key objective was to help establish a marine life inventory and map the physical and chemical environment of the sea-ice, pelagic, and benthic ecosystems of the Canada Basin. This kind of exploration is increasingly urgent, because the Arctic environment is changing at a dramatic rate. One visible result is rapid loss of glaciers and sea ice. Less visible are the impacts on living organisms that depend upon glaciers and sea ice for their habitat. Melting sea ice can also have direct effects on human communities. The Greenland Ice Sheet, for example, holds enough water to raise global sea levels by as much as 7 meters. Sea level increases at this magnitude would be sufficient to flood many coastal cities, including most of the city of London.

This lesson guides a student investigation into some of the impacts that are expected to result from a warmer Arctic climate.

Learning Procedure

1. To prepare for this lesson:
   - Review introductory information on the NOAA Ship *Okeanos Explorer* at *http://oceanexplorer.noaa.gov/okeanos/welcome.html*. You may also want to consider having students complete some or all of the lesson, *To Boldly Go*. . . .
   - To become more familiar with the 2005 Hidden Ocean expedition, you may want to visit the expedition's Web page (*http://oceanexplorer.noaa.gov/explorations/05arctic/welcome.html*) for an overview of the expedition and background essays.
   - Review *ACIA Highlights* and *Climate Change, the Arctic and the United Kingdom: Directions for Future Research* (*http://amap.no/acia/Highlights.pdf* and *http://www.scribd.com/doc/42980/Arctic*, respectively). You may want to download and copy these documents if students will not be using the Internet to complete their assignment.
   - Review questions on the *Arctic Climate Change Investigation Guide*.
   - Decide whether you want to have student groups make photocubes to show

changes in glaciers. These objects can be used very effectively as visual aids for student presentations about climate change to other audiences (other groups of students, parents, etc.); see Learning Procedure, Step 4 and *Photocube Construction Guide*.

2. If you have not previously done so, briefly introduce the NOAA Ship *Okeanos Explorer*, emphasizing that this is the first Federal vessel specifically dedicated to exploring Earth's largely unknown ocean. Lead a discussion of reasons that ocean exploration is important, which should include further understanding of climate change. Show students a graph of global surface temperature trends (e.g.,*http://www.pewclimate.org/docUploads/images/global-surface-temp-trends.gif*), and ask them if they can recognize any trend in the data. Data are variable prior to about 1910, but thereafter there is a distinct trend of increasing temperature. Ask students whether the drop in surface temperature between 1935 and 1945 cancels out the overall trend. Students should realize that year-to-year fluctuations do not negate trends over longer periods of time.

   Briefly review the geography of the Arctic Ocean, highlighting the location of the Canada Basin and the activities of the 2005 Hidden Ocean expedition. Do not discuss Arctic climate change at this point. Tell students that their assignment is to answer questions on the *Arctic Climate Change Investigation Guide*. Provide copies of the reports cited above, or direct students to the appropriate Web sites.

3. Lead a brief discussion of students' responses to worksheet questions. The discussion should include the following points:
   a. The extent of Arctic sea ice has decreased by 5% in the last 20 years (8% in the last 30 years). In some areas, sea ice thickness has decreased by 40%.
   b. The Arctic climate is warming more rapidly than elsewhere on Earth. Reasons for this include:
      – Reduced surface reflectivity caused by snow- and ice-melt allows more solar energy to be absorbed by Earth's surface;
      – More of the trapped energy goes directly to warming rather than to providing heat for evaporation;
      – Less heat is required to warm the atmosphere over the Arctic because the Arctic atmosphere is thinner than elsewhere;
      – With less sea ice, the heat absorbed by the ocean in summer is more easily transferred to the atmosphere in winter; and
      – Changes in atmospheric and oceanic circulation can cause heat to be retained in the Arctic region.
   c. Ice in the Greenland Ice Sheet contains enough water to raise global sea levels by 7 meters.
   d. Sea ice is melting at an increasing rate over the Greenland Ice Sheet.
   e. Global average sea level has risen by about 8 cm during the past 20 years.
   f. The melting trend on the Greenland Ice Sheet was interrupted in 1992 when ash from the Mt. Pinatubo volcano reduced the amount of sunlight reaching the Earth's surface, resulting in a short-term global cooling event.
   g. Changes in snow, ice, and vegetation lower the reflectivity of Arctic land and ocean surfaces, causing more solar energy to be absorbed and thus accelerate global warming.
   h. Rising sea level and reduced sea ice allow stronger waves and storm surges to reach shore, increasing coastal erosion; particularly where melting permafrost has weakened the soil structure.

i. The Arctic is believed to hold about one-fourth of the world's undiscovered petroleum resources.
j. While warmer temperatures were the trend for most of the Arctic region between 1966 and 1995, a cooling trend took place in the northernmost portions of the Arctic during this period.
k. At present, primary Arctic industries are fishing, timber production, mineral mining, and petroleum production. In addition, tourism and renewable energy are growing in importance.
l. Ultraviolet radiation in the Arctic is increasing due to depletion of stratospheric ozone.
m. Glaciers are shrinking throughout the Arctic region.
n. Woody plants and scrub vegetation are becoming more widely distributed and are replacing tundra-type vegetation.
o. Permafrost is thawing at an increasing rate, causing unstable ground conditions that damage roads, pipelines, and building foundations.
p. Travel across ice is being restricted because thinning ice is less stable.
q. Warmer climates could cause significant quantities of water, methane, and carbon dioxide to be released from the Arctic. The result of these releases would be rising sea level, and increasingly warm temperatures due to the "greenhouse effect" of methane and carbon dioxide.
r. Because many activities in the Arctic are presently hampered by sea ice, reduction in the extent of sea ice could be a stimulus to commercial development. Increased economic development could have serious negative impacts on wilderness areas, environmental quality, and indigenous cultures.
s. Major reductions in Arctic sea ice could make the Arctic Ocean the shortest sea route between North America and Asia.

Students should recognize that whether an impact is "positive" or "negative" often depends upon an individual's perspective. If you like polar bears and seals, or belong to an indigenous Arctic culture, then many of the changes resulting from a warmer Arctic climate are devastating. On the other hand, if you are involved in international shipping or petroleum industries, then the same changes could be seen as providing new opportunities.

Students should also understand that while greenhouse gas emissions from human activities are not the sole cause of climate change, they play a significant role in these changes (the ACIA says these emissions "have now become the dominant factor"). Be sure students realize that atmospheric concentrations of greenhouse gases will remain elevated for centuries even if emissions were completely eliminated, but the rate and extent of warming can be reduced if future emissions are sufficiently lowered.

4. (Optional) Tell students that communication is an essential element of the scientific process. Visual aids, particularly if they are three-dimensional, can greatly enhance the interest of an audience and make presentations much more memorable. You may choose to have your students create photocubes and present what they have learned to other classes or civic groups. Provide each student or student group with a copy of the *Photocube Construction Guide*, and materials listed in the *Guide*. You may also want to suggest the following Web site which contains images of glaciers that show changes caused by a warmer climate: *http://nsidc.org/cgi-bin/glacier_photos/glacier_photo_search.pl?collection=repeat*. This link opens the Search page for the National Snow and

Ice Data Center's collection of repeat glacier photography. Click the "Search" button and a new page will open showing thumbnails of the photographs.

The BRIDGE Connection

www.vims.edu/bridge/ – Scroll over "Ocean Science Topics," then click "Atmosphere" for links to resources atmosphere and climate change.

The "Me" Connection

Have students write a brief essay describing how they might be personally affected by climate change in the Arctic.

Connections to Other Subjects

Biology, English/Language Arts, Geography

Assessment

Students' responses to *Investigation Guide* questions and class discussions provide opportunities for evaluation.

Extensions

1. Follow events aboard the *Okeanos Explorer* at *http://oceanexplorer.noaa.gov/okeanos/welcome.html*.
2. Visit *http://earthednet.org/Ocean_Materials/Mini_Studies/Index.html* for links to Mini Studies from Earth Education Online, including Greenhouse Gases and Human Influenced Climate Change.

Other Relevant Lesson Plans from the Ocean Exploration Program

(All of the following Lesson Plans are targeted toward Grades 7-8)

Frozen Out (from the 2006 Tracking Narwhals in Greenland Expedition)
http://oceanexplorer.noaa.gov/explorations/06arctic/background/edu/media/frozenout.pdf

Focus: Impacts of climate change on Arctic predators (Life Science/Earth Science)

Students will explain the concepts of indicator species and microhabitats; compare and contrast average regional conditions with site-specific conditions; and explain at least three examples of the impacts of climate change on top predators in the Arctic.

Climate, Corals, and Change (from the North Atlantic Stepping Stones 2005 Expedition)
http://oceanexplorer.noaa.gov/explorations/05stepstones/background/education/ss_2005_climate.pdf

Focus: Paleoclimatology (Physical Science)

Students will explain the concept of "paleoclimatological proxies" and describe at least two examples, describe how oxygen isotope ratios are related to water temperature, and interpret data on oxygen isotope ratios to make inferences about the growth rate of deep-sea corals. Students will also define "forcing factor", describe at least three forcing factors for climate change and discuss at least three potential consequences of a warmer world climate.

Meet the Arctic Benthos (from the 2002 Arctic Exploration Expedition)
http://oceanexplorer.noaa.gov/explorations/02arctic/background/education/media/arctic_benthos.pdf

Focus: Benthic invertebrate groups in the Arctic Ocean (Life Science)

Students will recognize and identify major groups found in the Arctic benthos, describe common feeding strategies used by benthic animals in the Arctic Ocean, and discuss relationships between groups of animals in Arctic benthic communities. Students will also discuss the importance of diversity in benthic communities.

Other Resources

See page 217 for Other Resources.

Next Generation Science Standards

Lesson plans developed for Volume 1 are correlated with *Ocean Literacy Essential Principles and Fundamental Concepts* as indicated in the back of this book. Additionally, a separate online document illustrates individual lesson support for the Performance Expectations and three dimensions of the Next Generation Science Standards and associated Common Core State Standards for Mathematics and for English Language Arts & Literacy. This information is provided to educators as a context or point of departure for addressing particular standards and does not necessarily mean that any lesson fully develops a particular standard, principle or concept. Please see: *http://oceanexplorer.noaa.gov/okeanos/edu/collection/wdwe_ngss.pdf.*

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:
oceanexeducation@noaa.gov

For More Information

Paula Keener, Director, Education Programs
NOAA Office of Ocean Exploration and Research
Hollings Marine Laboratory
331 Fort Johnson Road, Charleston SC 29412
843.762.8818   843.762.8737 (fax)
paula.keener-chavis@noaa.gov

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Arctic Climate Change Investigation Guide

The following questions are intended to introduce you to some basic information about climate change in the Arctic.

a. What has happened to Arctic sea ice in the last 20 years?

b. How do climate trends in the Arctic compare with similar trends elsewhere on Earth?

c. How could water in the Greenland Ice Sheet affect global sea levels?

d. What is happening to sea ice in the Greenland Ice Sheet?

e. What has happened to global average sea level during the past 20 years?

f. What happened in 1992 that interrupted the pattern of change on the Greenland Ice Sheet?

g. How could changes in snow, ice, and vegetation in the Arctic affect global warming?

h. How could a warmer Arctic climate affect coastal erosion?

i. How significant are Arctic petroleum reserves?

j. Are climatic trends the same for the entire Arctic region?

k. At present, what are the major industries in the Arctic?

l. What is happening to ultraviolet radiation levels in the Arctic region?

m. What is happening to glaciers in the Arctic region?

n. How are vegetation patterns changing in the Arctic region?

o. How are changes in permafrost affecting human activities?

p. What changes are taking place in travel across Arctic ice?

q. Warmer climates could cause significant releases of what substances from the Arctic. What might be some of the consequences of these releases?

r. What positive and negative impacts might result from a reduction in Arctic sea ice?

s. What changes in sea transportation might result from major reductions in Arctic sea ice?

Photocube Construction Guide

These directions are adapted from "Create your own "magic" folding wooden photo cubes" (*http://www.chicaandjo.com/2008/05/08/magic-folding-wooden-photo-cubes/*), and are used with permission.

Materials

- 8 - 1.5" wooden blocks
- 8 - 3" x 3" photos printed on thin photo-quality paper such as HP Bright White Inkjet Paper*
- 2 - 3" x 6" photos, printed on paper described above*
- 2 - 8" x 11" sheets of double-sided tape ("red liner tape")
- Black felt tip marker
- Scissors or paper trimmer
- Sandpaper, 150 grit or finer

*Print several images on each page leaving space between them to allow for margins (Step 2).

1. Locate images of glaciers that you want to use for your photocube. There is a great collection at *http://nsidc.org/cgi-bin/glacier_photos/glacier_photo_search.pl?collection=repeat*. This link opens the Search page for the National Snow and Ice Data Center's collection of repeat glacier photography. Click the "Search" button and a new page will open showing thumbnails of the photographs.

   Select images that can be shown side-by-side in a 3" x 3" space or a 3" x 6" space. You will need a total of eight 3" x 3" image sets and two 3" x 6" image sets. Arrange the images in your photo editor and print them onto thin photo-quality paper.

   If the printed images aren't as bright as you'd like, try specifying "Photo/Glossy paper" in your Print dialogue box instead of ordinary paper. This causes your printer to apply more ink, making much bolder images.

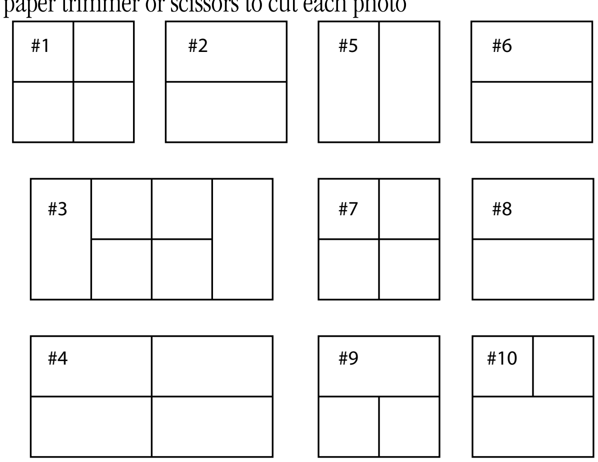
2. Cut each image about 1/8" larger on each side than the specified dimensions. You will cut out 8 photos measuring 3 1/8" x 3 1/8" and 2 photos measuring 3 1/8" x 6 1/8".

3. Back each image with double-sided adhesive. Peel off one side of the backing and lay the sheet down, sticky side up. Attach the images to the sticky surface so that the back of each photo is completely covered. Trim the adhesive sheets to match the images. Don't peel off the other adhesive backing layer yet!

4. Arrange the images as indicated in the diagram. Use a paper trimmer or scissors to cut each photo into squares or rectangles as indicated. Keep the pieces for each image together so they don't get mixed up! Don't throw out the scraps.

5. You will need a spacer to fill the space between blocks that will eventually be taken up by photos. To make a spacer, use the leftover scraps of photo paper and double-sided tape sheets. Start with three pieces of adhesive about 3" long and 1/2" wide. Peel the backing off of both sides of each piece and stack them together. Cover the top and bottom with scraps of your photo paper. Trim the sides to get rid of overhanging edges.

Step 4.

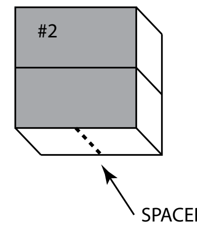


6. Check the edges of all eight cubes. If they are rough, use the sandpaper to smooth them. Using a black felt tip marker, color the edges of the blocks, otherwise, they may show up in the finished product.

7. Begin assembling your photocube by lining up four wooden blocks in a square. Remove the adhesive backing from the four pieces of image #1 and stick them onto the cubes.

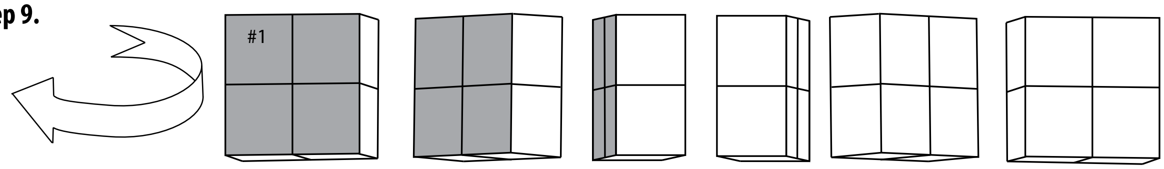
8. Line up the remaining four wooden blocks in a square. Slide your spacer strip between the blocks, so that it sticks out as shown in the diagram. Then stick your two rectangles onto the blocks as shown.

Step 8.



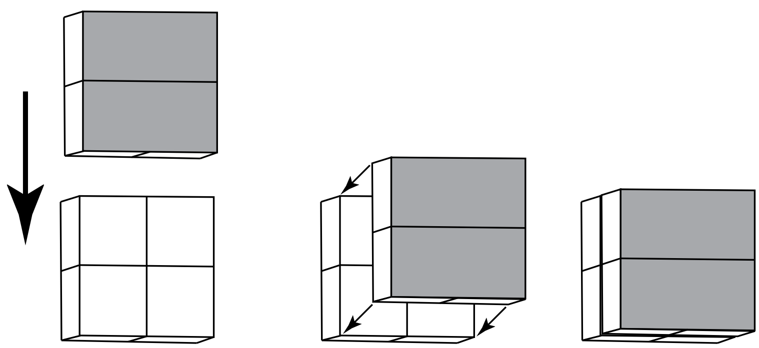
9. Turn over the set of four blocks with image #1 on them as shown below.

Step 9.

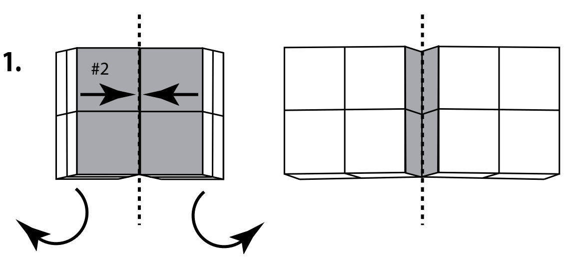


10. Place the four blocks with image #2 on them on top of the four you just flipped as shown.

Step 10.



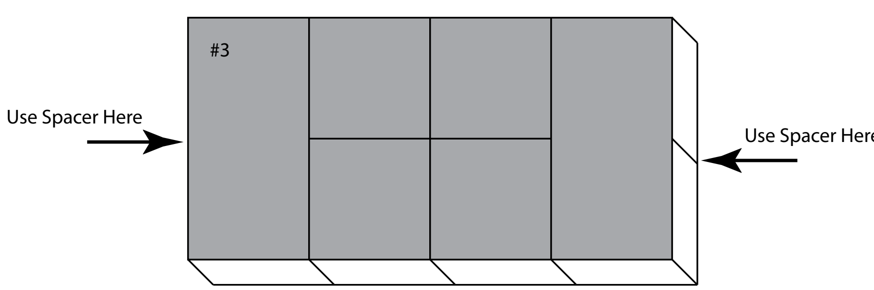
Step 11.



11. Put your hands on the left and right side of your cube, grabbing 4 blocks with each. Lift the sides up so that the top (image #2) folds in on itself, as seen at left, with the pivot being the dotted line in the diagram. The result will be all eight blocks laying in a rectangle.

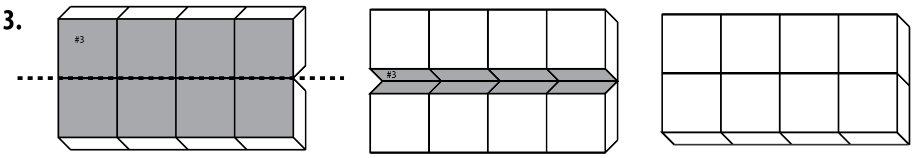
12. Apply the pieces of image #3 to the tops of the eight blocks, taking care to use the spacer whenever covering a span of two blocks, as indicated below.

Step 12.



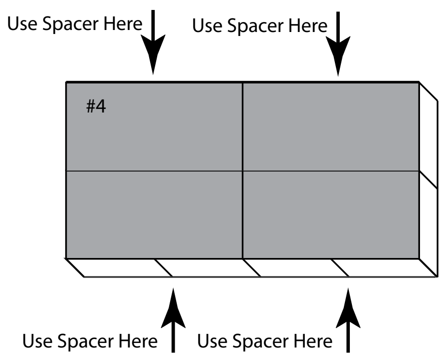
13. Fold the top four blocks down and the bottom four blocks up, with the pivot on the dotted line in the diagram. Your new image #3 that you just attached will fold in on itself and become hidden inside. You'll end up with eight blocks showing in a rectangle.

Step 13.



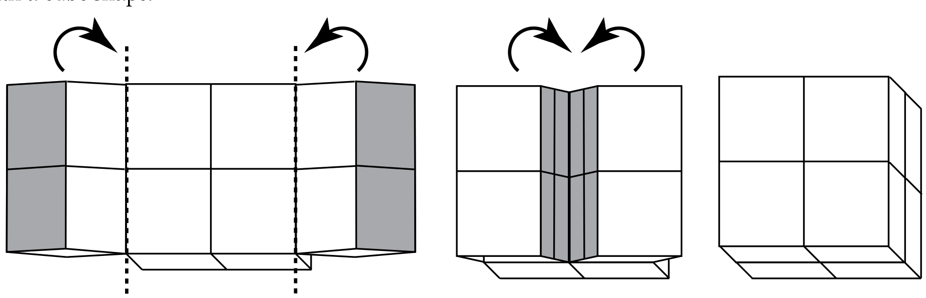
14. Apply the pieces of image #4 to the tops of the eight blocks, taking care to use the spacer whenever covering a span of two blocks, as indicated below. (You will not need the spacer where image #3 has been placed.)

Step 14.

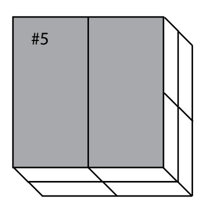


15. Fold the two leftmost blocks and two rightmost blocks up towards the center, pivoting on the dotted lines in the diagram. Your new image #4 that you just attached will become hidden inside. You'll end up with a cube shape.

Step 15.



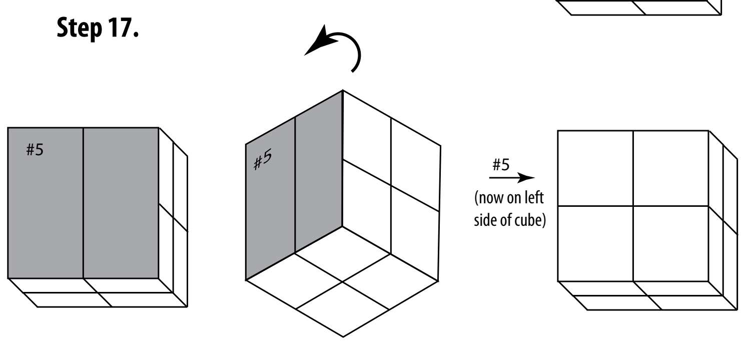
16. Apply the pieces of image #5 to the tops of the four blocks. **You do NOT need the spacer from here on, because the blocks underneath will already have photos attached to them.**



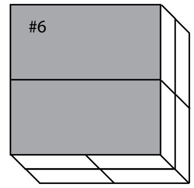
Step 16.

17. Rotate the entire cube to the left, so that image #5 moves from the top side to the left side. You will expose a new surface with no image on it.

Step 17.



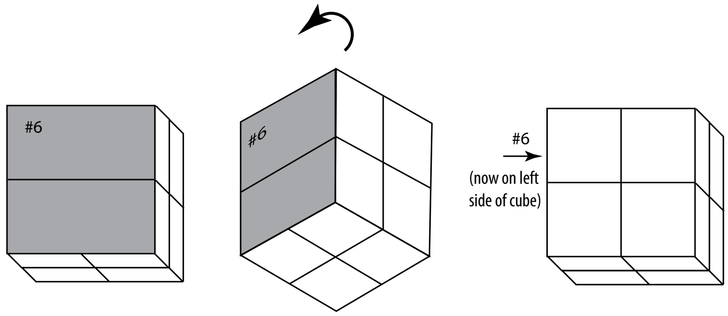
18. Apply the pieces of image #6 to the tops of the four blocks.



Step 18

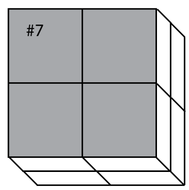
19. Rotate the entire cube to the left, so that image #6 moves from the top side to the left side (and #5 is now face-down on the table). You will expose a new surface with no image on it.

Step 19.



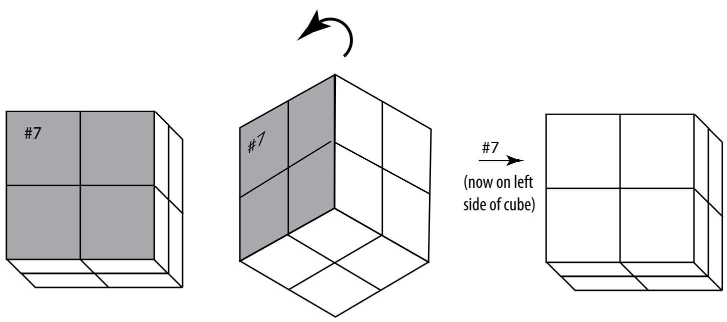
20. Apply the pieces of image #7 to the tops of the four blocks.

Step 20.



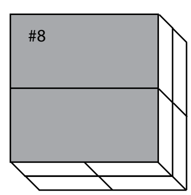
21. Rotate the entire cube to the left, so that image #7 moves from the top side to the left side (and #6 is now face-down on the table and #5 is now on the right). You will expose a new surface with no image on it.

Step 21.



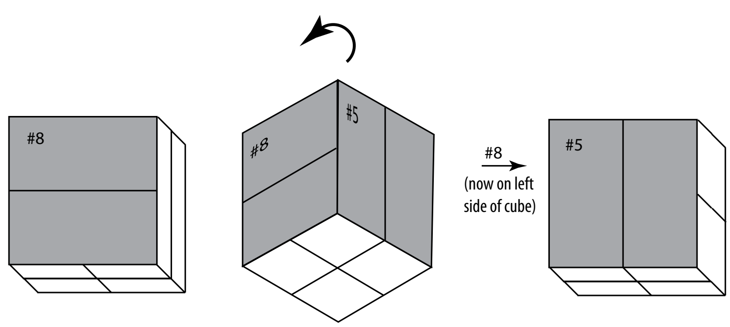
22. Apply the pieces of image #8 to the tops of the four blocks.

Step 22.



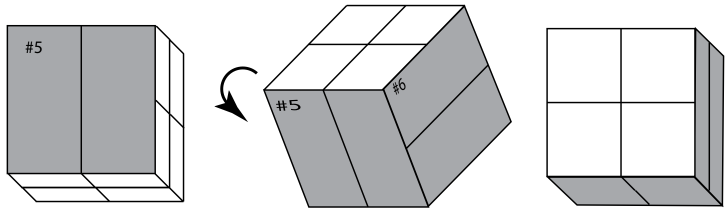
23. Rotate the entire cube to the left, so that image #8 moves from the top side to the left side. You will now have image #5 showing on top.

Step 23.



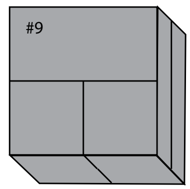
24. Now rotate again, this time towards you, so that #5 becomes the side closest to you and the top has no photos on it.

Step 24.



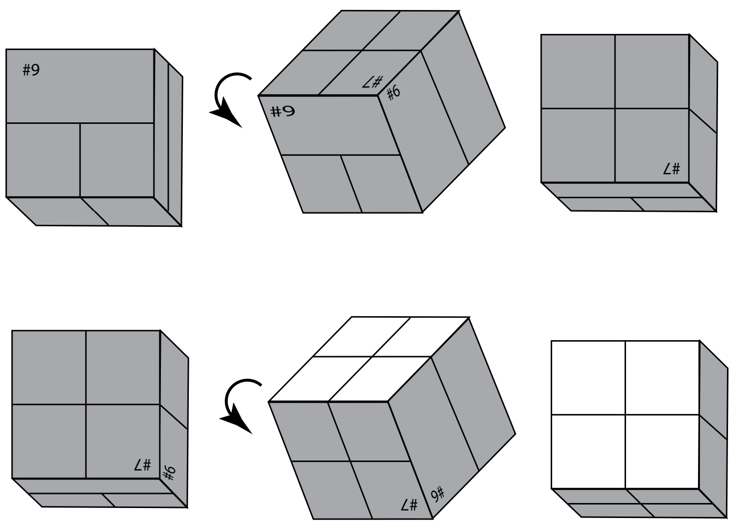
25. Apply the pieces of image #9 to the tops of the four blocks.

Step 25.



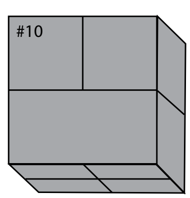
26. Rotate the entire cube towards you, so that image #9 moves from the top side to the side closest to you. You will now have image #7 showing on top. Now rotate again, towards you, so that #7 becomes the side closest to you and the top has no photos on it.

Step 26.



27. Apply the pieces of image #10 to the tops of the four blocks.

Step 27.



You're done!
To view all the images, just fold and unfold the cube, revealing a new side with every twist.
You can display the cube with any of the images showing.

Notes:

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*

Section 3:
Key Topic – Climate Change

History's Thermometers

(adapted from the 2006 Exploring Ancient Coral Gardens Expedition)

Focus

Paleoclimatological proxies

Grade Level

9-12 (Physics/Chemistry/Life Science)

Focus Question

How can deepwater corals be used to determine long-term patterns of climate change?

Learning Objectives

- Students will explain the concept of paleoclimatological proxies.
- Students will explain how oxygen isotope ratios are related to water temperature.
- Students will interpret data on oxygen isotope ratios to make inferences about climate and climate change in the geologic past.

Materials

- Copies of *Paleoclimatological Proxies Investigation Guide* enough for each student or student group
- Copy of a graph of global surface temperature, approximately 1850 - 2005 (*e.g.*, *http://www.pewclimate.org/docUploads/images/global-surface-temp-trends.gif*)

Audiovisual Materials

- None

Teaching Time

One 45-minute class period

Seating Arrangement

Classroom style, or groups of 2-3 students

Maximum Number of Students

No limit, if students work individually

Key Words and Concepts

Paleoclimatological proxy
Isotope
Deepwater coral
Climate change

Ocean Exploration and Research

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.

Within the world scientific community, there is a broad consensus that:

- Global warming is unequivocal and primarily human-induced.
- Climate changes are underway in the United States and are projected to grow.
- Widespread climate-related impacts are occurring now and are expected to increase.
- Climate change will stress water resources.
- Crop and livestock production will be increasingly challenged.
- Coastal areas are at increasing risk from sea-level rise and storm surge.
- Risks to human health will increase.
- Climate change will interact with many social and environmental stresses.
- Thresholds will be crossed, leading to large changes in climate and ecosystems.
- Future climate change and its impacts depend on choices made today. (Karl, Melillo, and Peterson, 2009).

The consensus on these points is supported by a huge amount of data from many places on Earth. A brief summary of some of the key data is provided in Diving Deeper (page 21); for more details, see references listed under "Other Resources," page 217.

Since the late 1800's, average global surface temperatures have increased by about 0.74°C. The word "average" is very important, because some parts of Earth (including the southeastern United States and parts of the North Atlantic) have cooled slightly during this period. The greatest warming has been observed in Eurasia and North America between latitude 40° and 70° N.

Some confusion about the warming trend has recently been generated by assertions that Earth's temperature has been dropping for the last ten years. These statements are based on the fact that 1998 was abnormally hot due to the strongest El Nino event in the last century. The years following 1998 were indeed cooler than 1998, but the long-term trend still shows continued warming. There are many factors that affect global temperatures in a single year, and it is not surprising that one year might be cooler than the preceding year. But the global warming trend is a matter of decades, not just one or two years. The long-term trend is still clear: Seven of the eight warmest years on record have occurred since 2001, and the ten warmest years on record have all occurred since 1995.

Evidence from longer periods also suggests that present temperatures are highly unusual. Deep-sea corals build their skeletons from calcium and carbonate ions which they extract from sea water. Oxygen and oxygen isotopes contained in the carbonate ions, as well as trace metals that are also incorporated into the corals' skeleton, can be used to determine the temperature of the water when the skeleton was formed. Because some corals live for several centuries, their skeletons contain a natural record of climate variability. Natural recorders are known as proxies, and include tree rings, fossil pollen, and ice cores in addition to corals. Analyses of over 400 proxies show that the 1990s was the warmest decade of the millennium and the 20th century was the warmest century. The warmest year of the millennium was 1998, and the coldest was probably (but with much greater uncertainty) 1601.

The black and white photograph of Muir Glacier was taken on August 13, 1941; the color photograph was taken from the same vantage on August 31, 2004. Between 1941 and 2004 the glacier retreated more than 12 kilometers (seven miles) and thinned by more than 800 meters (875 yards). Ocean water has filled the valley, replacing the ice of Muir Glacier; the end of the glacier has retreated out of the field of view. The glacier's absence reveals scars where glacier ice once scraped high up against the hillside. In 2004, trees and shrubs grew thickly in the foreground, where in 1941 there was only bare rock. Image credit: National Snow and Ice Data Center, W. O. Field, B. F. Molnia.
http://nsidc.org/data/glacier_photo/repeat_photography.html

When studying temperature records in proxies, we are usually interested in the ratio of the rare oxygen isotope ^{18}O to the common oxygen isotope ^{16}O. Stable isotope ratios of elements such as oxygen, hydrogen, carbon, nitrogen, and sulfur are normally compared to the stable isotope ratios of a standard material of known composition. The results of such comparison measurements are reported as delta (δ) values in parts per thousand (‰). The δ notation signifies difference; in this case the difference in isotope ratios between a standard and a sample. Delta value are abbreviated $\delta^{H}X$, where X is an element and the superscript H is the heavy isotope mass of that element. Delta values are found by subtracting the isotope ratio of the standard from the isotope ratio of the sample, dividing the result by the ratio of the standard, and multiplying by 1,000:

$$[(R_{SA} - R_{ST}) \div R_{ST}] \bullet 1000 = \delta^{H}X‰$$

where R_{SA} is the ratio of heavy/light isotopes in the sample and R_{ST} is the ratio of heavy/light isotopes in the standard. Positive delta values mean that the sample has more of the heavy isotope than the standard, and negative delta values mean that the sample has less of the heavy isotope than the standard. Scientists have found that the ratio of oxygen isotopes in carbonate samples is inversely related to the water temperature at which the carbonates were formed, so high ratios of ^{18}O mean lower temperatures. In the simplest case, a temperature change of 4° C corresponds to a $\delta^{18}O$ of about 1‰.

This lesson guides a student investigation into the interpretation of oxygen isotope data as a climate proxy.

Learning Procedure

1. To prepare for this lesson:
   - Review introductory information on the NOAA Ship *Okeanos Explorer* at *http://oceanexplorer.noaa.gov/okeanos/welcome.html*. You may also want to consider having students complete some or all of the lesson, *To Boldly Go*. . . .
   - Review the essay *Paleoclimate and Deep-Sea Corals* (*http://oceanexplorer.noaa.gov/explorations/05stepstones/background/paleoclimate/paleoclimate.html*) and the Ocean Explorer North Atlantic Stepping Stones 2005 Expedition.
   - Review procedures on the *Paleoclimatological Proxies Investigation Guide*.

2. If you have not previously done so, briefly introduce the NOAA Ship *Okeanos Explorer*, emphasizing that this is the first Federal vessel specifically dedicated to exploring Earth's largely unknown ocean. Lead a discussion of reasons why ocean exploration is important, which should include further understanding of climate change. Show students a graph of global surface temperature trends (*e.g.*, *http://www.pewclimate.org/docUploads/images/global-surface-temp-trends.gif*), and ask them if they can recognize any trend in the data. Data are variable prior to about 1910, but thereafter there is a distinct trend of increasing temperature. Ask students whether the drop in surface temperature between 1935 and 1945 cancels out the overall trend. Students should realize that year-to-year fluctuations do not negate trends over longer periods of time.

   Point out that reliable temperature measurements are only available for a few hundred years of human history, and the significance of recently observed trends might be more easily determined if temperature data were available for a longer time period. Ask how such data might be obtained. Explain the concept of proxies, perhaps drawing an analogy to tree rings. Briefly discuss deep-sea corals as climate proxies. Be sure students realize that these animals produce skeletons from calcium carbonate, and continue to grow and add to these skeletons throughout their lives.

Review the concept of isotopes and isotope ratios. Explain that the ratio of oxygen isotopes varies with temperature, and when oxygen (in both of its isotopic forms) is precipitated in the coral skeleton as calcium carbonate, a record is formed of the temperature at the time of precipitation. Be sure students understand that the ratio of oxygen isotopes in carbonate samples is inversely related to water temperature when the carbonates were formed, so high ratios of ^{18}O mean lower temperatures; and that a temperature change of 4°C corresponds to a $\delta^{18}O$ of about 1‰.

3. Distribute copies of *Paleoclimatological Proxies Investigation Guide*, and have each group complete the activities described in the *Guide*.

4. Lead a discussion of students' results. The correct $\delta^{18}O$ values are:

Coral Specimen	$\delta^{18}O$	*Coral Specimen*	$\delta^{18}O$
#1, base of coral	3.8	#4, base of coral	4.5
#1, 50 mm from base	3.9	#4, 75 mm from base	4.1
#1, 200 mm from base	4.5	#4, 150 mm from base	3.9
#1, 400 mm from base	4.1	#4, 300 mm from base	4.0
#2, base of coral	0.8	#5, base of coral	1.7
#2, 70 mm from base	0.9	#5, 80 mm from base	1.8
#2, 220 mm from base	1.1	#5, 85 mm from base	3.3
#2, 450 mm from base	1.0	#5, 100 mm from base	3.6
#3, base of coral	4.1	#6, base of coral	1.3
#3, 100 mm from base	4.3	#6, 100 mm from base	1.5
#3, 200 mm from base	3.9	#6, 155 mm from base	1.6
#3, 300 mm from base	4.1	#6, 400 mm from base	1.4

Students should recognize that corals 1, 3, and 4 grew during a period in which water temperatures were relatively low (as would be the case during periods of glaciation), while corals 2 and 6 grew in warmer conditions.

Coral 5 exhibits significantly different $\delta^{18}O$ in different portions of its skeleton. Students should recognize that the difference in $\delta^{18}O$ (1.5) between two samples only 5 mm apart on the coral skeleton indicates that this coral experienced a rapid cooling of about 6°C in the space of only 5 years.

Evidence for such a period of rapid cooling has been reported and linked to a rapid climate shift, the Younger Dryas cooling event which took place approximately 12,900 to 11,700 years ago. The exact cause (or causes) of the Younger Dryas cooling is not known, but available evidence suggests that an influx of cold, fresh water from melting ice sheets may have been at least partly responsible. This melting began well before the beginning of the Younger Dryas cooling, and freshwater influx is believed to have had an impact on deep ocean circulation. Although coral 5 lived 400 – 500 years before the onset of the Younger Dryas event, this coral was collected from Orphan Knoll in the northwestern Atlantic Ocean at a depth of 1,600 m. It is possible that some of the events involved with conditions accompanying the Younger Dryas event may also have subjected this coral to cooler temperatures before that event actually began.

What Caused the Younger-Dryas Cooling Event?

A recent hypothesis (Firestone *et al.*, 2007) to explain the Younger Dryas cooling event involves a meteor hitting the Earth about 12,900 years ago, sending enough debris (and possibly ash from fires) into the atmosphere to block incoming solar radiation and cause global temperatures to briefly decline. It has also been suggested that the same hypothesis explains the mass extinction of North American megafauna, the end of the Clovis culture of Paleo-Indians in North America, and the creation of elliptical depressions known as the Carolina Bays.

While there are still many unresolved questions, this hypothesis and its associated events can provide a fascinating context for lessons touching on archaeology, astronomy, and the nature of scientific discovery. A lesson plan based on this hypothesis is described by McGarry, Straffon, and Patterson (2012).

References

Firestone, R.B., A. West, J.P. Kennett, L. Becker, T.E. Bunch, Z.S. Revay, P.H. Schultz, T. Belgya, D.J. Kennett, J.M. Erlandson, O.J. Dickenson, A.C. Goodyear, R.S. Harris, G.A. Howard, J.B. Kloosterman, P. Lechler, P.A. Mayewski, J. Montgomery, R. Poreda, T. Darrah, S.S. Que Hee, A.R. Smith, A. Stich, W. Topping, J.H. Wittke, and W.S. Wolbach. 2007. Evidence for an extraterrestrial impact 12,900 years ago that contributed to the megafaunal extinctions and the Younger Dryas cooling. Proceedings of the National Academy of Sciences 104(41): 16016–21.

McGarry, M. A., D. Straffon, and C. Patterson. 2012. Explaining four Earth science enigmas with a new hypothesis. Science Scope 35:35-41. *http://www.nsta.org/publications/browse_journals.aspx?action=issue&id=10.2505/3/ss12_035_07*

Whatever connection may or may not exist with the Younger Dryas cooling, coral 5 provides clear evidence of very rapid climate change. Discuss the significance of rapid versus gradual changes to biological communities, emphasizing that it is much more difficult for biological organisms to adapt to rapid change. Consequently, extinctions are more likely to occur under rapidly changing conditions.

Encourage students to speculate about possible mechanisms that might account for changing $^{18}O/^{16}O$ ratio in response to temperature. There are numerous processes that contribute to isotope fractionation, ranging from processes that operate at the level of atoms to processes that operate at the level of ecosystems. The most obvious consequence of having one or more extra neutrons is that additional neutrons make atoms physically heavier. In general, light isotopes react faster than heavy isotopes in chemical reactions, and the bonds formed by heavy isotopes tend to be stronger than similar bonds formed by light isotopes. When water evaporates, light isotopes evaporate more readily so the ratio of heavy isotopes is lower in the vapor phase and higher in the liquid phase. At the ecosystem level, fractionation usually involves multiple processes that often are not well-understood. While the correlation between temperature and $\delta^{18}O$ has been repeatedly observed in corals, the exact mechanisms responsible for this fractionation are not fully known, and may vary among different coral species.

The BRIDGE Connection

www.vims.edu/bridge/ – Scroll over "Ocean Science Topics," then click "Chemistry," or "Atmosphere" for links to resources about ocean chemistry or climate change.

The "Me" Connection

Have students write a paragraph on how global climate change may affect their own lives over the next 20 to 50 years.

Connections to Other Subjects

English/Language Arts, Social Sciences, Mathematics

Assessment

Students' responses to *Invstigation* questions and class discussions provide opportunities for evaluation.

Extensions

1. Follow events aboard the *Okeanos Explorer* at *http://oceanexplorer.noaa.gov/okeanos/welcome.html*.
2. Have student groups prepare scientific posters about climate change. See Page 114 for information about scientific posters, and "Other Resources" for additional sources of information about climate change.
3. Visit NOAA's Climate Timeline and Paleoclimatology Web sites (*http://www.ngdc.noaa.gov/paleo/ctl/index.html* and *http://www.ncdc.noaa.gov/paleo/primer.html*) for more information and activities related to paleoclimatology.

Multimedia Discovery Missions

http://www.oceanexplorer.noaa.gov/edu/learning/welcome.html Click on the links to Lessons 3 for interactive multimedia presentations and Learning Activities on Deep-Sea Corals.

Other Relevant Lesson Plans from the Ocean Exploration Program

(All of the following Lesson Plans are targeted toward Grades 9-12)

Cool Corals (from the 2003 Life on the Edge Expedition)

http://oceanexplorer.noaa.gov/explorations/03edge/background/edu/media/cool.pdf

Focus: Biology and ecology of *Lophelia* corals (Life Science)

Students will describe the basic morphology of *Lophelia* corals and explain the significance of these organisms, interpret preliminary observations on the behavior of *Lophelia* polyps, and infer possible explanations for these observations. Students will also discuss why biological communities associated with *Lophelia* corals are the focus of major worldwide conservation efforts.

Top to Bottom (from the North Atlantic Stepping Stones 2005 Expedition)

http://oceanexplorer.noaa.gov/explorations/05stepstones/background/education/ss_2005_topbottom.pdf

Focus: Impacts of climate change on biological communities of the deep ocean (Earth Science/Life Science)

Students will describe thermohaline circulation, explain how climate change might affect thermohaline circulation, and identify the time scale over which such effects might take place. Students will also explain how warmer temperatures might affect wind-driven surface currents and how these effects might impact biological communities of the deep ocean, and discuss at least three potential impacts on biological communities that might result from carbon dioxide sequestration in the deep ocean.

The Good, the Bad, and the Arctic (from the 2006 Tracking Narwhals in Greenland Expedition)

http://oceanexplorer.noaa.gov/explorations/06arctic/background/edu/media/goodbad.pdf

Focus: Social, economic and environmental consequences of Arctic climate change (Biology/Earth Science)

Students will identify and explain at least three lines of evidence that suggest the Arctic climate is changing; identify and discuss at least three social, three economic and three environmental consequences expected as a result of Arctic climate change; identify at least three climate-related issues of concern to Arctic indigenous peoples; and identify at least three ways in which Arctic climate change is likely to affect the rest of the Earth's ecosystems.

Other Resources

See page 217 for Other Resources.

Next Generation Science Standards

Lesson plans developed for Volume 1 are correlated with *Ocean Literacy Essential Principles and Fundamental Concepts* as indicated in the back of this book. Additionally, a separate online document illustrates individual lesson support for the Performance Expectations and three dimensions of the Next Generation Science Standards and associated Common Core State Standards for Mathematics and for English Language Arts & Literacy. This information is provided to educators as a context or point of departure for addressing particular standards and does not necessarily mean that any lesson fully develops a particular standard, principle or concept. Please see: *http://oceanexplorer.noaa.gov/okeanos/edu/collection/wdwe_ngss.pdf.*

Lophelia pertusa, the bright white coral seen in the midst of a field of anemones and sponges, is one of the primary species of deepwater corals under study. It can occur as an individual colony, like this one, or in vast 'thickets' of many colonies clustered closely together. We are still in the process of learning what type of habitat is needed to support the growth of these corals. Image credit: University of Alabama and NOAA.
http://oceanexplorer.noaa.gov/explorations/03mex/logs/hirez/lophon_rock_hirez.jpg

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:
oceanexeducation@noaa.gov

For More Information

Paula Keener, Director, Education Programs
NOAA Office of Ocean Exploration and Research
Hollings Marine Laboratory
331 Fort Johnson Road, Charleston SC 29412
843.762.8818 843.762.8737 (fax)
paula.keener-chavis@noaa.gov

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Paleoclimatological Proxies Investigation

Background

A proxy is a person or thing that substitutes for another person or thing. Proxies are often used in scientific investigations when there is a known relationship between two things that makes it possible to measure one to predict the measurement of the other. Tree rings are an example: the number of tree rings is a proxy for the age of the tree, and the distance between rings can be a proxy for climatic conditions during the year when the rings were formed.

Deep-sea corals can be a proxy for water temperature, because these corals build their skeletons from calcium and carbonate ions which they extract from seawater. Carbonate ions (CO_3^{-2}) contain oxygen. Like other elements, oxygen can occur as several different isotopes. Isotopes are atoms with the same number of electrons and protons, but different numbers of neutrons. Different isotopes belong to the same element because they have the same number of electrons, which means that they behave similarly in chemical reactions. But different isotopes of the same element do not behave identically, and there are a variety of chemical and physical processes that can cause one isotope to become more or less concentrated relative to other isotopes. This process is called fractionation.

Oxygen in seawater may occur as the rare oxygen isotope ^{18}O (about 0.20% of all oxygen atoms) or the common oxygen isotope ^{16}O (about 99.76% of all oxygen atoms). You may notice that the percentages do not add to exactly 100.000%; this is because oxygen also occurs as the very rare ^{17}O. Scientists have found that the ratio of the ^{18}O isotope to the ^{16}O isotope in carbonate samples is inversely related to the water temperature at which the carbonates were formed, so higher ratios of $^{18}O/^{16}O$ mean lower temperatures.

Concentrations of isotopes of a specific element are measured in mass spectrometers, which separate molecules according to their mass. The stable isotope ratios of elements such as oxygen, hydrogen, carbon, nitrogen, and sulfur are normally compared to the stable isotope ratios of a standard material of known composition. The results of such comparison measurements are reported as delta (δ) values in parts per thousand (‰). The δ notation signifies difference; in this case the difference in isotope ratios between a standard and a sample. Delta values are abbreviated $\delta^{H}X$, where X is an element and the superscript H is the heavy isotope mass of that element. Delta values are found by subtracting the isotope ratio of the standard from the isotope ratio of the sample, dividing the result by the ratio of the standard, and multiplying by 1,000:

$$[(R_{SA} - R_{ST}) \div R_{ST}] \bullet 1000 = \delta^{H}X‰$$

where R_{SA} is the ratio of heavy/light isotopes in the sample and R_{ST} is the ratio of heavy/light isotopes in the standard. Note that positive delta values mean that the sample has more of the heavy isotope than the standard, and negative delta values mean that the sample has less of the heavy isotope than the standard.

Some deep-sea corals live for several centuries, and the carbonates in their skeletons contain a natural record of climate variability. The oldest part of the coral skeleton is at the base of the coral, where coral growth began after the coral larva settled on a suitable surface.

Analyze

Table 1 on the following page lists 18O/16O ratios for calcium carbonate samples taken from the skeletons of six corals collected at a depth of 1,600 m from Orphan Knoll in the northwestern Atlantic Ocean. The table also gives ages of the sample taken from the base of each coral skeleton and the sample taken from the tip of each skeleton. The difference in age between these two samples is the maximum age of the coral while it was alive. So, Coral #1 lived for 410 years (15,550 - 15,140).

Calculate $\delta^{18}O$ for each sample, and use the results to help answer the following questions. Assume that a temperature change of 4°C corresponds to a $\delta^{18}O$ of about 1‰.

The data for this activity came from: Smith, J. E., M. J. Risk, H. P. Schwarcz, and T. A. McConnaughey, 1997. Rapid climate change in the North Atlantic during the Younger Dryas recorded by deep-sea corals. Nature 386:818-820.
http://www.nature.com/nature/journal/v386/n6627/abs/386818a0.html

Table 1
Oxygen Isotope Ratios in Deepwater Coral Samples

Coral Specimen	$^{18}O/^{16}O$ Sample	$^{18}O/^{16}O$ Standard	$\delta^{18}O$ ‰	Years Ago	Specimen Age (yrs)
#1, base of coral	0.0020076	0.0020000	______	15,550	
#1, 50 mm from base	0.0020078	0.0020000	______		
#1, 200 mm from base	0.0020090	0.0020000	______		
#1, 400 mm from base	0.0020082	0.0020000	______	15,140	______
#2, base of coral	0.0020016	0.0020000	______	3,410	
#2, 70 mm from base	0.0020018	0.0020000	______		
#2, 220 mm from base	0.0020022	0.0020000	______		
#2, 450 mm from base	0.0020020	0.0020000	______	3,100	______
#3, base of coral	0.0020082	0.0020000	______	15,695	
#3, 100 mm from base	0.0020086	0.0020000	______		
#3, 200 mm from base	0.0020078	0.0020000	______		
#3, 300 mm from base	0.0020082	0.0020000	______	15,400	______
#4, base of coral	0.0020090	0.0020000	______	14,800	
#4, 75 mm from base	0.0020082	0.0020000	______		
#4, 150 mm from base	0.0020078	0.0020000	______		
#4, 300 mm from base	0.0020080	0.0020000	______	14,445	______
#5, base of coral	0.0020034	0.0020000	______	13,400	
#5, 80 mm from base	0.0020036	0.0020000	______		
#5, 85 mm from base	0.0020066	0.0020000	______		
#5, 100 mm from base	0.0020072	0.0020000	______	13,300	______
#6, base of coral	0.0020026	0.0020000	______	6,675	
#6, 100 mm from base	0.0020030	0.0020000	______		
#6, 155 mm from base	0.0020032	0.0020000	______		
#6, 400 mm from base	0.0020028	0.0020000	______	6,400	______

Interpret

1. Which corals grew during periods in which water temperatures were relatively low?

2. Which corals grew during periods in which water temperatures were relatively high?

3. Is there evidence that any coral experienced a rapid change in environmental temperature?

4. Is there any evidence that a rapid shift in climate has ever actually taken place? (Hint: Search the name "Dryas")

5. What processes might cause heavy oxygen isotopes (^{18}O) in carbonates to increase as temperature decreases?

Scientific Posters

Scientific posters are an increasingly popular way to communicate results of scientific research and technical projects. There are a number of reasons for this, including limited time at conferences for traditional "public speaking"-style presentations, better options for interacting one-on-one with people who are really interested in your work, opportunities for viewers to understand the details of your work (even if you aren't present), and having a more relaxed format for those who dislike speaking in public. In addition, posters are more durable that one-time presentations; once they are created they can be used in many different settings, over and over again. For more discussion of pros and cons, as well as examples of good and bad posters, visit

http://colinpurrington.com/tips/academic/posterdesign
http://www.ncsu.edu/project/posters/NewSite/

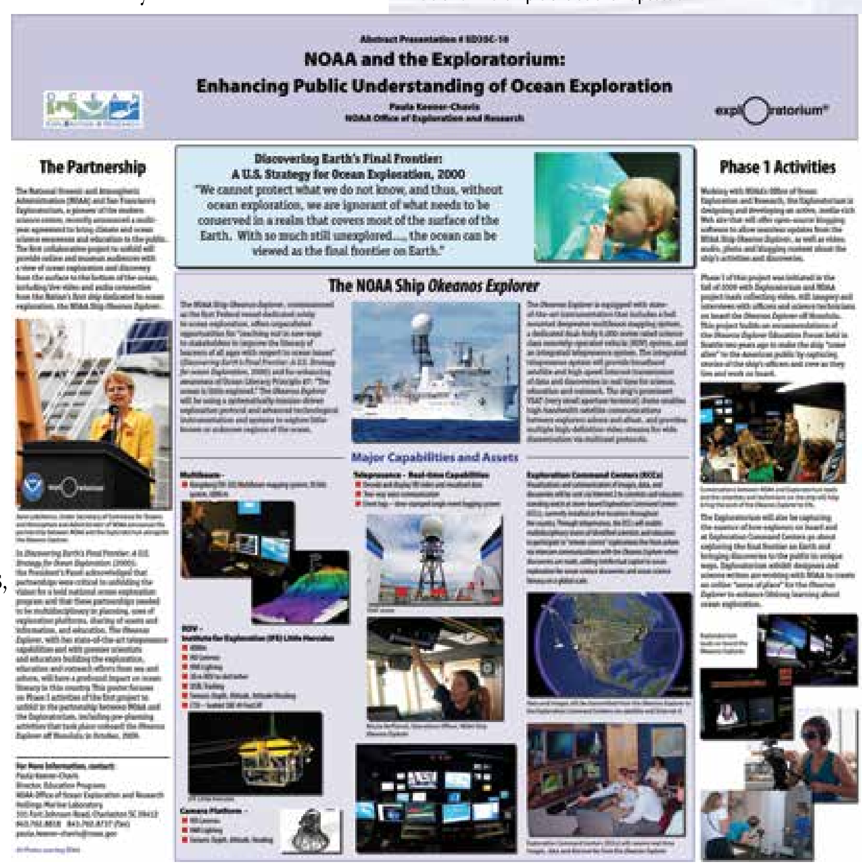
Scientific posters usually contain the same elements as traditional written reports: title, introduction, materials and methods, results, conclusions, literature cited (key citations only!), acknowledgments, and contact points for further information. Good posters do NOT usually have an abstract, though an abstract is often required as part of the submission process and may be included in a printed program.

Another similarity to traditional reports is that the best posters almost always go through several drafts. You should always expect that the first draft of your poster will change significantly before it emerges in final form. Be sure to allow enough time for others to review your first draft and for you to make needed changes.

An important difference (and advantage) that posters have compared to written reports is that posters can be much more flexible in terms of layout and where these elements appear, as long as there is still a clear and logical flow to guide viewers through your presentation. Here are a few more tips for good scientific posters (see the Web sites listed above for many other ideas):

- Posters should be readable from 6 feet away;
- Leave plenty of white space (35% is not too much) – densely packed posters can easily repel potential viewers;
- The top and right columns of your poster are prime areas for vital material, while the bottom edge will receive much less attention;
- Serif fonts (*e.g.*, Times) are easier to read than sans serif fonts (*e.g.*, Helvetica), so use sans serif fonts for titles and headings, and serif fonts for body text (usually no more than two font families on a single poster)
- Text boxes are easiest to read when they are about 40 characters wide

Below: An example of a scientific poster.



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*

Section 4: Key Topic – Energy

Animals of the Fire Ice

Focus
What are animals that have been found feeding on methane hydrates, and how may they interact with other species?

Grade Level
5-6 (Life Science)

Focus Question
What animals have been found feeding on methane hydrates and how may they interact with other species?

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

Materials
- Copies of the *Fire Ice Animals Investigation Guide*, one for each student group
- Copies of the *Methane Hydrate Model Construction Guide Student Handout*, one for each student group
- Materials for constructing a methane hydrate model:

  For constructing a pentagon:
  - Paper, unlined 8-1/2" x 11"
  - Pencil
  - Protractor or compass

For constructing the dodecahedron, clathrate cage, methane molecule and methane hydrate model:
  - Scissors
  - Cardboard or card stock (enough to make 7 pentagons)
  - Ruler, 12-inch
  - 11 - Bamboo skewers, 12" long
  - 20 - Styrofoam balls, 1/2" to 1" diameter
  - 4 - Styrofoam balls, 1" diameter
  - 1 - Styrofoam ball, 1-1/2" diameter
  - Tape, wrapping or strapping

Ocean Exploration and Research

- Spray paint, water-based latex; dark blue, light blue, red, and black
- Fishing line, 8 lb test; or light colored thread
- (Optional) Materials for constructing posters or three-dimensional models (see Learning Procedure, Step 7)

Audiovisual Materials

- None

Teaching Time

One or two 45-minute class periods plus time for student research

Seating Arrangement

Groups of four to six students

Maximum Number of Students

32

Key Words and Concepts

Cold seeps
Methane hydrate
Clathrate
Methanogenic Archaea
Polychaete
Alvinocarid shrimp
Ice worm
Hydrate shrimp

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.

> ***For kicks, oceanographer William P. Dillon likes to surprise visitors to his lab by taking ordinary-looking ice balls and setting them on fire. 'They're easy to light. You just put a match to them and they will go,' says Dillon, a researcher with the U.S. Geological Survey (USGS) in Woods Hole, Mass. If the truth be told, this is not typical ice. The prop in Dillon's show is a curious and poorly known structure called methane hydrate.***
>
> *from "The Mother Lode of Natural Gas"*
> *by Rich Monastersky,*
> *www.sciencenews.org/pages/pdfs/data/1996/150-19/15019-12.pdf*

Methane hydrate is a type of clathrate, a chemical substance in which the molecules of one material (water, in this case) form an open lattice that encloses molecules of another material (methane) without actually forming chemical bonds between the two materials. Methane is produced in many environments by a group of Archaea known as methanogenic Archaea. These Archaea obtain energy by anaerobic metabolism through which they break down the organic material contained in once-living plants and animals. When this process takes place in deep-ocean sediments, methane molecules are surrounded by water molecules, and conditions of low temperature and high pressure allow stable ice-like methane hydrates to form.

Methane hydrate looks like ice, but as the "ice" melts it releases methane gas which can be a fuel source. Image credit: Gary Klinkhammer, OSU-COAS

Iceworms *(Hesiocaeca methanicola)* infest a piece of orange methane hydrate at 540 m depth in the Gulf of Mexico. During the Paleocene epoch, lower sea levels could have led to huge releases of methane from frozen hydrates and contributed to global warming. Today, methane hydrates may be growing unstable due to warmer ocean temperatures. Image credit: Ian MacDonald. *http://oceanexplorer.noaa.gov/explorations/06mexico/background/plan/media/iceworms_600.jpg*

Besides providing entertainment for oceanographers, methane hydrate deposits are significant for several other reasons:

- The U.S. Geological Survey has estimated that on a global scale, methane hydrates may contain roughly twice the carbon contained in all reserves of coal, oil, and conventional natural gas combined.
- Methane hydrates can decompose to release large amounts of methane which is a greenhouse gas that could have (and may already have had) major consequences to the Earth's climate.
- Sudden release of pressurized methane gas may cause submarine landslides which in turn can trigger catastrophic tsunamis.
- Methane hydrates are associated with unusual and possibly unique biological communities containing previously-unknown species that may be sources of beneficial pharmaceutical materials.

The biological communities associated with methane hydrates are chemosynthetic, and include food webs that are based on the energy of chemical compounds (in contrast to photosynthetic communities whose food webs are based on photosynthesis that uses energy from the sun). Ocean Exploration expeditions to the Gulf of Mexico have found methane hydrates in the vicinity of "cold seeps," which are areas where hydrocarbons are seeping onto the ocean floor. In some of these areas, explorers have observed polychaete worms that appeared to be actively sculpting methane hydrate ices, and expeditions to other locations (such as the 2001 Deep East Expedition) observed shrimp that appeared to be feeding directly on methane hydrate ices (visit *http://oceanexplorer.noaa.gov/explorations/03mex/welcome.html*, *http://oceanexplorer.noaa.gov/explorations/02mexico/welcome.html*, and *http://oceanexplorer.noaa.gov/explorations/deepeast01/deepeast01.html* for more information).

What are these "fire ice animals" doing? Are they actually consuming methane hydrate ices for food? Until more detailed studies are done on these animals, we won't know for sure. But we can use what is already known about other shrimps and polychaete worms to infer some possible answers. These inferences can lead to hypotheses about the relationships between the animals and methane hydrate ices, and can form the basis for experiments to find out more about these strange deep-sea animals.

In this activity, students will research cold-seep communities and typical feeding habits of polychaetes and shrimp to make inferences about the relationships between fire ice animals and methane hydrates.

Learning Procedure

1. To prepare for this lesson:
   - Review introductory information on the NOAA Ship *Okeanos Explorer* at *http://oceanexplorer.noaa.gov/okeanos/welcome.html*. You may also want to consider having students complete some or all of the lesson, *To Boldly Go*….
   - Visit *http://oceanexplorer.noaa.gov/explorations/deepeast01/logs/oct1/oct1.html* and *http://oceanexplorer.noaa.gov/explorations/03windows/welcome.html* for background on the 2001 Deep East Expedition to the Blake Ridge and the 2003 Windows on the Deep Expedition.
   - Review questions on the *Fire Ice Animals Investigation Guide.*
   - Review procedures on the *Methane Hydrate Model Construction Guide (Educator's Version)*, and gather necessary materials. This activity may be done as a cross-curricular mathematics lesson using student-constructed

pentagons and dodecahedrons. Correlations with National Math Education Standards and Expectations are provided at the end of the *Educator's Version*. Alternatively, this activity may be done as a briefer demonstration using dodecahedrons constructed by the educator. In either case, you will need to complete Step 2 in advance. If you plan to construct the model as a demonstration, you should also complete Part 1 of the *Student Handout*.

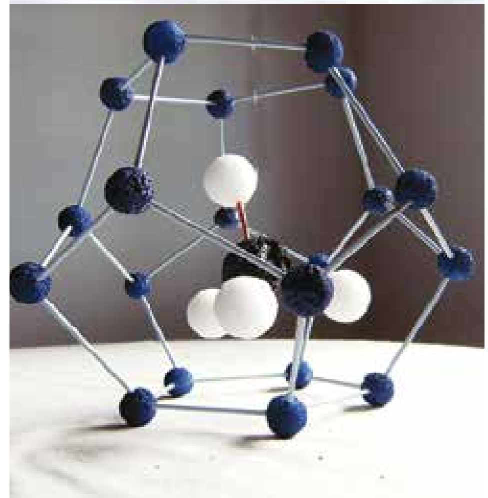
2. If you have not previously done so, briefly introduce the NOAA Ship *Okeanos Explorer*, emphasizing that this is the first Federal vessel specifically dedicated to exploring Earth's largely unknown ocean. Lead a discussion of reasons that ocean exploration is important, which should include further understanding of energy resources in the ocean.

   Lead an introductory discussion about the 2001 Deep East Expedition to the Blake Ridge and the 2003 Windows on the Deep Expedition. Briefly describe methane hydrates and why these substances are potentially important to human populations. You may also want to visit *http://www.pmel.noaa.gov/vents/* for more information and activities on hydrothermal vent communities.

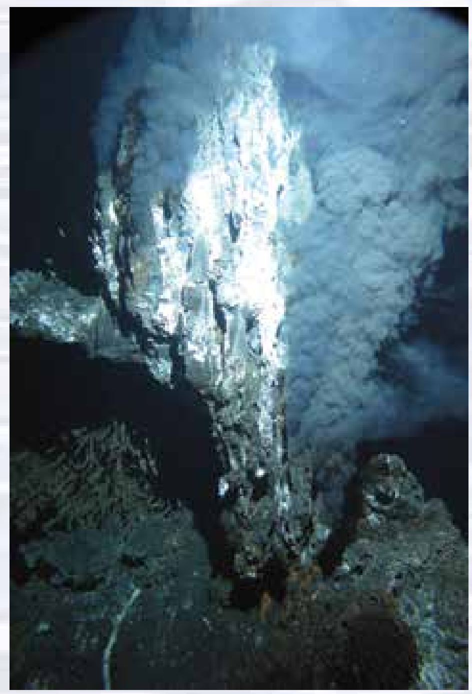
3. Lead a discussion about recently-discovered deep-sea chemosynthetic communities (hydrothermal vents and cold seeps). Emphasize the contrast between communities that depend upon chemosynthesis with those dependent upon photosynthesis. You may want to point out that through both processes, organisms build sugars from carbon dioxide and water. This process requires energy; photosynthesizers obtain this energy from the sun, while chemosynthesizers obtain energy from chemical reactions. Review the concepts of food chains or webs, emphasizing that the entire chain or web depends upon primary producers at the base of the chain (or web) that are able to create energy-rich food from non-living components in the surrounding environment.

4. Briefly describe methane hydrates. If you will be using student-constructed dodecahedrons for this activity, have students complete Parts 1 and 2 of the *Methane Hydrate Model Construction Guide*. Alternatively, complete Part 2 as a demonstration.

5. Tell students that expeditions to deep-sea communities often discover new and unusual types of living organisms. Two of these organisms are a type of polychaete called an ice worm and a type of crustacean called a hydrate shrimp. Explain that the ice worms make burrows in methane hydrate ices, and that hydrate shrimp have been seen crawling on top of methane hydrate ices, possibly feeding on the ice surface. Explain that scientists are not certain about the relationships between these animals and methane hydrates, nor how the fire ice animals obtain their food. To plan investigations to answer these questions, we need to use existing knowledge about other types of shrimp, polychaetes, and chemosynthetic communities to make hypotheses that are the basis for experiments and observations to learn more about these animals. Provide each group with a copy of the *Fire Ice Animals Investigation Guide*, and tell students that their assignment is to find out what is known about polychaetes and shrimps in cold-seep communities, how other polychaetes and shrimps obtain their food, and to make hypotheses about the relationships between methane hydrates, ice worms, and hydrate shrimp.



A methane hydrate model. Image credit: Mellie Lewis, College of Exploration



A black smoker chimney named 'Boardwalk' emitting 644°F (340°C) hydrothermal fluids in the northeastern Pacific Ocean at a depth of 7,260 feet (2,200 m). Microbes grow within and on the surface of such mineral formations. Image credit: James F. Holden, UMass Amherst.
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/hires/boardwalk_black_smoker_hires.jpg

The *Little Hercules* ROV shines its lights on a veritable field of sulphide chimneys and rocks covered with shrimp. In a short period of time, a thriving community over a large area of diffuse venting was revealed. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/hires/active_venting_hires.jpg

6. Have each student group present the results of their investigation, then lead a discussion of students' hypotheses. Encourage imagination and creativity, but challenge students to explain how their hypotheses are consistent with existing knowledge. Possible relationships could include:
   - Shrimp and/or worms are directly using methane hydrate as a source of food (this is not particularly likely, since other shrimps and polychaetes are heterotrophic).
   - Shrimp and/or worms are consuming methane hydrate which is used by symbiotic chemosynthetic bacteria living inside the animals (this would be analogous to many similar symbioses, and a variety of bacteria have been found to be closely associated with ice worms).
   - Shrimp and/or worms are grazing the surface or interior of methane hydrate ices, and are eating chemosynthetic bacteria that use methane hydrate as an energy source (bacterial mats have been found in cold-seep communities, and grazing or deposit-feeding is common among other shrimp and polychaetes).
   - Ice shrimp that burrow into methane hydrate ices could be deriving protection from predators (burrowing behavior is typical among many other polychaetes).

   Have students discuss what sort of investigations might be undertaken to test their hypotheses.

7. (Optional) Have student groups construct a poster or three-dimensional model illustrating their ideas about a methane hydrate community. You may provide materials, or challenge students to find their own, such as colored paper, color markers, modeling clay, glitter (to represent bacteria), Styrofoam pieces (to represent methane hydrates), etc.

The BRIDGE Connection

www.vims.edu/bridge/ – Scroll over "Ocean Science Topics," then click "Habitats," the "Deep Sea" for links to resources about hydrothermal vents and chemosynthetic communities.

The "Me" Connection

Have students write a short essay on how additional knowledge about "fire ice animals" could be important to their own lives.

Connections to Other Subjects

English/Language Arts, Earth Science, Physical Science

Assessment

Students' responses to *Investigation Guide* questions and class discussions provide opportunities for assessment.

Extensions

1. Follow events aboard the *Okeanos Explorer* at *http://oceanexplorer.noaa.gov/okeanos/welcome.html*.
2. Review Ocean Energy Overview in Diving Deeper, page 26.

Multimedia Discovery Missions

http://www.oceanexplorer.noaa.gov/edu/learning/welcome.html Click on the links to Lessons 3, 5, 6, 11, and 12 for interactive multimedia presentations and Learning Activities on Deep-Sea Corals, Chemosynthesis and Hydrothermal Vent Life, Deep-Sea Benthos, Energy from the Oceans, and Food, Water, and Medicine from the Sea.

Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

(All of the following Lesson Plans are targeted toward grades 5-6)

A Piece of Cake (from the Cayman Islands Twilight Zone 2007 Expedition)
http://oceanexplorer.noaa.gov/explorations/07twilightzone/background/edu/media/cake.pdf

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

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

Deep Gardens (from the Cayman Islands Twilight Zone 2007 Expedition)
http://oceanexplorer.noaa.gov/explorations/07twilightzone/background/edu/media/deepgardens.pdf

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

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

Let's Make a Tubeworm! (from the 2002 Gulf of Mexico Expedition)
http://oceanexplorer.noaa.gov/explorations/02mexico/background/edu/media/gom_tube_gr56.pdf

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

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

Journey to the Unknown & Why Do We Explore
(from the 2002 Galapagos Rift Expedition)
http://oceanexplorer.noaa.gov/explorations/02galapagos/background/education/media/gal_gr5_6_l1.pdf

Focus: Ocean Exploration (Life Science/Earth Science/Physical Science)

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

Chemists with No Backbones (from the 2003 Deep Sea Medicines Expedition)
http://oceanexplorer.noaa.gov/explorations/03bio/background/edu/media/meds_chemnobackbones.pdf

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

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

Keep Away (from the 2006 Expedition to the Deep Slope)
http://oceanexplorer.noaa.gov/explorations/06mexico/background/edu/gom_06_keepaway.pdf
Focus: Effects of pollution on diversity in benthic communities (Life Science)
Students will discuss the meaning of biological diversity and compare and contrast the concepts of variety and relative abundance as they relate to biological diversity. Given information on the number of individuals, number of species, and biological diversity at a series of sites, students will make inferences about the possible effects of oil drilling operations on benthic communities.

What's In That Cake? (from the 2006 Expedition to the Deep Slope)
http://oceanexplorer.noaa.gov/explorations/06mexico/background/edu/gom_06_cake.pdf
Focus: Exploration of deep-sea habitats (Life Science)
Students will explain what a habitat is, describe at least three functions or benefits that habitats provide, and describe some habitats that are typical of the Gulf of Mexico. Students will also describe and discuss at least three difficulties involved in studying deep-sea habitats and describe and explain at least three techniques scientists use to sample habitats, such as those found in the Gulf of Mexico.

Other Resources

See page 217 for Other Resources.

Next Generation Science Standards

Lesson plans developed for Volume 1 are correlated with *Ocean Literacy Essential Principles and Fundamental Concepts* as indicated in the back of this book. Additionally, a separate online document illustrates individual lesson support for the Performance Expectations and three dimensions of the Next Generation Science Standards and associated Common Core State Standards for Mathematics and for English Language Arts & Literacy. This information is provided to educators as a context or point of departure for addressing particular standards and does not necessarily mean that any lesson fully develops a particular standard, principle or concept. Please see: *http://oceanexplorer.noaa.gov/okeanos/edu/collection/wdwe_ngss.pdf.*

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: *oceanexeducation@noaa.gov*

For More Information

Paula Keener, Director, Education Programs
NOAA Office of Ocean Exploration and Research
Hollings Marine Laboratory
331 Fort Johnson Road, Charleston SC 29412
843.762.8818 843.762.8737 (fax)
paula.keener-chavis@noaa.gov

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Fire Ice Animals Investigation Guide

Background Research & Analysis

Expeditions to deep-sea communities often discover new and unusual types of living organisms. Two examples are polychaete worms called ice worms and crustaceans called hydrate shrimp. These animals have been seen on (and in) methane hydrates, which are ice-like substances formed when molecules of frozen water surround molecules of methane gas. If you hold a piece of methane hydrate in your hand, you can set it on fire, so methane hydrates have been nick-named "fire ice."

Methane hydrate looks like ice, but as the "ice" melts it releases methane gas which can be a fuel source. Image credit: Gary Klinkhammer, OSU-COAS

Ice worms make burrows in methane hydrates, and hydrate shrimp have been seen crawling on top of the ice surface, possibly feeding. Scientists are not certain about the relationships between these animals and methane hydrates, nor how the fire ice animals obtain their food. To plan investigations to answer these questions, we need to use existing knowledge about other types of shrimp, polychaetes, and chemosynthetic communities to develop hypotheses that guide experiments and observations to learn more about these animals.

Your assignment is to find out what is known about polychaetes and shrimp in cold-seep communities, how other polychaetes and shrimp obtain their food, and to make hypotheses about the relationships between methane hydrates, ice worms, and hydrate shrimp. You can find information on feeding habits of shrimp and polychaetes in general in encyclopedias and general biology books. Information at *http://www.wetwebmedia.com/polychaetes.htm* and *http://www.wetwebmedia.com/marine/inverts/arthropoda/shrimp/corlband.htm* may also be useful, although the emphasis of this site is on aquaria. There is not much information presently available on hydrate shrimp, other than the fact that they have been observed on methane hydrates at the Blake Ridge off the coast of South Carolina. Two good sources of information on ice worms are *http://www-ocean.tamu.edu/Quarterdeck/QD5.3/macdonald.html* and *http://nai.arc.nasa.gov/news_stories/news_detail.cfm?ID=86*. If you do keyword searches to find additional references, you need to know that the name "ice worm" has also been used to describe animals that inhabit glaciers and similar environments, so you should also include "methane" in your search query.

Iceworms *(Hesiocaeca methanicola)* infest a piece of orange methane hydrate at 540 m depth in the Gulf of Mexico. During the Paleocene epoch, lower sea levels could have led to huge releases of methane from frozen hydrates and contributed to global warming. Today, methane hydrates may be growing unstable due to warmer ocean temperatures. Image credit: Ian MacDonald. *http://oceanexplorer.noaa.gov/explorations/06mexico/background/plan/media/iceworms_600.jpg*

When you have completed your research, answer the following questions:

1. What is the basis of food webs in cold-seep communities?
2. What have explorers to cold-seep communities observed about ice worms and hydrate shrimp?
3. How do polychaetes and shrimp, in general, obtain their food?
4. What are the relationships that you hypothesize between ice worms, hydrate shrimp, and methane hydrates?

The NOAA Ship *Okeanos Explorer* Education Materials Collection

Methane Hydrate Model Construction Guide *(Educator's Version)*

Learning Objectives

- Students will demonstrate geometric properties through hands on manipulation of geometric shapes.
- Students will be able to construct a pentagonal dodecahedron.
- Students will be able to construct a model of a methane hydrate.

Materials

Materials for constructing a methane hydrate model

For constructing a pentagon:

- Paper, unlined 8-1/2" X 11"
- Pencil
- Protractor or compass

For constructing the dodecahedron half, clathrate cage, methane molecule and methane hydrate model:

- Scissors
- Cardboard or card stock (enough to make 13 pentagons)
- Ruler, 12-inch
- 11 - Bamboo skewers, 12" long
- 20 - Styrofoam balls, 1/2" to 1" diameter
- 4 - Styrofoam balls, 1" diameter
- 1 - Styrofoam ball, 1-1/2" diameter
- Tape, wrapping or strapping
- Spray paint, water-based latex; dark blue, light blue, red, and black
- Fishing line, 8 lb test; or light colored thread

Teaching Time

Three or four 50-minute class periods or may be sent home as an enrichment activity

Definitions

- Polygon – a geometric shape made up of vertices that are connected with line segments
- Vertex – a point where the sides of an angle meet
- Pentagon – a geometric shape with five equal sides and five 108° angles
- Dodecahedron – a three-dimensional geometric shape that has 12 faces (regular pentagons), 20 vertices, and 30 edges

Prerequisite Skills

Students should have basic knowledge of geometric shapes and know how to draw a pentagon. If not, directions for drawing a pentagon using a compass or protractor may be found in middle school math textbooks or in the links below.

Procedure

1. General Notes:
   - For grade 5-6 students, the educator may want to demonstrate each step of drawing the pentagon as students follow along.
   - Use a good quality latex spray paint; oil-based paints containing organic solvents tend to melt the Styrofoam.
   - When constructing the clathrate cage, the educator should demonstrate each step as students follow along.
   - Be sure the skewers are inserted into the middle of the Styrofoam balls.
2. (Advance Preparation) Spray paint skewers and Styrofoam balls:
   a. Paint ten skewers light blue to represent hydrogen bonds between water molecules
   b. Paint one skewer red to represent the electrostatic bonds in the methane molecule
   c. Paint twenty 1/2" Styrofoam balls dark blue to represent water molecules
   d. Paint one 1-1/2" Styrofoam ball black to represent the carbon atom
   e. Note: the four 1" Styrofoam balls remain white to represent hydrogen atoms
   f. Cutting skewers at an angle, cut light blue skewer sticks into thirty 3-3/4" lengths. Cut the red skewer stick into four 2" lengths.
3. Lead an introductory discussion of how mathematical models help us understand science concepts.
4. Tell students that they will be using concepts and skills they have learned in the math class to build a pentagonal dodecahedron, a clathrate cage, and methane hydrate model.
5. Give each student group a copy of the *Methane Model Construction Student Handout*. Have each group complete Part 1.
6. Have each group complete Part 2, or do this part as a demonstration.
7. Count the vertices, edges, and faces of the completed dodecahedron. Discuss the symmetry of the dodecahedron.

Be sure students understand that each of the dark blue Styrofoam balls represents a water molecule consisting of two hydrogen atoms and one oxygen atom. To keep the model simple, we don't show all of these atoms separately.

Resources

http://wiki.answers.com/Q/How_would_you_draw_a_regular_pentagon
http://www.barryscientific.com/lessons/polygon.html

Common Core State Standards for Mathematics

Grade 5:

5.G.B.4. Classify two-dimensional figures in a hierarchy based on properties.

Grade 6:

7.G.A.2. Draw (freehand, with ruler and protractor, and with technology) geometric shapes with given conditions.

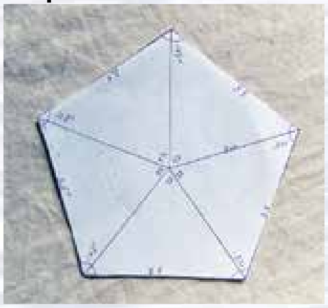
High School:

HSG.MG.A.1. Use geometric shapes, their measures, and their properties to describe objects.

Methane Hydrate Model Construction Guide

Part 1 – Build half of a pentagonal dodecahedron

Step 1



1. Draw a pentagon on paper and cut it out. Each side of the pentagon should be four inches long (72° angles). Option: Use Adobe Illustrator or Corel Draw.

Step 2

2. Trace the paper pentagon onto cardboard or card stock and cut it out. Your group will need 7 pentagons.

Step 3

3. Lay one pentagon on a flat surface and surround it with five more pentagons matched side to side. Tape the five outside pentagons to the center pentagon.

4. Carefully pull up one pair of pentagons and tape their common sides together. Repeat until the five pentagons have been taped together, forming a five-sided bowl. This is half of a pentagonal dodecahedron.

Part 2 – Build the Model

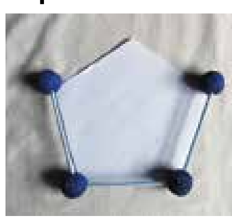
Build the clathrate cage:

1. Place the 7th pentagon on a flat surface. Place a blue stick on one side and two blue balls at each end. Carefully insert the end of the blue stick into the middle of each ball. Repeat with three more balls and four more sticks to form a ball-and-stick pentagon.

Step 1a

Step 1b

Step 1c



Step 1d

Step 1e

Step 2

2. Place the ball-and-stick pentagon in the dodecahedron half – be careful, it will lie approximately an inch up from the bottom. The dodecahedron half (bowl) is used as a template to build the ball and stick dodecahedron with the correct stick angle.

3. Place five light blue sticks inside the center of each of the dark blue balls using the dodecahedron half as a guide for the correct stick angle. It's very important to insert the sticks into the center of the ball at the same angle as the side of the dodecahedron half.

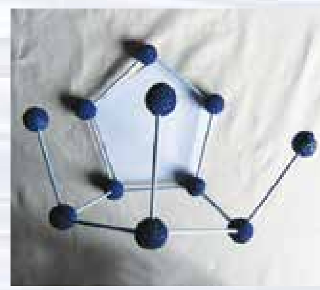
Step 3

4. Insert a dark blue ball on top of each light blue stick. Carefully remove the incomplete cage from the dodecahedron half and place it on a flat surface.

Step 4

5. Use the 7th pentagon to complete the bottom half of the cage. Turn the ball-and-stick model onto one side and, using the pentagon to determine the correct angle, insert a light blue stick into the center of the two dark blue balls. Then, attach another dark blue ball to connect the two light blue sticks you've just attached. This makes the second face and second pentagon of the cage. The first face was the bottom.

Step 5

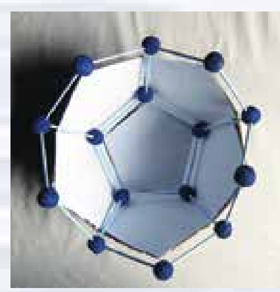


6. Repeat Step 5 four more times to form the remaining faces for the bottom half of the cage.

7. Repeat Steps 1, 2, and 3 to construct the top half of the cage.

8. Carefully place the bottom half of the cage into the bottom of the cardboard bowl.

Step 8

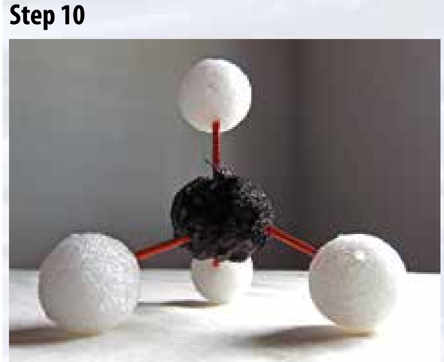


9. Carefully, attach the two halves of the cage together: Working together with your partners, hold the top half of the cage over the bottom half. The two halves will only fit together one way. Rotate the top half until all of the unattached sticks line-up with a ball. Insert each light blue stick into the center of the corresponding dark blue ball.

Build the Methane Molecule:

10. Insert four red sticks into the black Styrofoam ball so that they are evenly spaced (when the model is placed on a flat surface, three of the sticks and the black ball should look like a tripod with the fourth stick pointing straight up). Attach a white Styrofoam ball to the other end of each of the red sticks.

Step 10

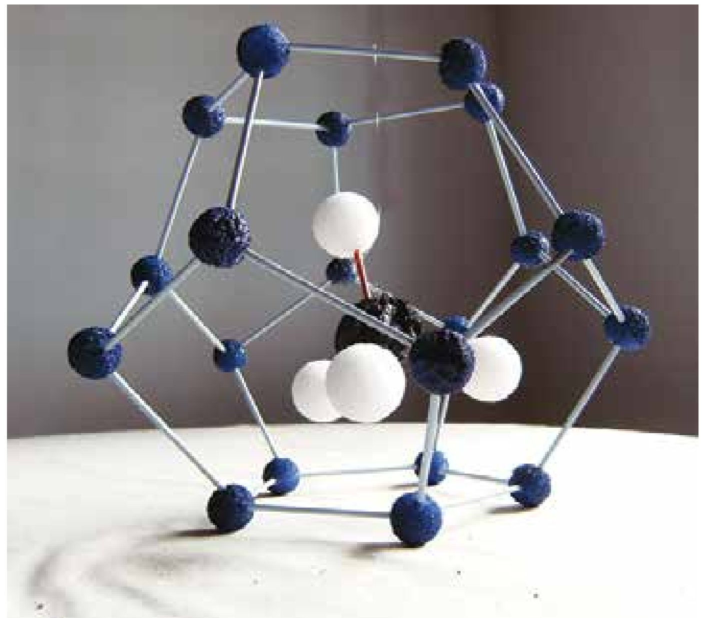


The NOAA Ship *Okeanos Explorer* Education Materials Collection

Assemble the Methane Hydrate Model:

11. Suspend the methane molecule model in the middle of the clathrate cage by attaching fishing line from one of its covalent bonds (red sticks) to two opposing hydrogen bonds (light blue sticks) at the top of the cage. Your Methane Hydrate Model is finished!

Step 11



All photographs by Mellie Lewis, Teacher Facilitator, The College of Exploration.

Notes:

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*

Section 4: Key Topic – Energy

Oceans of Energy

Focus
Ocean energy

Grade Level
7-8 (Physical Science/Earth Science)

Focus Question
What forms of energy are found in the ocean, and how might these be used by humans?

Learning Objectives
- Students will describe forms of energy.
- Students will explain how different forms of energy are used by humans.
- Students will explain at least three ways that energy can be obtained from the ocean.

Materials
- Copies of *Ocean Energy Investigation Guide*, one for each student group
- Copies of the *Micro-Hydro Electric Generators Construction Guide*, one for each student group
- Materials for constructing Micro-Hydro Electric Generators (For each student group):
  - 3.8 liter (1 gal) plastic jug (a rectangular jug used for cooking oil, orange juice or antifreeze is better than a square jug)
  - 6 or 8 plastic spoons
  - 90 m (300 ft) enameled magnet wire, 26 gauge or 30 gauge (inexpensive sources include Adapt Industries (*http://adaptengineering.com/wiresize.htm*) and the Electronic Goldmine (*http://www.goldmine-elec.com/*; check listings for solenoids and relays that can usually be opened to gain access to coils that contain many feet of magnet wire)
  - Lego® bricks (order from *http://shop.lego.com/en-US/Pick-A-Brick-11998*; alternate sources include *http://www.bricklink.com/; http://www.peeron.com/*)

    2 – cross axles, 80 mm long (Lego® part number 3707)

    3 – wheel rim, 18 mm diameter x 14 mm, with cross (Lego® part number 55982)

    2 – wheels with spokes, 56 mm diameter (Lego® part number 55817)

    2 – bush for cross axle (Lego® Technic part number 3713)

Ocean Exploration and Research

(depending upon the size of your plastic jug, you may also need one or two additional 80 mm cross axles and two axle connectors, Lego® Technic part number 6538c)
  - 1 – Piece of floral foam cut to the same diameter as the wheels with spokes
  - Foamcore, approximately 9 inches x 12 inches
  - 4 - Ceramic or rare earth magnets (Radio Shack Part Number 64-1883 or equivalent)
  - 4- brass paper fasteners, 2.5 cm (1 in) long
  - Safety glasses, 1 pair for each student
- Tools and Supplies that may be shared among student groups:
  - Inexpensive multimeter capable of measuring 0.1 volt AC (*e.g.* Extech MN15A)
  - 2 - Jumper cables (Radio Shack Part Number 278-1157 or equivalent)
  - Vinyl electrical tape
  - Ruler
  - Awl, ice pick, or 3-1/2 inch nail
  - Hot glue gun
  - Glue sticks
  - Spray glue or rubber cement
  - Utility knife
  - Pencil sharpener
  - Felt tip marker
  - Magnetic compass (optional)
  - Wire cutters (diagonal side-cutting type)
  - Gloves
  - 1 sheet sandpaper, 100 grit or finer

Mention of commercial names does not imply endorsement by NOAA.

Audiovisual Materials
- (Optional) Images of ocean energy technologies (see Learning Procedure Step 1) or computer projector

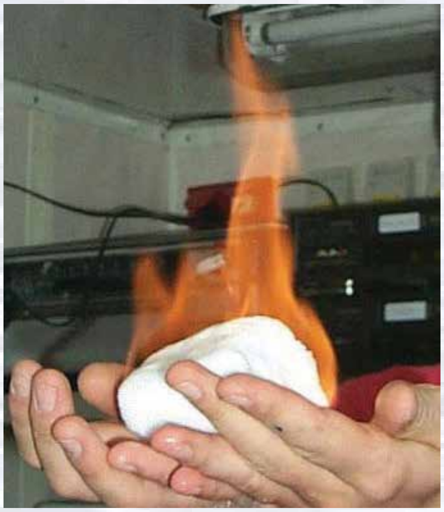
Teaching Time
Two or three 45-minute class periods, plus time for student research and hands-on activity

Seating Arrangement
Five groups of two to four students

Maximum Number of Students
32

Key Words and Concepts
Energy
Salinity gradient energy
Wave energy
Tidal energy
Current energy
Thermal energy
Solar energy
Wind energy
Geothermal
OTEC
Methane hydrates

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,



Methane hydrate looks like ice, but as the "ice" melts it releases methane gas which can be a fuel source. Image credit: Gary Klinkhammer, OSU-COAS

educators may need to adapt the language and instructional approach to styles that are best suited to specific student groups.

The ocean is Earth's largest collector and storage system for solar energy, as well as the environment that receives a great deal of the heat energy produced by the Earth itself. The energy contained in Earth's ocean is enormous; a small fraction could power the world. Yet, humans presently use almost none of this energy.

Ocean energy exists in several forms, including heat energy, mechanical (motion) energy, and chemical energy. Methane hydrates are one example of an abundant potential energy source that is virtually untapped. Hydrothermal vents and undersea volcanoes are manifestations of geothermal energy that may also have significant potential for human use. Because Earth's ocean is 95% unexplored, there are almost certainly yet-to-be-discovered areas that are particularly promising as sites for harvesting one or more forms of ocean energy. The mission of the NOAA Ship *Okeanos Explorer* is not specifically targeted toward developing ocean energy, but the ship's voyages of exploration will gather new information including undiscovered geologic formations, temperature gradients, currents, and geothermal processes that will contribute directly to efforts to enhance our use of ocean energy resources. Diving Deeper, page 26, provides an overview of ocean energy resources and some of the technologies being developed to harvest them.

This lesson guides student investigations into various forms of ocean energy and some of the technologies used to capture this energy for human use.

Learning Procedure

1. To prepare for this lesson:
   - Review introductory information on the NOAA Ship *Okeanos Explorer* at *http://oceanexplorer.noaa.gov/okeanos/welcome.html*. You may also want to consider having students complete some or all of the lesson, *To Boldly Go*. . . .
   - Review the Learning Procedure steps, procedures on the *Ocean Energy Investigation Guide*, and information in Appendix 1.
   - Assemble materials, tools, and supplies for the *Micro-Hydro Generator Construction* activity. Depending upon your students' manual dexterity and level of maturity, you may want to do some of the cutting and drilling in advance or recruit parent volunteers to assist with this preparation.
   - You may want to download images of various ocean energy technologies from the Web sites cited in Appendix 1, or bookmark these sites if you are using a computer projection system.

2. Provide each student group with a copy of the *Ocean Energy Investigation Guide*, and have them complete Questions 1 and 2 (you may want to assign this as homework in a prior class). Briefly discuss the definition of energy as the ability to do work. Be sure students understand that this definition includes stored (potential) energy as well as working (kinetic) energy. Briefly discuss the various forms of energy. Students may have encountered some variation in terms and descriptions depending upon their specific research sources. For example, the term "mechanical energy" is sometimes confined to potential energy of objects under tension, while the kinetic energy of objects in motion is described as "motion energy." Key points include:
   - **Thermal Energy (Heat)** – kinetic energy of vibration and movement of atoms and molecules within substances; increasing thermal energy causes atoms and molecules to move and collide more rapidly

- **Radiant Energy (including Light, Radio Waves, Microwaves, and X-rays)** – kinetic energy of electromagnetic waves; some definitions refer to radiant energy as the kinetic energy of a stream of photons, since some properties of electromagnetic waves resemble properties of particles; according to quantum field theory, both definitions are correct
- **Mechanical Energy** – potential energy stored in objects by tension, such as compressed springs and stretched rubber bands; kinetic energy in moving objects and substances
- **Electrical Energy** -- kinetic energy of electrons moving through a conductor
- **Chemical Energy** -- potential energy stored in the bonds of atoms and molecules
- **Nuclear Energy** – potential energy stored in the nucleus of an atom
- **Gravitational Energy** – potential energy stored in an object that may be accelerated by a gravitational force; if an object is raised above Earth's surface it may be accelerated by Earth's gravity; gravitational energy increases with increasing height and/or mass of the object
- **Sound Energy** – kinetic energy moving through a substance (such as air or water) in waves causing the substance to vibrate

Iceworms *(Hesiocaeca methanicola)* infest a piece of orange methane hydrate at 540 m depth in the Gulf of Mexico. During the Paleocene epoch, lower sea levels could have led to huge releases of methane from frozen hydrates and contributed to global warming. Today, methane hydrates may be growing unstable due to warmer ocean temperatures. Image credit: Ian MacDonald. *http://oceanexplorer.noaa.gov/explorations/06mexico/background/plan/media/iceworms_600.jpg*

Be sure students understand that our experience with energy frequently involves conversions between these forms. For example, when we use electrical energy in a battery, that energy results from a conversion of chemical energy in the components of the battery to electrical energy of electrons moving through a circuit. Similarly, when we feel heat from the sun, we are experiencing a conversion of electromagnetic energy from the sun to thermal energy in the atoms and molecules of our bodies. In the latter example, there actually are additional conversions involved in our "feeling" the heat: the thermal energy in our bodies is converted to chemical energy in nerves that causes a series of chemical reactions that eventually cause our brain to perceive the heat.

You may also want to remind students about the First and Second Laws of Thermodynamics:

First: Energy can be changed from one form to another, but cannot be created or destroyed.

Second: Converting one form of energy into another form always involves a loss of usable energy.

Make sure students understand that the electricity we use is a secondary source of energy (sometimes referred to as an "energy carrier"). Since we are not presently able to capture and control natural sources of electricity (*e.g.*, lightning), we have to use another energy source to make electricity. The chemical energy of coal and petroleum fuels, the mechanical energy of moving water or wind, and the nuclear energy of radioactive materials are common primary energy sources that are converted into electrical energy. The reason for doing this is that it is much easier to move electricity than it is to move coal, wind, or nuclear fuels. Point out that the problem of how to capture, control, and distribute energy from a given source is a key issue in developing new energy sources for human activities. Hydrogen is another energy carrier that is being considered for storing and transporting excess energy produced from offshore ocean energy sources such as wind, solar, and waves (*http://ocsenergy.anl.gov/guide/hydrogen/index.cfm*).

3. Briefly discuss the mission of NOAA Ship *Okeanos Explorer*, highlighting the fact that 95% of Earth's ocean is unexplored, and the potential importance of ocean exploration to major issues facing our society. Brainstorm various sources of energy that may be found on and in the ocean, and record these on a list that is visible to the students. Ideally, the list will eventually include:

   Salinity Gradient (Osmotic) Energy
   Wave Energy
   Tidal Energy
   Current Energy
   Thermal Energy
   Solar Energy
   Wind Energy
   Hybrids
   Methane Hydrates

   It is not very likely that students will mention all of these; that's okay, just leave unmentioned sources off the list for now. For each energy source on their list, have students discuss how the energy might be captured, controlled, and distributed in a useful form. In many cases, this will involve converting the energy to electricity. Briefly review the basic process through which most electricity is produced:

   The fundamental principle underlying electricity generators was discovered in 1831 by Michael Faraday: When a magnet is moved inside a coil of wire, an electrical current flows in the wire. The basic parts of a generator are a series of insulated coils of wire arranged to form a stationary cylinder, a magnet that rotates inside the cylinder, and a source of energy (because electricity is a SECONDARY energy source) to rotate the magnet. Steam turbines, internal-combustion engines, gas combustion turbines, water turbines, and wind turbines are the most common devices used to rotate the magnets in electricity generators. Steam turbine power plants powered by coal and nuclear energy produce about 70% of the electricity used in the United States. These plants are about 35% efficient, which means that for every 100 units of primary energy consumed by the generator, only 35 units are converted to usable electricity.

   Assign one or more ocean energy sources from the complete list (above) to each student group. Provide each group with a copy of the *Ocean Energy Investigation Guide*. You may also want to provide some of the references cited in Step 1, or allow students to discover them on their own—a Web search on "ocean energy" will produce most of these and millions of others (no kidding!). Have students complete the remaining questions on the *Investigation Guide*, as well as the Micro-Hydro Electric Generator activity.

   Note: Students may also mention biomass as a potential form of ocean energy. Marine algae have been cultivated for centuries as food, and a variety of projects have been proposed that use seaweed as a feedstock for biofuels and electricity generation (biopower). Only a few small-scale projects have actually been implemented, and biomass is not normally included in discussions of ocean energy. Even so, marine biomass may prove to be important on a local scale, and you may want to add this to the list.

4. Have each student group present the results of their investigations, then lead a discussion of which ocean energy technologies appear to be most promising. Students should realize that energy storage and distribution are major issues for all of these technologies. Ask students whether there are other types of "energy carriers" that may be useful in addition to electricity and hydrogen. If a hint is needed, suggest considering the various forms of energy discussed in Step 2; could one or more of these provide an alternative energy carrier? A land-based example is using wind power to pump water into an elevated reservoir, so that it can be released in a controlled way through an electricity-generating turbine when electricity is needed.

The BRIDGE Connection

http://www2.vims.edu/bridge/DATA.cfm?Bridge_Location=archive1005.html – An activity guide: Waves – An Alternative Energy Source

The "Me" Connection

Have students write a brief essay describing how they might use alternative energy resources to significantly reduce their personal consumption of energy derived from fossil fuels.

Connections to Other Subjects

English/Language Arts, Mathematics, Social Studies

Assessment

Students' responses to *Investigation Guide* questions and class discussions provide opportunities for assessment.

Extensions

1. Follow events aboard the *Okeanos Explorer* at *http://oceanexplorer.noaa.gov/okeanos/welcome.html*.
2. Visit *http://www.re-energy.ca* for additional hands-on renewable energy projects.
3. Visit *http://www.simplemotor.com/*, a site originally established by an 11th grade student to share his investigations into easy-to-build electric motors.

Multimedia Discovery Missions

http://www.learningdemo.com/noaa/ Click on the links to Lesson 11 for interactive multimedia presentations and Learning Activities on Energy from the Oceans

Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

(All of the following Lesson Plans are targeted toward grades 7-8)

Friendly Volcanoes (Submarine Ring of Fire 2004 Expedition)

http://oceanexplorer.noaa.gov/explorations/04fire/background/edu/media/RoF.friendlyvol.pdf

Focus: Ecological impacts of volcanism in the Mariana Islands (Life Science/Earth Science)

Students will describe at least three beneficial impacts of volcanic activity on marine ecosystems and will explain the overall tectonic processes that cause volcanic activity along the Mariana Arc.

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 (Physical Science)
Students will 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.

It's Going to Blow Up!
(from the New Zealand American Submarine Ring of Fire 2005 Expedition)
http://oceanexplorer.noaa.gov/explorations/05fire/background/edu/media/rof05_explosive.pdf
Focus: Volcanism on the Pacific Ring of Fire (Earth Science)
Students will be able to describe the processes that produce the "Submarine Ring of Fire," explain the factors that contribute to explosive volcanic eruptions, identify at least three benefits that humans derive from volcanism, describe the primary risks posed by volcanic activity in the United States, and will be able to identify the volcano within the continental U.S. that is considered most dangerous.

Other Resources

See page 217 for Other Resources.

Next Generation Science Standards

Lesson plans developed for Volume 1 are correlated with *Ocean Literacy Essential Principles and Fundamental Concepts* as indicated in the back of this book. Additionally, a separate online document illustrates individual lesson support for the Performance Expectations and three dimensions of the Next Generation Science Standards and associated Common Core State Standards for Mathematics and for English Language Arts & Literacy. This information is provided to educators as a context or point of departure for addressing particular standards and does not necessarily mean that any lesson fully develops a particular standard, principle or concept. Please see: *http://oceanexplorer.noaa.gov/okeanos/edu/collection/wdwe_ngss.pdf.*

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:
oceanexeducation@noaa.gov

For More Information

Paula Keener, Director, Education Programs
NOAA Office of Ocean Exploration and Research
Hollings Marine Laboratory
331 Fort Johnson Road, Charleston SC 29412
843.762.8818   843.762.8737 (fax)
paula.keener-chavis@noaa.gov

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Ocean Energy Investigation Guide

Background Research

1. What is the definition of energy?

2. List and briefly describe eight different forms of energy.

3. Your teacher will assign your group one or more ocean energy resources to investigate. Your research should include:

Assigned energy resource:

- Identification of the type of energy involved (radiant, mechanical, etc.);

- A description of technologies that can be used to capture energy from this resource;

- Information about installations that are proposed or are actually using these technologies to obtain energy; and

- Identification of major problems or obstacles to obtaining useful energy from this resource.

4. What kind of information might be obtained by the NOAA Ship *Okeanos Explorer* from unexplored areas in Earth's ocean that could enhance understanding and potential development of this ocean energy resource?

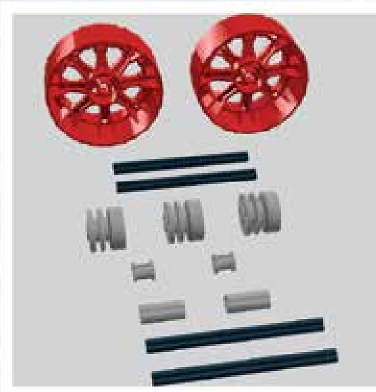
Micro-Hydro Electric Generator Construction Guide

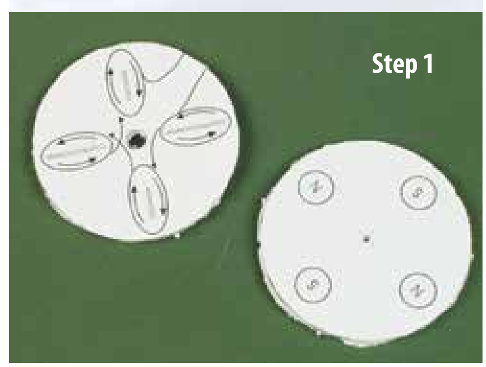
Read ALL of the directions before beginning construction.
When a magnet is moved inside a coil of wire, an electrical current flows in the wire. The basic parts of a generator are a series of insulated coils of wire, one or more magnets, and a source of energy to rotate the coils or the magnets. The generator you are about to build consists of four coils that remain stationary (called the stator), four magnets that rotate around the coils (called the rotor), and a paddle wheel that can capture the energy of falling water.

There are many ways to make and assemble these basic parts. The original design on the Re-energy.ca Web site uses a paddle wheel assembly made with plastic spoons, a cork, a dowel, and several pieces of plastic tubing. The following instructions use an alternative paddle wheel design that uses Lego® parts and floral foam to avoid the need to drill and cut slots into a cork. The specified Lego® parts were available at the time of printing, but may not be available in the future. Substitute parts and alternative designs can be easily identified by considering how each part functions in the assembled paddle wheel:

- The two wheels are used to hold the foam disc on the cross axle, and the hubs of the wheels have a cross-shaped hole that prevents the wheels from slipping on the axles as they rotate.
- The cross axles are used to transfer the energy and motion of the paddle wheel to the rotor disk, and to hold the paddle wheel in place inside the plastic jug.
- The wheel rims are used to hold the axles in place on the jug and to provide a gluing surface that allows the rotor disk to be attached to the paddle wheel assembly.
- Bushes are used to adjust the position of the rotor disk on the axle so that it can rotate as closely to the coil as possible without actually touching the coils.

Lego Bricks





Step 1

Construction Procedure

1. Glue the patterns for the rotor and stator (found on Page 145) onto a piece of foamcore using spray glue or rubber cement. Be sure the glue completely coats the side of the paper pattern that will be attached to the foamcore. Water-based (white) glue is not recommended because the paper pattern is likely to wrinkle and the final bond will not be as strong. When the glue has dried, use a utility knife to cut the rotor and stator disks from the foamcore sheet. Wear gloves when using the utility knife, and be careful! Use a cutting board, piece of scrap wood or several sheets of cardboard as a cutting surface.

Step 2

Step 3

Step 5

Step 7

Step12

2. Use an awl, ice pick, or nail to punch a small hole through the center of the Rotor Disk as indicated on the pattern. Use the utility knife to make a hole approximately 12 mm diameter in the center of the Stator Disk. Cut four slits through the disk as indicated. Be sure to make the 12 mm diameter hole ONLY in the Stator Disk. The hole in the center of the Rotor Disk should be less than 3 mm diameter.

Assemble the Stator

3. Make a form for winding your coils by cutting a 1 1/4 inch x 3 1/4 inch piece of cardboard, folding it in half, and taping the ends together with electrical tape. This form is called a jig.

4. Cut eight pieces of electrical tape about 3 inches long, and set aside.

5. Wind the first coil on the cardboard form. Beginning about 75 mm from the end of the wire, wrap 200 turns around the short dimension of the form so the diameter of the coil will be about 30 mm. Keep the turns close together to form a neat coil. Do not wrap too tightly, or it will be difficult to remove the form when the coil is finished.

6. Slip the coil off the jig and secure the wraps with two pieces of electrical tape. Be sure you have leads about 75mm long at both ends of the coil.

7. Repeat Steps 5 and 6 to make three more coils.

8. Place one of your coils flat on a table, and hold one of the lead wires with your left thumb and forefinger. Now imagine that electrons are flowing from your left hand into the coil. Identify the direction (clockwise or counterclockwise) that the electrons will flow as they move around the coil. Notice that if you hold the other lead wire instead, or turn the coil over, the direction of electron flow will be opposite.

9. Orient the coil so that the imaginary flow of electrons will be counterclockwise, and place the coil onto the Stator Disk in position [1]. The lead wire that you are holding between your left thumb and forefinger should be extending off of the bottom edge of the disk as shown by the feathered arrow on the pattern. Use a pencil to trace around the inside of the coil. Set the coil aside, being sure to keep track of the direction of the two lead wires.

10. Place a large bead of hot glue around the outside of the traced line, then press the coil into place on the pattern and hold it until the glue sets. BE SURE THE WIRES HAVE THE SAME ORIENTATION AS IN STEP 9!

11. Orient another coil so that the imaginary flow of electrons will be clockwise, and place the coil onto the Stator Disk in position [2]. The lead wire that you are holding between your left thumb and forefinger should be near the wire coming from the top of the coil installed in Step 10. Trace around the inside of the coil and glue it into place as in Step 10.

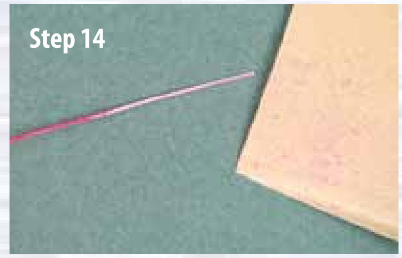
12. Install a third coil in position [3] so that the imaginary flow of electrons will be counterclockwise, and a fourth coil in position [4] so that the imaginary flow of electrons will be clockwise, as shown on the pattern. IT IS VERY

IMPORTANT THAT THE COILS ALTERNATE BETWEEN CLOCKWISE AND COUNTERCLOCKWISE!

13. When you are sure you have arranged the coils correctly, trim the lead wires between adjacent coils so that they are about 3 cm long. Do not cut the lead wires extending from the bottom of the Stator; these should still be about 75 mm long.

14. Use a small piece of sandpaper to remove about 18 mm of the enamel insulation from the ends of all lead wires. Connect adjacent coils by twisting the bare ends of the lead wires together. Be sure to leave two leads unconnected as shown on the pattern and in the photograph. Cover the twisted connections with short pieces of electrical tape.

15. Check your connections: Set your multimeter to measure resistance (ohms) and connect the leads of the multimeter to the two free ends of the stator coil assembly. If your connections are good, the resistance should be very low (about 10 ohms or less). If the resistance is very large, two or more of the connections are not good, probably because the enamel insulation was not completely removed from the ends of the wires. Note that this test does not check whether you have correctly arranged the coils with alternating clockwise-counterclockwise windings.



Assemble the Rotor

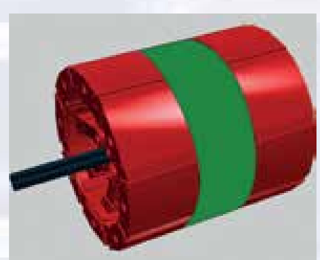
16. Use a magnetic compass to determine the north and south pole of each magnet. Mark the polarity on the appropriate faces of each magnet. If you don't have a magnetic compass handy, just arrange your magnets so they are stuck together. The faces of each pair of magnets that are stuck together have opposite polarity, so you can arbitrarily label the face of one magnet "N" and the face of the other magnet "S." Continue this process until all magnets in the stack are labeled. For the generator, the important thing is that the magnets are arranged on the Rotor Disk so that alternating north and south poles are facing up.

17. Attach the magnets to the Rotor Disk as indicated on the pattern. Put a small glob of glue onto the pattern, then press the magnet into place. Be sure you have alternating north and south poles facing up.

Assemble the Paddle Wheel

18. Place the piece of floral foam between the two wheels with spokes so that all three pieces are concentric. Insert one of the cross axles through all three pieces.

Step 18



19. Mark six or eight insertion points on the floral foam using the spokes of the wheels as a guide.

20. Use wire cutters to cut the handles off of six or eight plastic spoons, depending upon the number of insertion points marked in Step 19. **(Wear eye protection!)** Leave about 10 mm of the handle attached to the bowl of each spoon. For brittle plastics, the best cuts are made by using the wire cutters to nick the edge of the handle. This will cause the plastic to crack across the entire width of the handle.

21. Insert the spoons into the floral foam at the marked points. Push the spoons in until the bowl of the spoon meets the foam.

22. Glue each spoon into place with hot glue. Be sure the blob of glue contacts the wheels on both sides of the assembly as well as the spoon. The purpose of the floral foam is only to hold the spoons in position until they can be glued; it is not strong enough to hold the spoons when the generator is operating.

23. Remove the cross axle from the paddle wheel assembly.

Assemble the Generator

24. Cut the bottom off of the plastic jug. Hold your paddle wheel inside the jug to determine how it needs to be oriented so that it can spin freely when attached to the cross axles. If your jug has a handle on the side, this may interfere with the paddle wheel rotation unless it is properly oriented.

25. Use a ruler to find the center of the two sides that will support the cross axles. Mark the center with a felt tip marker, being sure to allow enough space inside the container for the paddle wheel to rotate freely.

26. Use an awl, ice pick, or nail to punch a small hole (approximately 3 mm diameter) through each of the marked points.

27. Test-fit the cross-axles through the holes. If they seem to stick, slightly enlarge the holes with the drill or utility knife.

28. Place the Stator assembly on the outside of the container so that the stator's center hole is over the hole in the container. Push an awl, ice pick, or nail through the slits in the Stator Disk to mark their location on the container.

Step 31

29. Use the utility knife to make four small slits on the side of the container to match the slits on the Stator Disk. Be careful! Wear gloves.

30. Attach the Stator Disk to the container with brass paper fasteners. Bend the tabs of the fasteners flat against the inside of the container.

31. Put an 18 mm diameter wheel rim onto one end of a 80 mm long cross axle. Make another rim-axle assembly the same way. Depending upon the size of your jug, you may need to increase the length of the rim-axle assemblies by adding another cross axle and a cross axle extension.

Note: The side of the jug has been cut out for the purpose of illustrating this step.

32. Put one of the rim-axle assemblies through one of the holes in the jug so that the rim is inside the jug. Put the other rim-axle assembly through the remaining hole in the jug so that the rim is also inside the jug.

33. Position the Paddle Wheel inside the jug and slide one of the rim-axle assemblies toward the Paddle Wheel. Push on the outside end of the axle so that the inside end of the axle slides about half-way into the Paddle Wheel. Push the outside end of the remaining axle into the other side of the Paddle Wheel. The Paddle Wheel should now be suspended inside the jug.

34. Place your thumb on the outside end of one axle, and grasp the rim inside the jug with your forefinger and middle finger. Slide the rim along the axle until it touches the side of the jug. Repeat this procedure with the axle and rim on the other side of the Paddle Wheel. Adjust the rims so that the Paddle Wheel is centered inside the jug.

35. Put a bush on the cross axle on the side of the jug without the Stator Disk, and push the bush along the axle until it touches the side of the jug.

36. Slide a 18 mm diameter wheel rim onto the other cross axle, then slide the Rotor Disk onto the cross axle so that the magnets face the Stator coils and are about 6 mm or less away from the coils.

37. Adjust the Rotor Disk so that it spins without wobbling and without having any of the magnets hit the coils. Use another wheel rim to hold the Rotor Disk in this position. Once you have tested your generator (Step 38), you may want to use some hot glue to hold the pieces of the Rotor axle assembly in their proper positions.

Test Your Generator!

38. Place your assembled generator under a faucet so the water will hit the spoons and turn on the water. The rotor should spin rapidly. Set your multimeter to measure AC volts, and connect the leads of the multimeter to the two free ends of the stator coil assembly. Measure the voltage produced by your generator.

How It Works

When a coil of wire moves through a magnetic field, an electric current is produced in the coil. If you hold the coil in your right hand with your fingers curled around it, so that your fingers point in the direction of the magnetic field, your thumb will point in the direction of conventional current flow. This is called the Right Hand Thumb Rule.

The basic principle that makes the generator work is called Faraday's Law, which states that a changing magnetic field will induce a voltage in a coil of wire. The voltage is proportional to the number of turns on the coil and the rate at which the magnetic field changes. So, more coils and/or faster rate of change means higher voltage. The "changing" part is key; if the magnetic field doesn't change, there's no voltage. This is why we have to arrange the magnets so that they alternate between north and south poles facing up, and why we have to spin the rotor. When the rotor spins, the magnetic field at any point under the rotor is constantly changing, and the direction of the magnetic field switches back and forth as north and south poles pass overhead. The faster the spin, the more voltage we get.

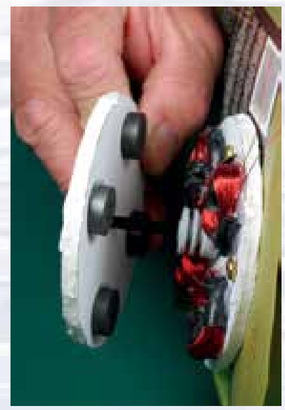
The direction of current flow in the coils is related to the direction of the magnetic field from the magnets. So, as north and south poles pass over the coil, the direction of the magnetic field switches back and forth, and this causes the direction of the current flowing in the coil to also switch back and forth. Since the magnets are arranged so that north and south poles alternate on the rotor, the direction of current flowing in any coil is always opposite to the direction of current flowing in the coils on either side.

If we arrange the coils so their windings are all clockwise, then at any instant the current will be flowing in one direction in two of the coils and the current in the other two coils will be flowing in the opposite direction; so the currents in the four coils will cancel each other out and there is no net current flow. As the rotor turns, the currents reverse, but there are still two coils with currents flowing in one direction while the other two coils have currents flowing in the opposite direction; so no net current flows out of the generator.

But if we alternate clockwise coils with counterclockwise coils, the direction of the currents flowing through the coils is the same, so we have a current flow! As the magnets pass over the coils, the direction of the current flow goes back and forth, so we get alternating (AC) current.

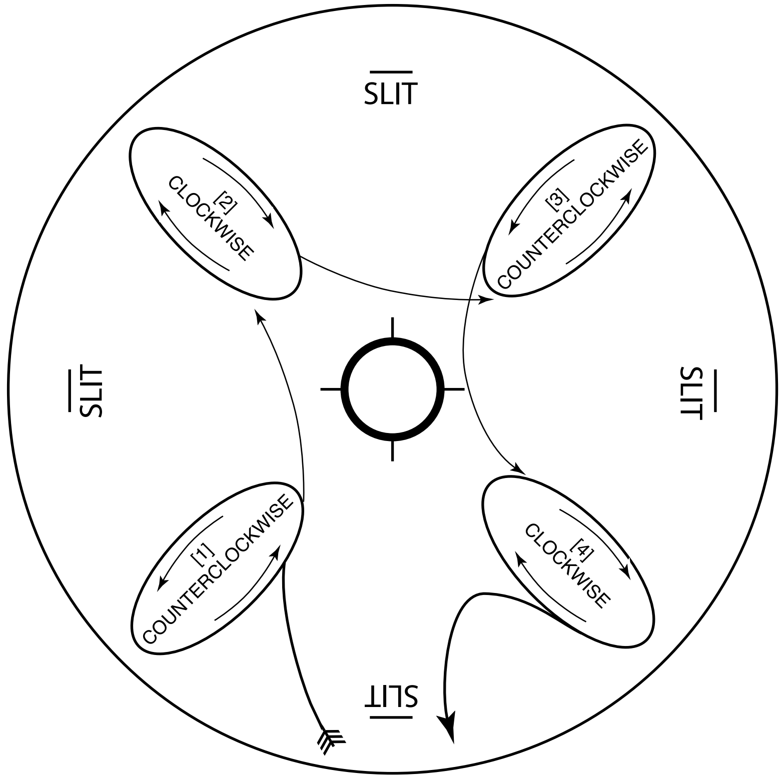
Step 35

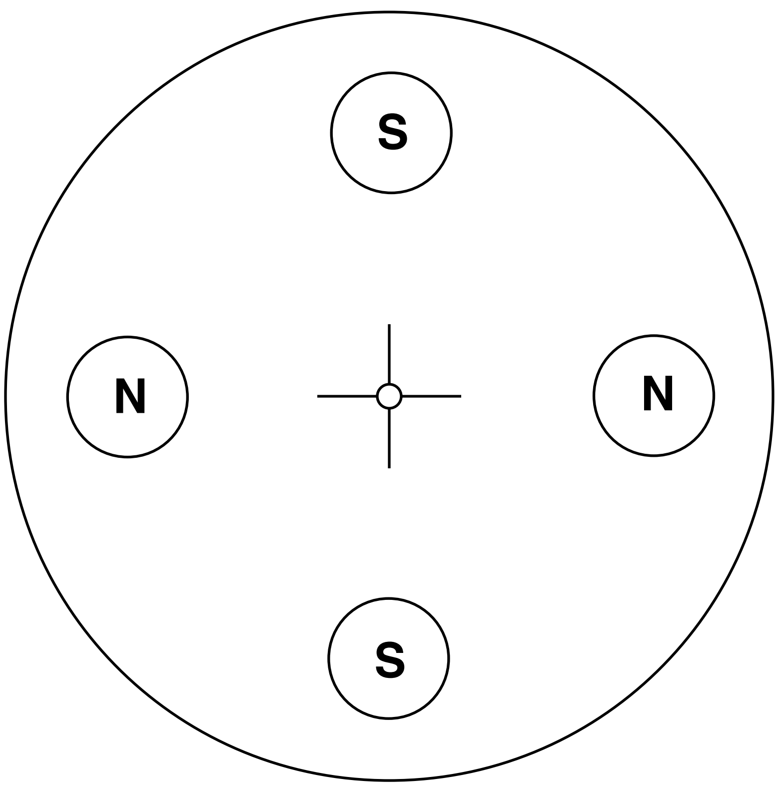
Step 36



Step 37

Stator Pattern





Rotor Pattern

Notes:

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

Section 4: Key Topic – Energy

What's the Big Deal?

[adapted from the 2003 Windows to the Deep Exploration]

Focus

Significance of methane hydrates

Grade Level

9-12 (Earth Science)

Focus Question

Why should a NOAA Ocean Exploration expedition focus investigations on methane hydrates?

Learning Objectives

- Students will define methane hydrates, describe where these substances are typically found, and explain how they are believed to be formed.
- Students will describe at least three ways in which methane hydrates could have a direct impact on their own lives.
- Students will describe how additional knowledge of methane hydrates expected to be found during Ocean Exploration and Research expeditions could provide human benefits.

Materials

- Copies of *Methane Hydrate Investigation Guide*, one for each student group
- Copies of the *Methane Hydrate Model Construction Guide*, one for each student group
- Materials for constructing a methane hydrate model:

  For constructing a pentagon:
  - Paper, unlined 8-1/2" X 11"
  - Pencil
  - Protractor or compass

  For constructing the half dodecahedron, clathrate cage, methane molecule and methane hydrate model:
  - Scissors
  - Cardboard or card stock (enough to make 7 pentagons)
  - Ruler, 12-inch
  - 11 - Bamboo skewers, 12" long
  - 20 - Styrofoam balls, 1/2" to 1" diameter
  - 4 - Styrofoam balls, 1" diameter
  - 1 - Styrofoam ball, 1-1/2" diameter
  - Tape, wrapping or strapping

Ocean Exploration and Research

- Spray paint, water-based latex; dark blue, light blue, red, and black
- Fishing line, 8 lb test; or light colored thread

Audiovisual Materials

- None

Teaching Time

One or two 45-minute class periods plus time for student research

Seating Arrangement

Five groups of 3-6 students

Maximum Number of Students

32

Key Words and Concepts

Cold seeps
Methane hydrate
Methanogenic Archaea
Clathrate
Greenhouse gas
Greenhouse effect
Paleocene extinction
Cambrian explosion
Alternative energy
Natural hazards

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.

> ***For kicks, oceanographer William P. Dillon likes to surprise visitors to his lab by taking ordinary-looking ice balls and setting them on fire. 'They're easy to light. You just put a match to them and they will go,' says Dillon, a researcher with the U.S. Geological Survey (USGS) in Woods Hole, Mass. If the truth be told, this is not typical ice. The prop in Dillon's show is a curious and poorly known structure called methane hydrate.***
>
> *from "The Mother Lode of Natural Gas"*
> *by Rich Monastersky,*
> *www.sciencenews.org/pages/pdfs/data/1996/150-19/15019-12.pdf*

Methane hydrate looks like ice, but as the "ice" melts it releases methane gas which can be a fuel source. Image credit: Gary Klinkhammer, OSU-COAS

Methane hydrate is a type of clathrate, a chemical substance in which the molecules of one material (water, in this case) form an open lattice that encloses molecules of another material (methane) without actually forming chemical bonds between the two materials. Methane is produced in many environments by a group of Archaea known as methanogenic Archaea. These Archaea obtain energy by anaerobic metabolism through which they break down the organic material contained in once-living plants and animals. When this process takes place in deep ocean sediments, methane molecules are surrounded by water molecules, and conditions of low temperature and high pressure allow stable ice-like methane hydrates to form. Besides providing entertainment for oceanographers, methane hydrate deposits are significant for several other reasons. A major interest is the possibility of methane hydrates as an energy source. The U.S. Geological Survey has estimated that on a global scale, methane hydrates may contain roughly twice the carbon contained in all reserves of coal, oil, and conventional natural gas combined. In addition to their potential importance as an energy source, scientists have found that methane hydrates are associated with unusual and possibly unique biological communities. In September, 2001, the Ocean Exploration Deep East Expedition explored the crest of the Blake Ridge at a depth of 2,154 m, and found methane hydrate-associated communities containing previously-unknown species that may be sources of beneficial pharmaceutical materials.

While such potential benefits are exciting, methane hydrates may also cause big problems. Although methane hydrates remain stable in deep-sea sediments for long periods of time, as the sediments become deeper and deeper they are heated by the Earth's core. Eventually, temperature within the sediments rises to a point at which the clathrates are no longer stable and free methane gas is released (at a water depth of 2 km, this point is reached at a sediment depth of about 500 m). The pressurized gas remains trapped beneath hundreds of meters of sediments that are cemented together by still-frozen methane hydrates. If the overlying sediments are disrupted by an earthquake or underwater landslide, the pressurized methane can escape suddenly, producing a violent underwater explosion that may result in disastrous tsunamis.

The release of large quantities of methane gas can have other consequences as well. Methane is one of the greenhouse gases. In the atmosphere, these gases allow solar radiation to pass through to the surface of the Earth, but absorb heat radiation that is reflected back from the Earth's surface, thus warming the atmosphere. A sudden release of methane from deep-sea sediments could increase this effect, since methane has more than 30 times the heat-trapping ability of carbon dioxide.

In 1995, Australian paleoceanographer Gerald Dickens suggested that a sudden release of methane from submarine sediments during the Paleocene Epoch (at the end of the Tertiary Period, about 55 million years ago) caused a greenhouse effect that raised the temperatures in the deep ocean by about 6° C. The result was the extinction of many deep-sea organisms known as the Paleocene extinction event. More recently, other scientists (*e.g.*, Kirschvink and Raub, 2003; Simpson, 2000) have suggested that similar events could have contributed to mass extinctions during the Jurassic Period (183 million years ago), as well as to the sudden appearance of many new animal phyla during the Cambrian Period (the Cambrian Explosion, about 520 million years ago).

This lesson guides a student investigation into the significance of methane hydrates.

Iceworms *(Hesiocaeca methanicola)* infest a piece of orange methane hydrate at 540 m depth in the Gulf of Mexico. During the Paleocene epoch, lower sea levels could have led to huge releases of methane from frozen hydrates and contributed to global warming. Today, methane hydrates may be growing unstable due to warmer ocean temperatures. Image credit: Ian MacDonald. *http://oceanexplorer.noaa.gov/explorations/06mexico/background/plan/media/iceworms_600.jpg*

Learning Procedure

1. To prepare for this lesson:
   - Review introductory information on the NOAA Ship *Okeanos Explorer* at *http://oceanexplorer.noaa.gov/okeanos/welcome.html*. You may also want to consider having students complete some or all of the lesson, *To Boldly Go*….
   - Visit *http://oceanexplorer.noaa.gov/explorations/deepeast01/logs/oct1/oct1.html* and *http://oceanexplorer.noaa.gov/explorations/03windows/welcome.html* for background on the 2001 Deep East Expedition to the Blake Ridge and

the 2003 Windows on the Deep Expedition.
- Review questions on the *Methane Hydrates Investigation Guide.*
- Review procedures on the *Methane Hydrate Model Construction Guide*, and gather necessary materials. This activity may be done as a cross-curricular mathematics lesson using student-constructed pentagons and dodecahedrons. Correlations with Common Core State Standards for Mathematics are provided in Appendix A on page 159.

2. If you have not previously done so, briefly introduce the NOAA Ship *Okeanos Explorer*, emphasizing that this is the first Federal vessel specifically dedicated to exploring Earth's largely unknown ocean. Lead a discussion of reasons that ocean exploration is important, which should include further understanding of energy resources in the ocean.

   Lead an introductory discussion about the 2001 Deep East Expedition to the Blake Ridge and the 2003 Windows on the Deep Expedition. Briefly describe methane hydrates and why these substances are potentially important to human populations. You may also want to visit *http://www.pmel.noaa.gov/vents/* for more information and activities on hydrothermal vent communities.

3. Provide each student group with a copy of the *Methane Hydrates Investigation Guide* and the *Methane Hydrate Model Construction Guide*. Tell students that they will be expected to present a group report, including a model of a methane hydrate, that addresses these questions, and participate in a class discussion of their results.

4. Lead a discussion of students' research results. Referring to students' models, begin with a discussion of what methane hydrates are, where they are found, and how they are formed. Next, ask for a group that can explain one way in which methane hydrates are significant to humans. Continue this process until all five groups have had a chance to present one piece of the whole story. Now, ask students what scientific research priorities and public policies should be established concerning methane hydrates. Encourage students to comment on the potential significance of global warming, alternative energy sources, useful biological products, and natural hazards.

   Be sure the following points are included in the discussion:
   - A clathrate is a chemical substance in which molecules of one material (*e.g.*, water) form an open solid lattice that encloses, without chemical bonding, molecules of another material (*e.g.*, methane).

   - Methane hydrate is a clathrate in which a lattice of water molecules encloses a molecule of methane.

   - In general, methane hydrates formed under conditions of low temperature and high pressure, such as are found in deep ocean environments. See *http://oceanexplorer.noaa.gov/explorations/03windows/background/hydrates/media/fig1_phase_diagram.html* for a phase diagram illustrating combinations of pressure and temperature that are suitable for methane hydrate formation.

- Clathrates have been known as a type of chemical substance since the 1800's, but methane hydrates first received serious attention when they were found to be plugging natural gas pipelines, particularly pipelines located in cold environments. In the late 1960s, naturally-occurring methane hydrate was observed in subsurface sediments in Western Siberia and Alaska. Marine methane hydrate deposits were first found in the Black Sea and subsequently in cores of ocean bottom sediments collected by the R/V *Glomar Challenger* from many areas of Earth's ocean.

- Methane is a greenhouse gas that is ten times more effective than carbon dioxide in causing climate warming. Carbon isotope variations in carbonate rocks and sediments indicate that large-scale releases of methane from ocean hydrates could have occurred at various times in Earth's history, including the Pre-cambrian and Cretaceous Periods. Such releases could have caused significant climate change that may be related to extinction events, as well as to the rapid evolution of new species during the Cambrian Period.

- Methane can be released from methane hydrates when deposits are disrupted by earthquakes or landslides; or when pressure on hydrates is reduced due to a sea-level drop, such as occurred during glacial periods; or when clathrates become unstable due to warming.

- Methane is a fossil fuel that could be used in many of the same ways that other fossil fuels (*e.g.*, coal and petroleum) are used. According to the U.S. Department of Energy, the quantity of methane potentially available is enormous. For example, the U.S. domestic natural gas recoverable resource is roughly 2,300 trillion cubic feet (Tcf). In the case of methane hydrates, the potentially-recoverable domestic resource base could be on the order of 5,000 Tcf.

- Oil and gas drilling and production activities may disturb methane hydrate deposits that are near the seafloor surface, and such disruption poses hazards to personnel and equipment. Ongoing natural phenomena (*e.g.*, subsidence and uplift of the seafloor, global climatic cycles, changes in ocean circulation patterns, changes in global sea level) continually alter the temperature and pressure conditions in sea-bottom sediments. These processes affect the stability of natural methane hydrates, and can result in potentially massive destabilization of these hydrates. If a large quantity of methane enters the atmosphere, it will reside there for roughly 10-20 years, during which it will act as a very efficient greenhouse gas. Over the longer term, the atmospheric impact of methane will continue at lesser levels as the methane slowly dissipates through oxidation into water and carbon dioxide.

- In September, 2001, the Deep East Expedition explored the crest of the Blake Ridge at a depth of 2,154 m, and found methane hydrate-associated communities containing previously-unknown species that may be sources of beneficial pharmaceutical materials.

The BRIDGE Connection

www.vims.edu/bridge/ – Scroll over "Ocean Science Topics," then click "Habitats," the "Deep Sea" for links to resources about hydrothermal vents and chemosynthetic communities.

The "Me" Connection

Have students write an essay describing why ocean exploration expeditions are, or are not, personally relevant and important.

Connections to Other Subjects

English/Language Arts, Biology, Chemistry, Mathematics

Assessment

Students' responses to *Investigation Guide* questions and class discussions provide opportunities for assessment.

Extensions

1. Follow events aboard the *Okeanos Explorer* at *http://oceanexplorer.noaa.gov/okeanos/welcome.html*.
2. Have students investigate events in Earth's history that may have been influenced in some way by methane hydrates. The next-to-last paragraph in the Background section refers to some of these.

Multimedia Discovery Missions

http://www.oceanexplorer.noaa.gov/edu/learning/welcome.html Click on the links to Lessons 5, 11, and 12 for interactive multimedia presentations and Learning Activities on Chemosynthesis and Hydrothermal Vent Life, Energy from the Oceans, and Food, Water, and Medicine from the Sea.

Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

(All of the following Lesson Plans are targeted toward grades 9-12)

This Life Stinks (from the 2006 Expedition to the Deep Slope)
http://oceanexplorer.noaa.gov/explorations/06mexico/background/edu/gom_06_stinks.pdf

Focus: Methane-based chemosynthetic processes (Physical Science)

Students will define the process of chemosynthesis, and contrast this process with photosynthesis. Students will also explain the process of methane-based chemosynthesis and explain the relevance of chemosynthesis to biological communities in the vicinity of cold seeps.

The Big Burp: Where's the Proof?
(from the 2007 Expedition to the Deep Slope)
http://oceanexplorer.noaa.gov/explorations/07mexico/background/edu/media/burp.pdf

Focus: Potential role of methane hydrates in global warming (Earth Science)

Students will describe the overall events that occurred during the Cambrian Explosion and Paleocene Extinction events and will define methane hydrates and hypothesize how these substances could contribute to global warming. Students will also describe and explain evidence to support the hypothesis that methane hydrates contributed to the Cambrian Explosion and Paleocene Extinction events.

The Benthic Drugstore
(from the Cayman Islands Twilight Zone 2007 Expedition)
http://oceanexplorer.noaa.gov/explorations/07twilightzone/background/edu/media/drugstore.pdf
Focus: Pharmacologically-active chemicals derived from marine invertebrates (Life Science/Chemistry)
Students will identify at least three pharmacologically-active chemicals derived from marine invertebrates, describe the disease-fighting action of at least three pharmacologically-active chemicals derived from marine invertebrates, and infer why sessile marine invertebrates appear to be promising sources of new drugs.

Chemosynthesis for the Classroom
(from the 2006 Expedition to the Deep Slope)
http://oceanexplorer.noaa.gov/explorations/06mexico/background/edu/gom_06_chemo.pdf
Focus: Chemosynthetic bacteria and succession in chemosynthetic communities (Chemistry/Biology)
Students will observe the development of chemosynthetic bacterial communities and will recognize that organisms modify their environment in ways that create opportunities for other organisms to thrive. Students will also explain the process of chemosynthesis and the relevance of chemosynthesis to biological communities in the vicinity of cold seeps.

Other Resources
See page 217 for Other Resources.

Next Generation Science Standards
Lesson plans developed for Volume 1 are correlated with *Ocean Literacy Essential Principles and Fundamental Concepts* as indicated in the back of this book. Additionally, a separate online document illustrates individual lesson support for the Performance Expectations and three dimensions of the Next Generation Science Standards and associated Common Core State Standards for Mathematics and for English Language Arts & Literacy. This information is provided to educators as a context or point of departure for addressing particular standards and does not necessarily mean that any lesson fully develops a particular standard, principle or concept. Please see: *http://oceanexplorer.noaa.gov/okeanos/edu/collection/wdwe_ngss.pdf.*

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: *oceanexeducation@noaa.gov*

For More Information
Paula Keener, Director, Education Programs
NOAA Office of Ocean Exploration and Research
Hollings Marine Laboratory
331 Fort Johnson Road, Charleston SC 29412
843.762.8818 843.762.8737 (fax)
paula.keener-chavis@noaa.gov

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Methane Hydrate Investigation Guide

Research Questions

1. What is a clathrate?

Methane hydrate looks like ice, but as the "ice" melts it releases methane gas which can be a fuel source. Image credit: Gary Klinkhammer, OSU-COAS

2. What is methane hydrate? Include a model of a methane hydrate with your written report (refer to the *Methane Hydrate Model Construction Guide*).

3. How are methane hydrates formed?

4. Where are methane hydrates found?

5. What is the effect of methane in the atmosphere? Is there any evidence of a direct effect on life on Earth in geological time?

6. In what ways can methane be released from methane hydrates?

7. Is there any practical use for methane hydrates?

8. Do methane hydrates pose any immediate danger to coastal areas?

9. Are any unusual biological organisms or communities associated with methane hydrates? If so, do these communities have any known or potential significance to humans?

Research Tips

1. Try a keyword search using the following terms, alone or in combination:
   Cold seeps, Methane hydrate, Clathrate, Methanogenic Archaea
   Paleocene extinction, Energy hazard
   Note: Use quotation marks or underlined spaces to tell your search engine to look for two-word phrases as a single term

2. Explore the following Web sites:
   http://oceanexplorer.noaa.gov
   http://www.netl.doe.gov/technologies/oil-gas/FutureSupply/MethaneHydrates/maincontent.htm
   http://marine.usgs.gov/fact-sheets/gas-hydrates/title.html

Methane Hydrate Model Construction Guide

Materials

Materials for constructing a methane hydrate model:

For constructing a pentagon:

- Paper, unlined 8-1/2" X 11"
- Pencil
- Protractor or compass

For constructing the dodecahedron half, clathrate cage, methane molecule and methane hydrate model:

- Scissors
- Cardboard or card stock (enough to make 7 pentagons)
- Ruler, 12-inch
- 11 - Bamboo skewers, 12" long
- 20 - Styrofoam balls, 1/2" to 1" diameter
- 4 - Styrofoam balls, 1-1/2" diameter
- 1 - Styrofoam ball, 1" diameter
- Tape, wrapping or strapping
- Spray paint, water-based latex; dark blue, light blue, red, and black
- Fishing line, 8 lb test; or light colored thread

Procedure

1. General Notes:
   - Use a good quality latex spray paint; oil-based paints containing organic solvents tend to melt the Styrofoam.
   - Be sure the skewers are inserted into the middle of the Styrofoam balls.

Part 1 – Build a pentagonal dodecahedron

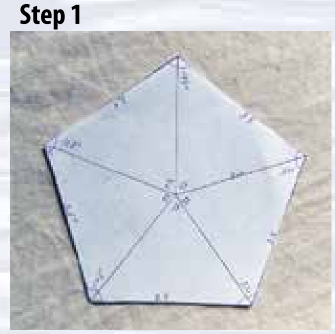
1. Draw a pentagon on paper and cut it out. Each side of the pentagon should be four inches long.

2. Trace the paper pentagon onto cardboard or card stock and cut it out. Each group will cut out 13 pentagons.

3. Lay one pentagon on a flat surface and surround it with five more pentagons matched side to side. Tape the five outside pentagons to the center pentagon.

4. Carefully pull up one pair of pentagons and tape their common sides together. Repeat until the five pentagons have been taped together, forming a five-sided bowl. This is one half of a pentagonal dodecahedron.

Step 1



Step 2

Step 3

Part 2 – Build the Model Molecules

1. Spray paint skewers and Styrofoam balls:
   a. Paint ten skewers light blue to represent hydrogen bonds between water molecules
   b. Paint one skewer red to represent the covalent bonds in the methane molecule
   c. Paint twenty 1/2" Styrofoam balls dark blue to represent water molecules
   d. Paint one 1" Styrofoam ball black to represent the carbon atom
   e. Note: the 4 1-1/2" Styrofoam balls remain white to represent hydrogen atoms

2. Cut light blue skewer sticks into thirty 3-3/4" lengths. Cut the red skewer stick into four 2" lengths. Cut them at an angle so the ends are sharp.

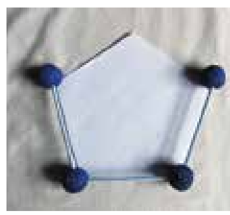
Build the clathrate cage:

3. Place the 7th pentagon on a flat surface. Place a blue stick on one side and two blue balls at each end. Carefully insert the end of the blue stick into the middle of each ball. Repeat with three more balls and four more sticks to form a ball-and-stick pentagon.

Step 3a

Step 3b

Step 3c



Step 3d

Step 3e

Step 4

4. Place the ball-and-stick pentagon in the dodecahedron half—be careful, it will lay approximately an inch up from the bottom. The dodecahedron half (bowl) is used as a template to build the ball and stick dodecahedron with the correct stick angle.

Step 5

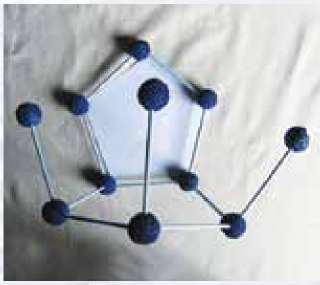
5. Place five light blue sticks inside the center of each of the dark blue balls using the dodecahedron half as a guide for the correct stick angle. It's very important to insert the sticks into the center of the ball at the same angle as the side of the dodecahedron half.

Step 6

6. Insert a dark blue ball on top of each light blue stick. Carefully remove the incomplete cage from the bowl and place it on a flat surface.

7. Use the 7th pentagon to complete the bottom half of the cage. Turn the ball-and-stick model onto one side and, using the pentagon to determine the correct angle, insert a light blue stick into the center of the two dark blue balls. Then, attach another dark blue ball to connect the two light blue sticks you've just attached. This makes the second face and second pentagon of the cage. The first face was the bottom.

Step 7



8. Repeat Step 7 four more times to form the remaining faces for the bottom half of the cage.

Step 8

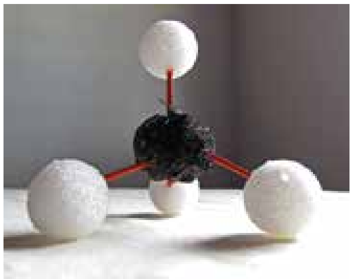
9. Repeat Steps 3, 4, and 5 to construct the top half of the cage.

10. Carefully place the bottom half of the cage into the bottom of the cardboard bowl. Attach the two halves of the cage together: Working together with your partners, hold the top half of the cage over the bottom half. The two halves will only fit together one way. Rotate the top half until all of the unattached sticks line-up with a ball. Insert each light blue stick into the center of the corresponding dark blue ball.

Build the Methane Molecule:

11. Insert four red sticks into the black Styrofoam ball so that they are evenly spaced (when the model is placed on a flat surface, three of the sticks and the black ball should look like a tripod with the fourth stick pointing straight up). Attach a white Styrofoam ball to the other end of each of the red sticks.

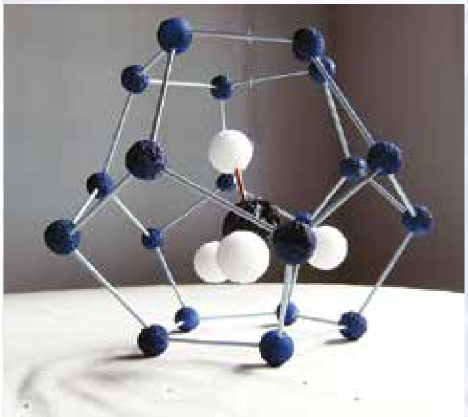
Step 11



Assemble the Methane Hydrate Model

12. Suspend the methane molecule in the middle of the clathrate cage by attaching fishing line from one of its covalent bonds (red sticks) to two opposing hydrogen bonds (light blue sticks) at the top of the cage. Your Methane Hydrate Model is finished!

Step 12



Note: Each of the dark blue Styrofoam balls represents a water molecule consisting of two hydrogen atoms and one oxygen atom. To keep the model simple, we don't show all of these atoms separately.

All photographs by Mellie Lewis, Teacher Facilitator, The College of Exploration.

Appendix A

Adapting the Methane Hydrate Model Construction Activity as a Cross-curricular Mathematics Lesson

Learning Objectives

- Students will demonstrate geometric properties through hands on manipulation of geometric shapes.
- Students will be able to construct a pentagonal dodecahedron.
- Students will be able to construct a model of a methane hydrate.

Teaching Time

Three or four 50-minute class periods or may be sent home as an enrichment activity

Definitions

- Polygon – a geometric shape made up of vertices that are connected with line segments
- Vertex – a point where the sides of an angle meet
- Pentagon – a geometric shape with five equal sides and five 108° angles
- Dodecahedron – a three-dimensional geometric shape that has 12 faces (regular pentagons), 20 vertices, and 30 edges

Prerequisite Skills

Students should have basic knowledge of geometric shapes and know how to draw a pentagon. If not, directions for drawing a pentagon using a compass or protractor may be found in middle school mathematics textbooks or in the links below.

Procedure

1. Lead an introductory discussion of how mathematical models help us understand science concepts.
2. Tell students that they will be using concepts and skills they have learned in mathematics class to build a pentagonal dodecahedron, a clathrate cage, and methane hydrate model.
3. Provide students with copies of the *Methane Hydrate Construction Guide* and required materials.

Resources

http://wiki.answers.com/Q/How_would_you_draw_a_regular_pentagon
http://www.barryscientific.com/lessons/polygon.html

Common Core State Standards for Mathematics

High School:

HSG.MG.A.1. Use geometric shapes, their measures, and their properties to describe objects.

Notes:

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

Section 5:
Key Topic – Human Health

Microfriends

(adapted from the 2003 Medicines from the Deep Sea: Exploration of the Gulf of Mexico Expedition)

Focus
Beneficial microorganisms

Grade Level
5-6 (Life Science)

Focus Question
How may microorganisms benefit humans?

Learning Objectives
- Students will describe at least three ways in which microorganisms benefit humans.
- Students will describe aseptic procedures.
- Students will obtain and culture a bacterial sample on a nutrient medium.

Materials
For each student group:
- Copies of *Microfriends Investigation Guide*
- Squirt bottle containing household bleach diluted to a 10% solution
- Paper towels
- Sterile cotton swabs (see Learning Procedure), 2 or more
- Culture dish(es) containing nutrient medium (see Learning Procedure), one or more
- Wax pencils or permanent markers
- Safety glasses, one pair for each student
- Protective disposal gloves

For full class:
- Glo-Germ™ kit (order from Glo-Germ Co., POB 189, Moab, Utah 84532; 800-842-6622; or online at www.glogerm.com), 4 oz.
- Ultraviolet light
- Pressure cooker (not needed if pre-sterilized materials are used; see Learning Procedure)

Audiovisual Materials
- Marker board, blackboard (or digital equivalent), or overhead projector with transparencies for group discussions

Teaching Time
One or two 45-minute class periods, plus time for student research

Seating Arrangement
Groups of 2-4 students

Maximum Number of Students
32

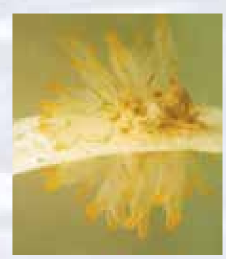
Key Words and Concepts
Cardiovascular disease
Cancer
Arthritis
Natural products
Microorganisms
Mutualism
Commensalism
Parasitism
Bacterial culture
Aseptic technique
Symbiosis

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.

Despite the many advances of modern medicine, disease is still the leading cause of death in the United States. Cardiovascular disease and cancer together account for more than 1.5 million deaths annually (40% and 25% of all deaths, respectively). In addition, one in six Americans have some form of arthritis, and hospitalized patients are increasingly threatened by infections that are resistant to conventional antibiotics. The cost of these diseases is staggering: $285 billion per year for cardiovascular disease; $107 billion per year for cancer; $65 billion per year for arthritis. Death rates, costs of treatment and lost productivity, and emergence of drug-resistant diseases all point to the need for new and more effective treatments.

The deepwater sponge *Discodermia* is now in clinical trials for the treatment of cancer. Image credit: NOAA.
http://oceanexplorer.noaa.gov/explorations/03bio/background/plan/media/discodermia.html

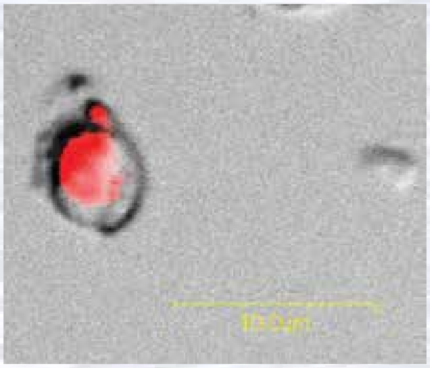
Most drugs in use today are produced from compounds that come from nature. Aspirin, for example, was first isolated from the willow tree. Morphine is extracted from the opium poppy. Penicillin was discovered from common bread mold. To date, almost all of the drugs derived from natural sources come from terrestrial organisms. But recently, systematic searches for new drugs have shown that marine invertebrates produce more antibiotic, anti-cancer, and anti-inflammatory substances than any group of terrestrial organisms. Particularly promising invertebrate groups include sponges, tunicates, ascidians, bryozoans, octocorals, and some molluscs, annelids, and echinoderms.



Though they may be visually unimpressive, *Forcepia* sponges (left) are the source of the lasonolides and tunicates (right) are the source of ecteinascidin, potential new drugs for treating cancer. Image credit: NOAA.
http://oceanexplorer.noaa.gov/explorations/03bio/logs/hirez/lasonolide1_hirez.jpg
http://oceanexplorer.noaa.gov/explorations/03bio/logs/hirez/figure4_hirez.jpg

The list of drugs derived from marine invertebrates includes:

Ecteinascidin – Extracted from tunicates; being tested in humans for treatment of breast and ovarian cancers and other solid tumors; acts by blocking transcription of DNA



Autofluorescent microorganism from a sponge cell suspension. Transmitted light and Krypton laser. Image credit: NOAA.
http://oceanexplorer.noaa.gov/explorations/03bio/logs/sept18/media/microorg.html

Harbor Branch Oceanographic Institution researcher Dr. Shirley Pomponi removes a bright yellow sponge from a rock collected by an underwater robot during the 2003 Medicines from the Deep Sea Expedition. Extracts from the sponge were tested for anti-cancer properties. Image credit: Laura Rear, NOAA.
http://oceanexplorer.noaa.gov/explorations/03bio/logs/summary/media/10249_bio_600.jpg

Topsentin – Extracted from the sponges *Topsentia genitrix*, *Hexadella* sp., and *Spongosorites* sp.; anti-inflammatory agent; mode of action not certain

Lasonolide – Extracted from the sponge *Forcepia* sp.; anti-tumor agent; acts by binding with DNA

Discodermalide – Extracted from deep-sea sponges belonging to the genus *Discodermia*; anti-tumor agent; acts by interfering with microtubule networks

Bryostatin – Extracted from the bryozoan *Bugula neritina*; potential treatment for leukemia and melanoma; acts as a differentiating agent, forcing cancer cells to mature and thus halting uncontrolled cell division

Pseudopterosins – Extracted from the octocoral *Pseudopterogorgia elisabethae* (sea whip); anti-inflammatory and analgesic agents that reduce swelling and skin irritation and accelerate wound healing; acts as an inhibitor of phospholipase A, which is a key enzyme in inflammatory reactions

ω-conotoxin MVIIA – Extracted from the cone snail *Conus magnus*; potent pain-killer; acts by interfering with calcium ion flux, thereby reducing the release of neurotransmitters

This list reflects an interesting fact about invertebrates that produce pharmacologically-active substances: most species are sessile; they are immobile and live all or most of their lives attached to some sort of surface. Several reasons have been suggested to explain why these particular animals produce potent chemicals. One possibility is that they use these chemicals to repel predators, because they are sessile, and are basically "sitting ducks." Since many of these species are filter feeders, and consequently are exposed to all sorts of parasites and pathogens in the water, they may use powerful chemicals to repel parasites or as antibiotics against disease-causing organisms. Competition for space may explain why some of these invertebrates produce anti-cancer agents: if two species are competing for the same piece of bottom space, it would be helpful to produce a substance that would attack rapidly dividing cells of the competing organism. Since cancer cells often divide more rapidly than normal cells, the same substance might have anti-cancer properties.

The goal of the 2003 Medicines from the Deep Sea Expedition was to discover new resources with pharmaceutical potential in the Gulf of Mexico. To achieve this goal, the expedition:

- Collected selected benthic invertebrates from deepwater bottom communities in the Gulf of Mexico (sponges, octocorals, molluscs, annelids, echinoderms, tunicates), identified these organisms, and obtained samples of DNA and RNA from the collected organisms;
- Isolated and cultured microorganisms that live in association with deep-sea marine invertebrates;
- Prepared extracts of benthic invertebrates and associated microorganisms, and tested these extracts to identify those that might be useful in treatment of cancer, cardiovascular disease, infections, inflammation, and disorders of the central nervous system;
- Isolated chemicals from extracts that show pharmacological potential and determined the structure of these chemicals;
- Studied the pharmacological properties of active compounds; and
- Developed methods for the sustainable use of biomedically important marine resources.

The last activity is particularly important, since many potentially useful compounds found in animals are present in very small quantities. This makes it impossible to obtain useful amounts of the substances simply by harvesting large numbers of animals from the sea. Some alternatives are chemical synthesis of specific products, aquaculture to produce large numbers of productive species, or culture of the cells that produce the desired compounds.

Notice that in addition to selected benthic invertebrates, scientists on the Medicines from the Deep Sea Expedition were equally interested in associated microorganisms as possible sources of useful pharmaceuticals. Many students assume that most microorganisms are dangerous and cause diseases in humans. This activity is designed to introduce students to some of the ways that humans benefit from microorganisms.

Learning Procedure

[**NOTE:** Steps 2 – 5 are based, in part, on activities developed during the 1996/1997 teacher internship program of the Center for Engineering Plants for Resistance Against Pathogens at the University of California, Davis. You may want to download a copy of "Microbial World" which has other background information and activities from *http://ceprap.ucdavis.edu/index.php?option=com_content&view=article&id=56&Itemid=138* - Click on "Microbe Laboratories" and it will automatically download.]

An agar plate with microorganisms isolated from a deepwater sponge. Image credit: NOAA.
http://oceanexplorer.noaa.gov/explorations/03bio/background/microbiology/media/figure_03.html

1. To prepare for this lesson:
   - Review introductory information on the NOAA Ship *Okeanos Explorer* at *http://oceanexplorer.noaa.gov/okeanos/welcome.html*. You may also want to consider having students complete some or all of the lesson, *To Boldly Go*. . . .

   - Prepare culture dishes: Petri dishes containing sterile nutrient agar can be purchased from biological supply companies, or you can prepare your own. If you are using nutrient agar, prepare the solution according to manufacturers' instructions. Sterilize the agar solution in a pressure cooker by placing the agar container in a basket just above the water level. Seal the lid onto the cooker and allow steam to flow freely for 10 minutes. Place the pressure control on the vent and maintain the pressure at 15 pounds for 30 minutes. At the end of this time, let the cooker cool, then pour the agar into sterilized petri dishes, baby food jars, or shallow glass dishes with glass covers.

     As an alternative to nutrient agar, you can use unflavored gelatin. Prepare the gelatin according to directions on the package, but substitute beef broth (made from a bouillon cube) for boiling water. Sterilize the gelatin as described above and pour it into sterilized petri dishes or other containers.

     Prepare sterile cotton swabs by wrapping one or two swabs in white paper (butcher paper), taping with masking tape, and sterilizing in a pressure cooker as described above. Alternatively, you can buy pre-packaged sterile swabs from a biological supply company.

   - Review information that accompanied your Glo-Germ™ kit, or check out educational materials at *http://www.glogerm.com/worksheet.html*. Decide how much time you want to devote to handwashing activities. Considering emerging issues of pandemics, this portion of the lesson may have the most immediate potential benefit to students and educators. "Infect" student lab stations with Glo-Germ™ powder by rubbing the powder into a few areas on each station and brushing off any excess powder. Check the "infected" areas to be sure the powder shows up when illuminated with ultraviolet light.

2. If you have not previously done so, briefly introduce the NOAA Ship *Okeanos Explorer*, emphasizing that this is the first Federal vessel specifically dedicated to exploring Earth's largely unknown ocean. Lead a discussion of reasons that ocean exploration is important, which should include human health.

   Review the importance of finding new drugs for the treatment of cardiovascular disease, cancer, inflammatory diseases, and infections. Describe the potential of marine communities as sources for these drugs, and highlight the fact that new drugs may be found in microorganisms as well as the larger benthic invertebrates with which the microorganisms are associated.

3. Tell students that they are going to culture some bacteria living in your classroom, and that this type of work requires special procedures called aseptic techniques to minimize the risks of contamination. Begin with handwashing exercises, as detailed in the Glo Germ™ worksheets.

   Next, explain that to practice proper aseptic lab procedures, lab stations have been "infected" with glowing particles that represent bacteria. Show students what an "infected" area looks like under ultraviolet light. Provide students with protective gloves, eye protection, paper towels, and squirt bottles of 10% bleach solution. Have them carefully wipe down the entire lab area with the bleach solution, then inspect the area again with ultraviolet light.

4. Provide each student group with a copy of *Microfriends Investigation Guide*, and have students complete Part 1 (you may want to assign Part 1 as homework).

5. Provide each student group with one or more culture dishes containing nutrient agar or gelatin, sterile cotton swabs, and wax pencils or markers. Tell students to follow instructions for Part 2 of the *Investigation Guide*. When Part 2 is completed, have students place their dishes upside down in the incubation area. If an incubator is not used, be sure that the dishes are not placed in direct sunlight or a cold part of the room. Have students clean their lab stations and wash their hands before leaving the lab.

6. After two and four days, students should record their observations on Part 3 of the *Investigation Guide*.

7. Review students' answers to questions on the worksheet. The following points should be included:
   (1) Bacteria have existed on Earth longer than any other known organism.
   (2) Bacterial cells are structurally simpler than those of other organisms and do not have a nucleus.
   (3) Bacteria are extremely hardy; some can live well below freezing, others survive in boiling water, and others live in solid rock.
   (4) Bacteria are everywhere, and in large numbers; a teaspoon of garden soil contains about ten billion bacteria, and there are more bacteria in the human mouth than the total number of people who have ever lived.
   (5) Virtually all plants and animals live in association with bacteria and other microorganisms; these associations may benefit both organisms

(mutualism), benefit one organism without affecting the other (commensalism); or benefit one organism and harm the other (parasitism). Mutualism, commensalism and parasitism are all types of symbiotic relationships.

(6) Most bacteria are not parasitic.

(7) Some benefits provided by bacteria include:
- Bacteria in human intestines aid in the digestion of certain foods;
- Production of cheese, yogurt, and other foods;
- Decomposition and recycling of dead organisms;
- Fixation of nitrogen from the atmosphere into usable nitrogen in soils;
- Production of antibiotics;
- Photosynthetic bacteria produce oxygen; cyanobacteria produced the Earth's oxygen atmosphere 2.45-2.7 billion years ago;
- Bacteria are responsible for the production of fossil fuels;
- Bacteria are used to clean up polluted areas, including oil spills;
- Bacteria produce a variety of chemicals used in many industries, including acetone, butanol, and citric acid;
- Bacteria are used to treat sewage;
- Bacteria are what makes composting work; and
- Bacteria can be used to generate methane gas from sewage waste.

Have each group present their results, and lead a discussion focusing on which parts of the classroom seem to have the most bacteria and why.

8. After completion of the activity, collect the culture dishes, and immerse them in a 10% bleach solution for at least 15 minutes. Drain the excess solution and seal the dishes in a plastic bag for disposal. Alternatively, you may sterilize the dishes for 30 minutes in a pressure cooker at 15 lb pressure.

The BRIDGE Connection

www.vims.edu/bridge/ – Scroll over "Ocean Science" in the navigation menu to the left, then "Human Activities" then "Technology" for resources on biotechnology and drugs from the sea.

The "Me" Connection

Have students write a short essay describing how bacteria affect their own lives on any typical day.

Connections to Other Subjects

English/Language Arts, Physical Science

Assessment

Students' responses to *Investigation Guide* questions and class discussions provide opportunities for assessment.

Extensions

1. Visit *http://oceanexplorer.noaa.gov/explorations/03bio/welcome.html* to find out more about the Deep Sea Medicines 2003 Expedition.
2. Visit the following web sites for other activities related to microorganisms:
   www.glogerm.com
   http://ceprap.ucdavis.edu/index.php?option=com_content&view=article&id=56&Itemid=138 - Click on "Microbe Laboratories" and it will automatically download

http://spikesworld.spike-jamie.com/science/index.html
http://www.umsl.edu/~microbes/

Multimedia Discovery Missions

http://oceanexplorer.noaa.gov/edu/learning/welcome.html Click on the links to Lessons 12 for interactive multimedia presentations and Learning Activities on Food, Water, and Medicine from the Sea.

Other Relevant Lesson Plans from NOAA's Ocean Explorer Program

(The following Lesson Plan is targeted toward grades 5-6)

Chemists with no Backbones

(from the 2003 Medicines from the Deep Sea: Exploration of the Gulf of Mexico Expedition)

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

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

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

Other Resources

See page 217 for Other Resources.

Next Generation Science Standards

Lesson plans developed for Volume 1 are correlated with *Ocean Literacy Essential Principles and Fundamental Concepts* as indicated in the back of this book. Additionally, a separate online document illustrates individual lesson support for the Performance Expectations and three dimensions of the Next Generation Science Standards and associated Common Core State Standards for Mathematics and for English Language Arts & Literacy. This information is provided to educators as a context or point of departure for addressing particular standards and does not necessarily mean that any lesson fully develops a particular standard, principle or concept. Please see: *http://oceanexplorer.noaa.gov/okeanos/edu/collection/wdwe_ngss.pdf.*

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: *oceanexeducation@noaa.gov*

For More Information

Paula Keener, Director, Education Programs
NOAA Office of Ocean Exploration and Research
Hollings Marine Laboratory
331 Fort Johnson Road, Charleston SC 29412
843.762.8818   843.762.8737 (fax)
paula.keener-chavis@noaa.gov

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Microfriends Investigation Guide

Part 1. Background Research

1. How long have bacteria existed on Earth compared to other organisms?

2. How are bacterial cells different from the cells of other organisms?

3. Are bacteria, in general, delicate or hardy?

4. Where are bacteria found? In general, are bacteria rare or abundant?

5. Are bacteria generally absent from healthy plants and animals?

6. Are most bacteria harmful to humans?

7. What are at least three benefits that we may receive from bacteria?

Part 2. Grow Some Bacteria!

1. Select an area of your classroom where you think there will be large numbers of bacteria.

2. Sample your selected area by having one student rub the surface with a sterile swab.

3. Have another student raise the top of a culture dish while the student with the sample swab gently streaks the surface of the agar or gelatin with the swab. Be careful not to tear the surface! Do not put the top of the dish on any other surface; just keep the top raised until the streaking is completed, then put the top back onto the dish.

4. After replacing the top, seal the top to the dish with strapping tape and label the dish with the names of students in your group and the collection site where you collected your sample.

5. Place your culture dish in an incubation area as directed by your teacher.

6. Clean your lab station and wash your hands before leaving the lab.

Part 3. Observe

After two days, record your observations on the chart below. Be sure to estimate how many different types of bacteria seem to be present. Repeat your observations after four days. DO NOT REMOVE THE TOPS FROM YOUR CULTURE DISH!

Microfriends Observations

Collection Site ____________________

Description of Colony	# of Colonies Observed	Observations in Culture Dish
After 2 days:		
After 4 days:		

Notes:

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*

Section 5: Key Topic – Human Health

What Killed the Seeds?

Focus
Bioassays

Grade Level
7-8 (Life Science)

Focus Question
How can the biological effects of chemicals be studied?

Learning Objectives
- Students will explain and carry out a simple process for studying the biological effects of chemicals.
- Students will infer why organisms such as sessile marine invertebrates appear to be promising sources of new drugs.

Materials
- Radish seeds; at least 60 for each student group (ten seeds for each replicate)
- 10% household bleach solution, about 50 ml for each student group
- Kitchen strainer; may be shared among several student groups
- Zip-top plastic freezer bags, 1-quart size, or disposable plastic petri dishes, 100 mm x 10 mm (Carolina Biological Supply No. 741248); at least six for each student group
- Felt tip markers
- Paper towels
- Disposable plastic pipettes with rubber bulb or aspirator, one for each student group
- Ruler graduated in millimeters
- Distilled water
- Clean glass containers with stoppers or caps for collecting water samples; minimum capacity about 100 ml
- Copies of *Bioassay Investigation Guide*, one for each student group

Audiovisual Materials
- Marker board, blackboard, or overhead projector with transparencies for group discussions

Teaching Time
One or two 45-minute class periods, plus time for student observations over several class periods

Ocean Exploration and Research

Seating Arrangement
Groups of 2-3 students

Maximum Number of Students
32

Key Words and Concepts
Natural products
Drugs from the sea
Bioassay

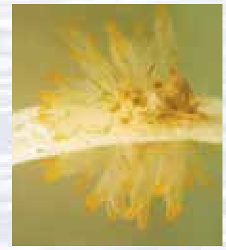
Background Information
NOTE: Explanations and procedures in this lesson are written at a level appropriate to professional educators. In presenting and discussing this material with students, educators may need to adapt the language and instructional approach to styles that are best suited to specific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

People who are not familiar with ocean exploration often believe that the primary reason for investigating deep-sea ecosystems is little more than scientific curiosity. This perspective quickly changes, however, when they learn that these ecosystems are the source of promising new drugs for treating some of the most deadly human diseases.

Despite the many advances of modern medicine, disease is still the leading cause of death in the United States. Cardiovascular disease and cancer together account for more than 1.5 million deaths annually (40% and 25% of all deaths, respectively). In addition, one in six Americans have some form of arthritis, and hospitalized patients are increasingly threatened by infections that are resistant to conventional antibiotics. The cost of these diseases is staggering: \$285 billion per year for cardiovascular disease; \$107 billion per year for cancer; \$65 billion per year for arthritis. Death rates, costs of treatment and lost productivity, and emergence of drug-resistant diseases all point to the need for new and more effective treatments.

Most drugs in use today are produced from compounds that come from nature, and almost all of these are derived from terrestrial organisms. Aspirin, for example, was first isolated from the willow tree. Morphine is extracted from the opium poppy. Penicillin was discovered from common bread mold. But recently, systematic searches for new drugs have shown that marine invertebrates produce more antibiotic, anti-cancer, and anti-inflammatory substances than any group of terrestrial organisms. Particularly promising invertebrate groups include sponges, tunicates, ascidians, bryozoans, octocorals, and some molluscs, annelids, and echinoderms.

Most of these animals do not appear particularly impressive. Many are sessile, and live all or most of their lives attached to some sort of surface. Several reasons have been suggested to explain why these animals are particularly productive of potent chemicals. One possibility is that they use these chemicals to repel predators, because they are basically "sitting ducks." Since many of these species are filter feeders, and consequently are exposed to all sorts of parasites and pathogens in the water, they may use powerful chemicals to repel parasites or as antibiotics against disease-causing organisms. Competition for space may explain why some of these invertebrates produce anti-cancer agents: If two species are competing for the same piece of bottom space, it would be helpful to produce a substance that would attack rapidly dividing cells of the competing organism. Since cancer cells often divide more

Though they may be visually unimpressive, *Forcepia* sponges (left) are the source of the lasonolides and tunicates (right) are the source of ecteinascidin, potential new drugs for treating cancer. Image credit: NOAA.
http://oceanexplorer.noaa.gov/explorations/03bio/logs/hirez/lasonolide1_hirez.jpg
http://oceanexplorer.noaa.gov/explorations/03bio/logs/hirez/figure4_hirez.jpg

Some drugs derived from marine invertebrates:

Ecteinascidin – Extracted from tunicates; being tested in humans for treatment of breast and ovarian cancers and other solid tumors

Topsentin – Extracted from the sponges *Topsentia genitrix*, *Hexadella* sp., and *Spongosorites* sp.; anti-inflammatory agent

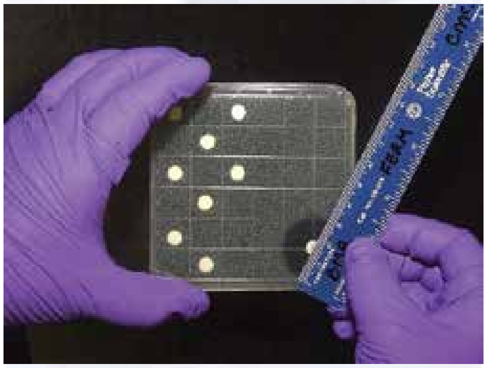
Lasonolide – Extracted from the sponge *Forcepia* sp.; anti-tumor agent

Discodermalide – Extracted from deep-sea sponges belonging to the genus *Discodermia*; anti-tumor agent

Bryostatin – Extracted from the bryozoan *Bugula neritina*; potential treatment for leukemia and melanoma

Pseudopterosins – Extracted from the octocoral (sea whip) *Pseudopterogorgia elisabethae*; anti-inflammatory and analgesic agents that reduce swelling and skin irritation and accelerate wound healing

ω-conotoxin MVIIA – Extracted from the cone snail *Conus magnus;* potent pain-killer



This bioassay plate detects antimicrobial activity. Small disks of blotter paper are dipped in marine-organism extracts and placed on an agar plate with various bacteria. The clear zone indicates that the extracts are inhibiting microbial growth. Image credit: NOAA.
http://oceanexplorer.noaa.gov/explorations/03bio/background/microbiology/media/figure_04.html

Harbor Branch Oceanographic Institution researcher Dr. Shirley Pomponi removes a bright yellow sponge from a rock collected by an underwater robot during the 2003 Medicines from the Deep Sea Expedition. Extracts from the sponge were tested for anti-cancer properties. Image credit: Laura Rear, NOAA.
http://oceanexplorer.noaa.gov/explorations/03bio/logs/summary/media/10249_bio_600.jpg

rapidly than normal cells, the same substance might have anti-cancer properties. The potential for discovering important new drugs from deep-ocean organisms is high, because most of Earth's seafloor is still unexplored, and deep-sea explorations routinely find species that have never been seen before. In 2003, the Ocean Explorer Deep Sea Medicines Expedition visited the Gulf of Mexico to search for new resources with pharmaceutical potential. The expedition collected selected benthic invertebrates from deepwater bottom communities (sponges, octocorals, molluscs, annelids, echinoderms, tunicates), and tested extracts of these organisms to identify those that may be useful in treatment of cancer, cardiovascular disease, infections, inflammation, and disorders of the central nervous system. This lesson guides student investigations into bioassays, which are tests that use biological organisms to study the action of chemicals or physical changes in the environment.

Learning Procedure

1. To prepare for this lesson:
   - Review introductory information on the NOAA Ship *Okeanos Explorer* at *http://oceanexplorer.noaa.gov/okeanos/welcome.html*. You may also want to consider having students complete some or all of the lesson, *To Boldly Go…*.
   - Review background essays on Deep Sea Medicines, Microbiology, Natural Products and Molecular Biology linked from the Deep Sea Medicines 2003 Expedition welcome page (*http://oceanexplorer.noaa.gov/explorations/03bio/welcome.html*).
   - Review procedures on the *Bioassay Investigation Guide*, and assemble materials listed on Page 2 of this lesson plan. To prepare a 10% bleach solution, mix 50 ml household bleach with 450 ml tap water. Keep the solution away from sunlight. The Guide instructs students to prepare at least three replicates for each solution being tested and for each control solution. This is the minimum number of replicates needed for statistical analysis; more is better, if time and materials permit.

2. If you have not previously done so, briefly introduce the NOAA Ship *Okeanos Explorer*, emphasizing that this is the first Federal vessel specifically dedicated to exploring Earth's largely unknown ocean. Lead a discussion of reasons that ocean exploration is important, which should include human health.

3. Discuss the importance of finding new drugs for the treatment of cardiovascular disease, cancer, inflammatory diseases, and infections. Describe the potential of marine communities as sources for these drugs, and briefly discuss some potentially useful drugs that have been discovered from these communities. Ask students to list some reasons that these kinds of drugs might be found primarily among sessile invertebrates. Tell students that they will be learning to use a technique for studying the effects of chemicals on living organisms. Explain that a bioassay uses a biological organism to study the effects of chemicals or physical environmental change (such as radiation or heat). When toxicity is being studied, bioassays provide an integrated measure of a test organism's response to chemicals or environmental change, and give a more complete understanding than would be obtained from direct measurements of specific chemical or physical factors.

   Tell students that they will be using radish seeds as a bioassay organism. Two responses will be investigated: germination and growth rate. Lead a discussion to identify one or more substances (liquids are easiest) whose toxicity is to be tested. Runoff water from a street (usually contaminated with vehicle emissions) or a nearby water body suspected of being polluted are common test subjects. Have students collect the substances to be tested. A sample of 100 ml is adequate for the test. Remind students to wash their hands thoroughly after handling water that is suspected of being contaminated. **(Washing hands is considered standard practice after ANY laboratory procedure!)**

4. Have students perform bioassays using the procedure described on the *Bioassay Investigation Guide.*

5. Lead a discussion of students' results. Students should realize that different organisms are not equally sensitive to chemical agents. For example, the concentration of copper in water that would kill algae or a snail is harmless to most fish. When choosing a bioassay organism, investigators need to consider which compounds or organism responses are of most concern. Seed bioassays are very sensitive to herbicides and fairly sensitive to metals. They are less sensitive than fish or invertebrate assays to industrial chemicals like polychlorinated biphenyls (PCBs) or solvents. A full evaluation of a sample's biological activity requires performing several different bioassays. Bioassays for drug screening, for example, often include bacteria (to screen for potential antibacterial activity) and specific tissue cultures (to screen for anti-cancer activity).

The BRIDGE Connection

www.vims.edu/bridge/ – Enter "pharmaceutical" in the Search box for resources on drugs from the sea.

Click on "Ocean Science Topics" then "Habitats," then "Deep Sea" for resources on deep-sea communities.

Click on "Ocean Science Topics," then "Human Activities" then "Technology" for resources on biotechnology.

The "Me" Connection

Have students write a short essay on how bioassays might be of personal benefit.

Connections to Other Subjects

English/Language Arts, Mathematics (Statistics)

Assessment

Written reports and class discussions offer opportunities for assessment.

Extensions

1. Visit *http://oceanexplorer.noaa.gov/explorations/03bio/welcome.html* to find out more about the Deep Sea Medicines 2003 Expedition.
2. Visit *http://www.epa.gov/owow/monitoring/volunteer/newsletter/volmon09no1.pdf* for more examples and ideas for using bioassays.

Multimedia Discovery Missions

http://www.oceanexplorer.noaa.gov/edu/learning/welcome.html Click on the links to Lesson 12 for an interactive multimedia presentation and learning activities on Medicine from the Sea.

Other Relevant Lesson Plans from NOAA's Ocean Explorer Program

While each lesson is targeted toward a specific grade level, most can be adapted for use in other grades as well.

Chemists with no Backbones (Grades 5-6)
(from 2003 Medicines from the Deep Sea Expedition)
http://oceanexplorer.noaa.gov/explorations/03bio/background/edu/media/meds_chemnobackbones.pdf

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

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

Living by the Code (Grades 7-8)
(from 2003 Medicines from the Deep Sea Expedition)
http://oceanexplorer.noaa.gov/explorations/03bio/background/edu/media/meds_livingcode.pdf

Focus: Functions of cell organelles and the genetic code in chemical synthesis (Life Science)

Students will explain why new drugs are needed to treat cardiovascular disease, cancer, inflammation, and infections; infer why sessile marine invertebrates appear to be promising sources of new drugs; and explain the overall process through which cells manufacture chemicals. Students will also explain why it may be important to synthesize new drugs, rather than relying on the natural production of drugs.

Cell Mates (Grades 9-12) (from 2003 Medicines from the Deep Sea Expedition)
http://oceanexplorer.noaa.gov/explorations/03bio/background/edu/media/meds_cellmates.pdf

Focus: Bacterial endosymbionts and organelles of eukaryotic cells (Life Science)

Students will be able to compare and contrast prokaryotic and eukaryotic cells, explain the endosymbiont theory for the origin of eukaryotic cell organelles, and explain evidence that suggests an endosymbiotic origin for at least two common eukaryotic cell organelles.

The Benthic Drugstore (Grades 9-12)
(from 2003 Medicines from the Deep Sea Expedition)
http://oceanexplorer.noaa.gov/explorations/03bio/background/edu/media/meds_drugstore.pdf

Focus: Pharmacologically-active chemicals derived from marine invertebrates (Life Science)

Students will identify at least three pharmacologically-active chemicals derived from marine invertebrates, describe the disease-fighting action of at least three pharmacologically-active chemicals derived from marine invertebrates, and infer why sessile marine invertebrates appear to be promising sources of new drugs.

The Electric Sieve (Grades 9-12)
(from 2003 Medicines from the Deep Sea Expedition)
http://oceanexplorer.noaa.gov/explorations/03bio/background/edu/media/meds_elecsieve.pdf
Focus: Separation of complex mixtures (Chemistry)
Students will explain and carry out a simple process for separating complex mixtures, and will infer why organisms such as sessile marine invertebrates appear to be promising sources of new drugs.

Watch the Screen! (Grades 9-12)
(from 2003 Medicines from the Deep Sea Expedition)
http://oceanexplorer.noaa.gov/explorations/03bio/background/edu/media/meds_watchscreen.pdf
Focus: Screening natural products for biological activity (Life Science)
Students will explain and carry out a simple process for screening natural products for biological activity, and will infer why organisms such as sessile marine invertebrates appear to be promising sources of new drugs.

Other Resources

See page 217 for Other Resources.

Next Generation Science Standards

Lesson plans developed for Volume 1 are correlated with *Ocean Literacy Essential Principles and Fundamental Concepts* as indicated in the back of this book. Additionally, a separate online document illustrates individual lesson support for the Performance Expectations and three dimensions of the Next Generation Science Standards and associated Common Core State Standards for Mathematics and for English Language Arts & Literacy. This information is provided to educators as a context or point of departure for addressing particular standards and does not necessarily mean that any lesson fully develops a particular standard, principle or concept. Please see: *http://oceanexplorer.noaa.gov/okeanos/edu/collection/wdwe_ngss.pdf.*

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: *oceanexeducation@noaa.gov*

For More Information

Paula Keener, Director, Education Programs
NOAA Office of Ocean Exploration and Research
Hollings Marine Laboratory
331 Fort Johnson Road, Charleston SC 29412
843.762.8818   843.762.8737 (fax)
paula.keener-chavis@noaa.gov

Acknowledgments

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

Bioassay Investigation Guide

(Adapted from an article by Joe Rathbun in the spring 1996 issue of the Volunteer Monitor*)*

1. Soak seeds for 20 minutes in a 10% solution of household bleach in distilled water, then rinse thoroughly under running tap water. The solution kills fungi, which could interfere with seed germination.

2. Cut paper towels into pieces approximately 11'' x 6''. You will need at least three pieces for each solution being tested, as well as at least three pieces for each control solution.

3. Place 10 seeds in the middle of each paper towel, leaving about 1/2'' space between the seeds. Fold the edges of the paper towel over to cover the seeds.

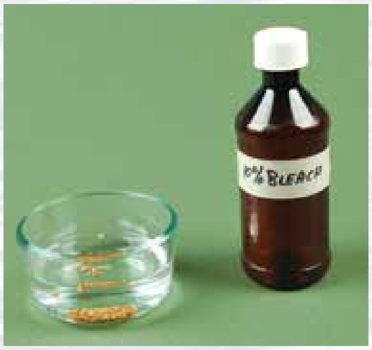
4. Place each paper towel with the seeds into a zip-top plastic freezer bag or disposable plastic petri dish. Pipette enough undiluted sample solution into the bag or dish to saturate the paper towel. Prepare at least three replicates for each sample being tested, as well as at least three controls using distilled water instead of sample water. Use the same volume in each bag or dish.

5. Incubate bags or dishes at room temperature, in the dark, for five days. (It is OK to briefly check the dishes during incubation. If the paper seems dry, pipette a few ml of distilled water onto the paper.)

6. When incubation is complete, record the number of seeds that germinated in each bag or dish, and measure (to the nearest mm) the length of the root that has emerged from each germinated seed (the image shows a seed after 24 hours' incubation). If fewer than 80% of the seeds in the control sample germinate, this indicates a problem with the assay (*e.g.*, bad seeds, poor incubation conditions). If this happens, the test should be re-run.

7. For each sample (including the controls), calculate the mean and standard deviation of root lengths. Comparisons can be made by using the Student's t-test. A more approximate method is to compare the mean ±1 standard deviation of each sample to the control. If a sample's mean plus 1 standard deviation is less than the mean of the control minus 1 standard deviation, there is a strong likelihood that the sample is significantly more toxic than the control. Prepare a written report of your results, including a discussion of the outcome.

Step 1a:



Step 1b:

Step 3:

Step 4:

Step 6:

Notes:

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

Section 5: Key Topic – Human Health

Watch the Screen!

(adapted from the 2003 Medicines from the Deep Sea: Exploration of the Gulf of Mexico Expedition)

Focus

Screening natural products for biological activity

Grade Level

9-12 (Life Science)

Focus Question

How can natural products be tested for biological activity?

Learning Objectives

- Students will explain and carry out a simple process for screening natural products for biological activity.
- Students will infer why organisms such as sessile marine invertebrates appear to be promising sources of new drugs.

Materials

For each student group:

- 1 Copy of *Active Ingredient Screening Guide*
- Disposable plastic serological pipettes, 1 ml (Carolina Biological Supply No. 736122)
- 1 Mortar and pestle set (Carolina Biological Supply No. 742892)
- 3 Disposable plastic Petri dishes, 100 mm x 10 mm (Carolina Biological Supply No. 741248), three for each student group
- 1 1-liter Erlenmeyer flask, one for each student group
- Forceps, one for each student group

For preparation and for class:

- *Escherichia coli B* culture (Carolina Biological Supply No. 124300)
- Dehydrated nutrient agar, pre-measured packs (Carolina Biological Supply No. 789642)
- Luria Broth (Carolina Biological Supply No. 216620)
- Nichrome wire inoculating loops (Carolina Biological Supply No. 703060)
- Antibiotic sensitivity disks, blank, sterile (Carolina Biological Supply No. 805091)
- Incubator
- Autoclave or pressure cooker
- Alcohol or gas burner for sterilization of forceps
- Distilled water
- Strapping tape

Ocean Exploration and Research

Audiovisual Materials

- Marker board, blackboard (or digital equivalent), or overhead projector with transparencies for group discussions

Teaching Time

One or two 45-minute class periods, plus time for student research

Seating Arrangement

Groups of 2-4 students

Maximum Number of Students

32

Key Words and Concepts

Cardiovascular disease
Cancer
Arthritis
Natural products
Active ingredient screening

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.

Despite the many advances of modern medicine, disease is still the leading cause of death in the United States. Cardiovascular disease and cancer together account for more than 1.5 million deaths annually (40% and 25% of all deaths, respectively). In addition, one in six Americans have some form of arthritis, and hospitalized patients are increasingly threatened by infections that are resistant to conventional antibiotics. The cost of these diseases is staggering: $285 billion per year for cardiovascular disease; $107 billion per year for cancer; $65 billion per year for arthritis. Death rates, costs of treatment and lost productivity, and emergence of drug-resistant diseases all point to the need for new and more effective treatments.

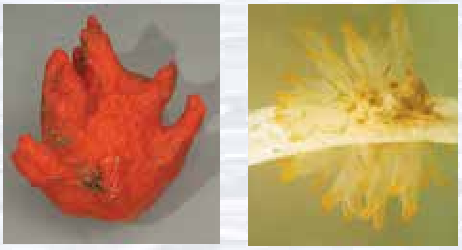
Most drugs in use today are produced from compounds that come from nature. Aspirin, for example, was first isolated from the willow tree. Morphine is extracted from the opium poppy. Penicillin was discovered from common bread mold. To date, almost all of the drugs derived from natural sources come from terrestrial organisms. But recently, systematic searches for new drugs have shown that marine invertebrates produce more antibiotic, anti-cancer, and anti-inflammatory substances than any group of terrestrial organisms. Particularly promising invertebrate groups include sponges, tunicates, ascidians, bryozoans, octocorals, and some molluscs, annelids, and echinoderms.

The list of drugs derived from marine invertebrates includes:

Ecteinascidin – Extracted from tunicates; being tested in humans for treatment of breast and ovarian cancers and other solid tumors; acts by blocking transcription of DNA

Topsentin – Extracted from the sponges *Topsentia genitrix*, *Hexadella* sp., and *Spongosorites* sp.; anti-inflammatory agent; mode of action not certain

The deepwater sponge *Discodermia* is now in clinical trials for the treatment of cancer. Image credit: NOAA.
http://oceanexplorer.noaa.gov/explorations/03bio/background/plan/media/discodermia.html



Though they may be visually unimpressive, *Forcepia* sponges (left) are the source of the lasonolides and tunicates (right) are the source of ecteinascidin, potential new drugs for treating cancer. Image credit: NOAA.
http://oceanexplorer.noaa.gov/explorations/03bio/logs/hirez/lasonolide1_hirez.jpg
http://oceanexplorer.noaa.gov/explorations/03bio/logs/hirez/figure4_hirez.jpg

Harbor Branch Oceanographic Institution researcher Dr. Shirley Pomponi removes a bright yellow sponge from a rock collected by an underwater robot during the 2003 Medicines from the Deep Sea Expedition. Extracts from the sponge were tested for anti-cancer properties. Image credit: Laura Rear, NOAA.
http://oceanexplorer.noaa.gov/explorations/03bio/logs/summary/media/10249_bio_600.jpg

An agar plate with microorganisms isolated from a deepwater sponge. Image credit: NOAA.
http://oceanexplorer.noaa.gov/explorations/03bio/background/microbiology/media/figure_03.html

Lasonolide – Extracted from the sponge *Forcepia* sp.; anti-tumor agent; acts by binding with DNA

Discodermalide – Extracted from deep-sea sponges belonging to the genus *Discodermia*; anti-tumor agent; acts by interfering with microtubule networks

Bryostatin – Extracted from the bryozoan *Bugula neritina*; potential treatment for leukemia and melanoma; acts as a differentiating agent, forcing cancer cells to mature and thus halting uncontrolled cell division

Pseudopterosins – Extracted from the octocoral *Pseudopterogorgia elisabethae* (sea whip); anti-inflammatory and analgesic agents that reduce swelling and skin irritation and accelerate wound healing; acts as an inhibitor of phospholipase A, which is a key enzyme in inflammatory reactions

ω-conotoxin MVIIA – Extracted from the cone snail *Conus magnus*; potent pain-killer; acts by interfering with calcium ion flux, thereby reducing the release of neurotransmitters

This list reflects an interesting fact about invertebrates that produce pharmacologically-active substances: most species are sessile; they are immobile and live all or most of their lives attached to some sort of surface. Several reasons have been suggested to explain why these particular animals produce potent chemicals. One possibility is that they use these chemicals to repel predators, because they are sessile, and are basically "sitting ducks." Since many of these species are filter feeders, and consequently are exposed to all sorts of parasites and pathogens in the water, they may use powerful chemicals to repel parasites or as antibiotics against disease-causing organisms. Competition for space may explain why some of these invertebrates produce anti-cancer agents: if two species are competing for the same piece of bottom space, it would be helpful to produce a substance that would attack rapidly dividing cells of the competing organism. Since cancer cells often divide more rapidly than normal cells, the same substance might have anti-cancer properties.

The goal of the 2003 Medicines from the Deep Sea Expedition was to discover new resources with pharmaceutical potential in the Gulf of Mexico. To achieve this goal, the expedition:

- Collected selected benthic invertebrates from deepwater bottom communities (sponges, octocorals, molluscs, annelids, echinoderms, tunicates), identified these organisms, and obtained samples of DNA and RNA from the collected organisms;
- Isolated and cultured microorganisms that live in association with deep-sea marine invertebrates;
- Prepared extracts of benthic invertebrates and associated microorganisms, and tested these extracts to identify those that might be useful in treatment of cancer, cardiovascular disease, infections, inflammation, and disorders of the central nervous system;
- Isolated chemicals from extracts that show pharmacological potential and determined the structure of these chemicals;
- Studied the pharmacological properties of active compounds; and
- Developed methods for the sustainable use of biomedically important marine resources.

The last activity is particularly important, since many potentially useful compounds found in animals are present in very small quantities. This makes it impossible to obtain useful amounts of the substances simply by harvesting large numbers of animals from the sea. Some alternatives are chemical synthesis of specific products, aquaculture to produce large numbers of productive species, or culture of the cells that produce the desired compounds. Some techniques for producing specific drugs are based on the cells' own machinery for chemical synthesis: enzymes, guided by information contained in the cells' DNA and RNA.

This activity is designed to acquaint students with the process of screening for active ingredients in biological materials.

Learning Procedure

[NOTE: This lesson is based upon an activity designed by Jane Settle while participating in the 1993 Woodrow Wilson Biology Institute (*http://www.woodrow.org/teachers/bi/1993/active.html*). This activity is used with permission from the Woodrow Wilson National Fellowship Foundation. Visit *http://woodrow.org* for information on other activities and current programs.]

1. To prepare for this lesson:
   - Review established safety procedures for working with microbial materials, including school, district, and state policies; also see *http://www.nsta.org/portals/safety.aspx#elem* and *http://www.isbe.net/ils/science/pdf/science_safety.pdf*.
   - Review introductory information on the NOAA Ship *Okeanos Explorer* at *http://oceanexplorer.noaa.gov/okeanos/welcome.html*. You may also want to consider having students complete some or all of the lesson, *To Boldly Go*. . . .
   - Review the *Active Ingredient Screening Guide*, and prepare one copy for each student group. You may also want to review "Active Ingredient Screening Test for Plants" from *http://www.woodrow.org/teachers/bi/1993/active.html*
   - One day before the lab, prepare Luria broth for culturing *E. coli* bacteria, and innoculate the broth medium with a loopful of culture using sterile technique. Incubate at 35 – 37°C for 24 hours.
   - Before the lab begins, prepare nutrient agar and sterilize by autoclaving or in a pressure cooker. If you use a pressure cooker, place the agar container in a basket just above the water level. Seal the lid onto the cooker and allow steam to flow freely for 10 minutes. Place the pressure control on the vent and maintain the pressure at 15 pounds for 30 minutes. At the end of this time, let the cooker cool, then keep the agar warm in a water bath on a hot plate to prevent gelling.

2. If you have not previously done so, briefly introduce the NOAA Ship *Okeanos Explorer*, emphasizing that this is the first Federal vessel specifically dedicated to exploring Earth's largely unknown ocean. Lead a discussion of reasons that ocean exploration is important, which should include human health.

   Several days before beginning the lab investigation, review the importance of finding new drugs for the treatment of cardiovascular disease, cancer, inflammatory diseases, and infections. Describe the potential of marine communities as sources for these drugs, and briefly discuss some potentially useful drugs that have been discovered from these communities. Ask students to list some reasons that these kinds of drugs might be found primarily among sessile invertebrates. Briefly discuss the initial steps in the search for new drugs, and tell students that they will soon be testing various plant extracts for antibiotic activity using techniques similar to those used to screen for biologically active ingredients in the field. Brainstorm plants that students think may have antibiotic properties, and develop a list of plants for the students to collect. Jane Settle suggests yew, golden meadow parsnips, parsley, pussy willow leaves and/or bark, wild garlic, wild onion, wild iris, bedstraw, larkspur, blue-eyed grass, penstemon, wild licorice, four o'clock, big bluestem grass, and basil. Have students bring at least 5 leaves from the plants they choose to test. If wild plants are not available, try commonly available herbs or other food that may have medicinal properties, such as garlic, mustard (leaves and seeds), banana, honey, goldenseal, and *Echinacea* root.

3. Provide each student group with a copy of the *Active Ingredient Screening Guide*. Have students prepare Petri dishes and inoculate them with *E. coli* culture as directed by the *Guide.* While the agar is cooling, have students prepare plant extracts as directed (Steps B1 through B3). Each group should prepare extracts from four plants, and test them in three replicate Petri dishes (Steps C1 through C3).

4. After 48 hours of incubation, have students examine their petri dishes and look for zones of inhibition (a clear area formed around the test disks due to the inhibition of *E. coli* growth by the plant extract). Have students measure the diameter of any zones of inhibition they observe. Each group should summarize their results on the *Active Ingredient Screening Data Sheet*, and prepare a brief written analysis of their conclusions based on these tests. You may also want to require that these reports include answers to the questions on the *Active Ingredient Screening Guide*.

5. Upon completion of this activity, collect the culture dishes, and immerse them in a 10% bleach solution for at least 15 minutes. Drain the excess solution and seal the dishes in a plastic bag for disposal. Alternatively, you may sterilize the dishes for 30 minutes in a pressure cooker at 15 lb pressure.

6. Have each group make a brief presentation of their results. Summarize these results on a marker board or overhead transparency. Lead a discussion of how this lab activity relates to the process of actually searching for new drugs. Students should recognize that scientists might want to screen for other types of biological activity in addition to antibiotic properties.

   Discuss the process of developing a useful drug from a marine organism. The first step, of course, is to locate a promising candidate. This involves "prospecting" among many different species, though past experience suggests some groups (sessile invertebrates) that may be particularly promising. Extracts of each species are prepared, usually by grinding tissue from the organisms in organic solvents. Next, the extracts are tested for pharmacological activity through a series of bioassays (for example, finding out whether an extract can kill leukemia cells or reduce inflammation). When an extract is found to have positive biological activity, the active substance in the extract is isolated and identified. If the isolated chemical turns out to be new, the next step is to test the chemical in animal models (for example, mice with tumors). If animal testing is successful, the chemical may be approved for evaluation in humans. If the chemical is effective in humans without toxic side effects, it may be approved as a new drug. The entire process can take a lot of time and money: a new anti-cancer drug may require 10 – 20 years and an average of $40,000,000 to develop to the point of commercialization.

The BRIDGE Connection

www.vims.edu/bridge/ – Scroll over "Ocean Science" in the navigation menu to the left, then "Human Activities" then "Technology" for resources on biotechnology and drugs from the sea.

The "Me" Connection

Have students write a short essay about natural products that are of personal importance, and why it is important to protect rare or unknown species.

Connections to Other Subjects

English/Language Arts

Assessment

Students' responses to the *Guide* questions and class discussions provide opportunities for assessment.

Extensions

1. Visit *http://oceanexplorer.noaa.gov/explorations/03bio/welcome.html* to find out more about the Deep Sea Medicines 2003 Expedition.
2. Visit *http://www.woodrow.org/teachers/bi/1993/* for more activities related to biotechnology from the 1993 Woodrow Wilson Biology Institute.
3. Visit the following web sites for other activities related to microorganisms:
   www.glogerm.com
   http://ceprap.ucdavis.edu/index.php?option=com_content&view=article&id=56&Itemid=138 - Click on "Microbe Laboratories" and it will automatically download
   http://spikesworld.spike-jamie.com/science/index.html
   http://www.umsl.edu/~microbes/

Multimedia Discovery Missions

http://oceanexplorer.noaa.gov/edu/learning/welcome.html Click on the links to Lessons 12 for interactive multimedia presentations and Learning Activities on Food, Water, and Medicines from the Sea.

Other Relevant Lesson Plans from NOAA's Ocean Explorer Program

(The following Lesson Plans are targeted toward grades 9-12)

Cell Mates (from the 2003 Medicines from the Deep Sea Expedition)
http://oceanexplorer.noaa.gov/explorations/03bio/background/edu/media/meds_cellmates.pdf

Focus: Bacterial endosymbionts and organelles of eukaryotic cells (Life Science)
Students will compare and contrast prokaryotic and eukaryotic cells, explain the endosymbiont theory for the origin of eukaryotic cell organelles, and explain evidence that suggests an endosymbiotic origin for at least two common eukaryotic cell organelles.

The Benthic Drugstore (from the 2003 Medicines from the Deep Sea Expedition)
http://oceanexplorer.noaa.gov/explorations/03bio/background/edu/media/meds_drugstore.pdf

Focus: Pharmacologically-active chemicals derived from marine invertebrates (Life Science)

Students will identify at least three pharmacologically-active chemicals derived from marine invertebrates, describe the disease-fighting action of at least three pharmacologically-active chemicals derived from marine invertebrates, and infer why sessile marine invertebrates appear to be promising sources of new drugs.

The Electric Sieve (from the 2003 Medicines from the Deep Sea Expedition)
http://oceanexplorer.noaa.gov/explorations/03bio/background/edu/media/meds_elecsieve.pdf
Focus: Separation of complex mixtures (Chemistry)
Students will explain and carry out a simple process for separating complex mixtures, and will infer why organisms such as sessile marine invertebrates appear to be promising sources of new drugs.

Other Resources

See page 217 for Other Resources.

Next Generation Science Standards

Lesson plans developed for Volume 1 are correlated with *Ocean Literacy Essential Principles and Fundamental Concepts* as indicated in the back of this book. Additionally, a separate online document illustrates individual lesson support for the Performance Expectations and three dimensions of the Next Generation Science Standards and associated Common Core State Standards for Mathematics and for English Language Arts & Literacy. This information is provided to educators as a context or point of departure for addressing particular standards and does not necessarily mean that any lesson fully develops a particular standard, principle or concept. Please see: *http://oceanexplorer.noaa.gov/okeanos/edu/collection/wdwe_ngss.pdf.*

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Paula Keener, Director, Education Programs
NOAA Office of Ocean Exploration and Research
Hollings Marine Laboratory
331 Fort Johnson Road, Charleston SC 29412
843.762.8818 843.762.8737 (fax)
paula.keener-chavis@noaa.gov

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Active Ingredient Screening Guide

(adapted from *Active Ingredient Screening Test for Plants* by Jane Settle, 1993 Woodrow Wilson Biology Institute)

Purpose

To determine if various plant materials contain active ingredients that will inhibit the growth of bacteria.

Procedure

A. Prepare and Inoculate Petri Dishes

1. Prepare three empty, sterile Petri dishes by marking off the bottom of each Petri dish into quadrants, using a permanent felt-tip marker. Place a letter near the periphery of each quadrant that represents the plant material you will test. Label each dish with your name, class period and date.

2. Use a pipette to transfer 1 ml of the inoculum of *Escherichia coli* to each of the three sterile Petri dishes. Add 20 ml of the sterile liquid nutrient agar. Gently agitate the plate to diffuse the inoculum and allow it to gel and cool.

B. Prepare Plant Materials for Testing

1. Grind the plant material from one plant with a little distilled water in a mortar and pestle.

2. Use a sterile pipette to transfer the liquid from the mortar into an empty sterile Petri dish. Label the Petri dish with the name of the plant material.

3. Repeat Steps B1 and B2 for three other plant materials.

C. Test Plant Extracts for Bacterial Inhibition

1. Sterilize forceps by flaming or soaking in alcohol. Use the sterilized forceps to place 3 sterile disks into each of the liquid plant materials. Allow to soak for one minute.

2. After the agar has gelled in the Petri dishes prepared in Part A, use sterile forceps to carefully place one disk (blot any excess liquid before placing it on the Petri dish) in the correctly labeled quadrant, about 2 cm from the outer edge of the Petri dish. Place a control disk saturated with sterile distilled water in the center of each dish. Seal the dish with strapping tape.

   Repeat this step twice more, so that you have three replicate Petri dishes in which you are testing four plant materials for their ability to inhibit bacterial growth.

3. Invert the Petri dishes and incubate at 35–37° C for 48 hours.

4. If desired, you may save the plant extracts in the refrigerator for future use.

5. After 48 hours, examine the plates with the plant disks and look for zones of inhibition. This is a clear area formed around the disc due to inhibitory action of the substances in the plant material. If a zone of inhibition is present, measure the diameter of this clear area and record your results on the *Data Sheet*.

Analysis

1. Which of the plant materials inhibited the bacteria growth?

2. Which of the plant materials had no effect on the bacteria growth?

3. What does the clear zone around the disk indicate in this investigation?

4. Why is it important to use sterile techniques in this investigation?

5. What variable factors could affect the zone of inhibition in this investigation?

6. Why do plants vary in their active ingredients? How might these active ingredients be advantageous to plants that produce them?

Active Ingredient Screening Data Sheet

Plant Material	Zone of Inhibition (Diameter)	Zone of Inhibition (Degree of Sensitivity)*
Petri Dish A.		
1.		
2.		
3.		
4.		
Control:		
Petri Dish B.		
1.		
2.		
3.		
4.		
Control:		
Petri Dish C.		
1.		
2.		
3.		
4.		
Control:		

*Identify inhibition zones as:
No Effect = 0, Slightly Sensitive = +, Sensitive = ++, Very Sensitive = +++

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*

Section 6: Key Topic – Ocean Health

Build Your Own Ocean Ecosystem

Focus
Key functions of healthy ocean ecosystems

Grade Level
5-6 (Life Science)

Focus Question
What key functions are present in healthy ocean ecosystems?

Learning Objectives
- Students will identify key functions that are present in healthy ocean ecosystems.
- Students will discuss how these functions are met by living and non-living components in a model aquatic ecosystem.

Materials
- Copies of *Build Your Own Ocean Ecosystem Construction Guide*, one copy for each student group
- Materials for constructing model ecosystems

Materials for one model:
- 1 - 1 quart glass canning jar
- 3 - Plastic containers, 1 quart capacity or larger
- 12 (Approximately) - River pebbles, about grape-size; enough to cover the bottom of the glass jar in a single layer
- 3-4 - Small shells
- 1 - Amano shrimp, *Caridina multidentata* (from an aquarium store)
- 4 - Aquatic snails, each less than 1 cm overall length
- 8-inch stem of hornwort (*Ceratophyllum demersum*; from an aquarium store)
- Duckweed, approximately 2 inches x 2 inches (from an aquarium store or local pond)
- 2-8 - Amphipods (from a local pond)
- Student logbook for recording observations

Materials that may be shared by several groups:
- Fishnet or kitchen strainer
- Dechlorinating solution (for treating tap water; from an aquarium store)
- Solution of freshwater minerals (*e.g.*, "cichlid salts;" from an aquarium store)
- Calcium carbonate powder (from an aquarium store)
- Pond sludge

Ocean Exploration and Research

- Tablespoon measure
- Plastic bucket, 1 gallon or larger capacity

Audiovisual Materials

- None

Teaching Time

Four or five 45-minute class periods, plus time for student research and periodic discussion of model ecosystems

Seating Arrangement

Groups of 2-4 students

Maximum Number of Students

32

Key Words and Concepts

Ocean health	Invasive species
Model ecosystem	Climate change
Overfishing	Pollution
Habitat destruction	Ocean acidification

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.

"The great mass extinctions of the fossil record were a major creative force that provided entirely new kinds of opportunities for the subsequent explosive evolution and diversification of surviving clades. Today, the synergistic effects of human impacts are laying the groundwork for a comparably great Anthropocene mass extinction in the oceans with unknown ecological and evolutionary consequences. Synergistic effects of habitat destruction, overfishing, introduced species, warming, acidification, toxins, and massive runoff of nutrients are transforming once complex ecosystems like coral reefs and kelp forests into monotonous level bottoms, transforming clear and productive coastal seas into anoxic dead zones, and transforming complex food webs topped by big animals into simplified, microbially dominated ecosystems with boom and bust cycles of toxic dinoflagellate blooms, jellyfish, and disease. Rates of change are increasingly fast and nonlinear with sudden phase shifts to novel alternative community states. We can only guess at the kinds of organisms that will benefit from this mayhem that is radically altering the selective seascape far beyond the consequences of fishing or warming alone. The prospects are especially bleak for animals and plants compared with metabolically flexible microbes and algae. Halting and ultimately reversing these trends will require rapid and fundamental changes in fisheries, agricultural practice, and the emissions of greenhouse gases on a global scale."

– Dr. Jeremy Jackson, Scripps Institution of Oceanography, 2008

Limacina helicina, a free-swimming planktonic snail. These snails, known as pteropods, form a calcium carbonate shell and are an important food source in many marine food webs. As levels of dissolved CO_2 in sea water rise, skeletal growth rates of pteropods and other calcium-secreting organisms will be reduced due to the effects of dissolved CO_2 on ocean acidity. Image credit: Russ Hopcroft, UAF/NOAA. *http://www.noaanews.noaa.gov/stories2006/images/pteropod-limacina-helicina.jpg*

According to the Intergovernmental Panel on Climate Change (the leading provider of scientific advice to global policy makers), surface ocean pH is very likely to decrease by as much as 0.5 pH units by 2100, and is very likely to impair shell or exoskeleton formation in marine organisms such as corals, crabs, squids, marine snails, clams and oysters.

Large *Paragorgia* colonies on basalt substrate. Image credit: NOAA. *http://oceanexplorer.noaa.gov/explorations/04mountains/logs/hirez/paragorgia_hirez.jpg*

Unusual spiny crab spotted on NW Rota 1 volcano. Crabs are opportunistic predators at vent sites. The body of this crab is ~2 in. (~5 cm) across. Image credit: NOAA. *http://oceanexplorer.noaa.gov/explorations/04fire/logs/hirez/spinycrab_hirez.jpg*

At NW Eifuku volcano, mussels are so dense in some places that they obscure the bottom. The mussels are ~18 cm (7 in) long. The white galatheid crabs are ~6 cm (2.5 in) long. Image credit: NOAA. *http://oceanexplorer.noaa.gov/explorations/04fire/logs/hirez/mussel_mound_hirez.jpg*

The health of Earth's ocean is simultaneously threatened by over-exploitation, destruction of habitats, invasive species, rising temperatures, and pollution. Most, if not all, of these threats are the result of human activity. An overview of these issues can be found in Diving Deeper, page 33, and are discussed in greater detail in Allsopp, Page, Johnston, and Santillo (2007) and Jackson (2008). Most of these threats involve entire ocean ecosystems, which are highly complex and are not well-understood. Since Earth's ocean occupies more than 70% of our planet and the entire ocean is being affected, these issues inevitably will affect the human species as well.

As is true for many environmental problems, these threats do not exist because of a single, deliberate action, but are the result of numerous individual actions that take place over many years without any consideration for their collective impacts on Earth's ecosystems. Not surprisingly, effective solutions to these problems also usually involve numerous individual actions that by themselves seem insignificant, but collectively can have global impacts over time. Your students will be part of these solutions, which are rooted in an ecosystem perspective that understands our dependence on Earth's fundamental ecological systems and processes.

This activity guides a student investigation into some of these systems and processes, and may be a springboard for initiatives that can have a significant positive impact on the health of Earth's ocean.

Learning Procedure

Note: This activity is adapted from *Ecosystems Engineering* by Martin John Brown, which appeared in Volume 10 of *Make* magazine. In a followup comment, Brown says:

> *"Most of the questions I've gotten have to do with switching ingredients or adding extra animals. The short answer is, DON'T. Making a bottle ecosystem is not the same as just throwing some stuff from the local pond in a jar, and it is nothing like running a regular fish tank. There is a reason for everything in the article. If you get too many animals or nutrients in there the animals are going to run out of oxygen pronto. You don't want your little civilization to just survive, anyway—you want it to thrive. It's a tenuous balance, but you can learn to walk it like a tightrope artist."*

You can download Brown's original article from *http://cachefly.oreilly.com/make/wp_aquanaut.pdf*.]

1. To prepare for this lesson:
 - Review introductory information on the NOAA Ship *Okeanos Explorer* at *http://oceanexplorer.noaa.gov/okeanos/welcome.html*. You may also want to consider having students complete some or all of the lesson, *To Boldly Go*....
 - Review information in Diving Deeper, *Ocean Health Overview*,starting on page 33, and decide how to present this information to your students. One option is to divide the topics discussed in the *Overview* among individual student groups as subjects for group investigations. Another possibility is to assign sections of the *Overview* to student groups as background for group reports. A third option is to use Allsopp, Page, Johnston, and Santillo (2007) and Jackson (2008) as background materials. The most appropriate approach will depend upon the amount of class time available, students' reading capabilities and research skills, and availability of resources for student research.
 - Review procedures for constructing Tabletop Shrimp Support Modules in the *Build Your Own Ocean Ecosystem Construction Guide*, and assemble the

necessary materials for the number of modules that your students will construct. Pond sludge should be collected in the late afternoon (when pH is higher as plants have had the day to photosynthesize and produce oxygen), ideally from an area of the pond near aquatic plants, and it should contain a mixture of substrates such as sand, rock, and decaying wood. Collect the sludge from the pond bottom, and drag a fine-mesh net through the water as well. Ideally, you will collect a mixture of amphipods, copepods, and ostracods along with the sludge. You may also want to review the original article, available online at *http://cachefly.oreilly.com/make/wp_aquanaut.pdf*.

You may also want to check out Jeremy Jackson's *Brave New Ocean* presentation at *http://www.esi.utexas.edu/outreach/ols/lectures/Jackson/* (has links to a Webcast of the presentation).

2. If you have not previously done so, briefly introduce the NOAA Ship *Okeanos Explorer*, emphasizing that this is the first Federal vessel specifically dedicated to exploring Earth's largely unknown ocean. Lead a discussion of reasons that ocean exploration is important, which should include understanding ocean health issues.

3. Tell students that they are going to construct a functioning model of an aquatic ecosystem. To prepare for this assignment, their first task is to identify the key functions that are needed to make an ecosystem work, and how these functions can be provided in a model system. Show the glass jar that will be used to contain the system. Brainstorm these functions as a class activity.

   Students may recognize the need for a source of energy, and that the primary source of energy in most familiar ecosystems is sunlight which is converted to chemical energy by green plants through photosynthesis. Ask students to identify organisms that could provide an energy source for their model ecosystem. Algae (both microscopic and macroscopic) and other green plants are the most likely possibilities.

   So now we have the beginnings of a food chain for our model system. Ask students how many more links could reasonably be added to this food chain. You may need to remind them that energy transfer efficiency between trophic levels is less than 10% (*i.e.*, it takes at least 10 grams of primary producers to support 1 gram of herbivores, and 1 gram of herbivores can support less than 0.1 gram of primary carnivores, etc.). This means that the number of trophic levels in your model ecosystem may be limited. This also calls attention to the issue of size and types of organisms that should be included in the model ecosystem.

   Highly active organisms (such as fishes) will require a lot of food which may be difficult to provide in a total volume of one quart. This leads to the issue of waste disposal. Be sure students understand that the concept of "waste" is a human invention: in nature, by-products from one organism are raw materials for other organisms. This process is essential to natural recycling. Much of this work is done by microorganisms, which need to be present for a model system to work well.

   Discuss key physical factors. Temperature is one factor. Since the model systems will be maintained at room temperature, it is important to know how much that temperature changes over a 24-hour period, as well as over a weekly period (does your school turn off heating & cooling systems at night or over the weekend to save energy?) Light is another important factor when photosynthesis is involved. Natural sunlight contains substantially more blue wavelengths than most artificial lights, but if the model systems are placed in sunlight, temperature may be a problem. Water movement is also important in many natural aquatic systems. Since the model systems will have almost no water movement, except that created by mobile organisms, it is important to know that all of the potential occupants are okay with these conditions.

Oxygen may already have been mentioned in the context of energy from photosynthesis. Ask students how energy from photosynthesis is used by living organisms, which leads to the process of respiration, and the fact that carbon dioxide is a by-product of this process. Discuss the effects of carbon dioxide in an aquatic system. Students may say that carbon dioxide from respiration will be recycled through photosynthesis. This is true, but since photosynthesis needs light which is absent at night, this process cannot occur for about half of every day. But all of the organisms (including green plants) in the system will continue to respire during this period, which will cause carbon dioxide to build up in the system. At this point, you may want to show the effects of carbon dioxide on pH using the demonstration in Diving Deeper, page 41. It might be a good idea to include some way to reduce pH fluctuations in the model system.

Show students the materials (or the list of materials) that they will be using to construct their model ecosystems, and discuss how each of the key ecosystem functions they have identified will be met with these materials.

4. Provide each student group with a copy of the *Build Your Own Ecosystem Construction Guide*, access to necessary materials, and have each group assemble their model ecosystem. If all goes reasonably well, the model systems should function for at least several months. If a system fails before the end of the school year, discuss what might have happened. Students should realize that even if everything functions perfectly, the longevity of the system will eventually be limited by the lifespan of the organisms present.

5. Have student groups research topics of ocean health according to the plan identified in Step 1. Part of this assignment should be for each group to summarize their research in a written report that includes:
   - Causes of the problem;
   - What should be done to fix the problem; and
   - What individuals can do to be part of the solution.

   Since many of these problems exist on a global scale, it may be difficult for students to identify solutions and meaningful individual action. You may want to ask, "How do you eat an elephant?" The answer is, "One bite at a time." The key point is that these problems didn't happen all at once, so we probably shouldn't expect to fix them all at once.

   If you need to provide additional stimulus for student ideas, ask students to consider that most people are unaware of these problems, which means that there are opportunities for students to communicate their results to other audiences. In most cases, solutions involve public policy decisions that can be stimulated by large numbers of people expressing concern, or (even better) demanding that specific action be taken.

Students may also identify local, regional, or national organizations that are concerned with these issues and may have projects that involve individual participation. You may want to remind students that ocean health issues involve global ecosystems, so actions they take on their particular part of the globe are connected to the rest of the system. This is precisely why it is unlikely that ocean health issues can be resolved with a single action, and why numerous small actions in many different places can be the most effective means of improving the health of Earth's ocean.

The BRIDGE Connection

www.vims.edu/bridge/ – Scroll over "Ocean Science Topics," "Human Activities," then "Environmental Issue" for links to resources about pollution, conservation, bycatch, sustainability, and policy.

The "Me" Connection

Have students write a brief essay describing how they could have a personal impact on an issue affecting ocean health.

Connections to Other Subjects

English/Language Arts, Social Sciences, Physical Science

Assessment

Students' model ecosystems, written reports, and class discussions provide opportunities for assessment.

Extensions

1. Follow events aboard the *Okeanos Explorer* at *http://oceanexplorer.noaa.gov/okeanos/welcome.html*.
2. The abstract of Jackson's (2008) paper (quoted at the beginning of the Background section) provides a good opportunity for English/Language Arts and Science reading. Some suggested vocabulary terms are:

Mass extinction	Anthropocene
Diversification	Anoxic
Clade	Dinoflagellate
Synergistic	bloom

Multimedia Discovery Missions

http://www.oceanexplorer.noaa.gov/edu/learning/welcome.html Click on the links to Lessons 12 and 14 for interactive multimedia presentations and Learning Activities on Food, Water, and Medicine from the Sea; and Seamounts.

Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

(Unless otherwise noted, the following Lesson Plans are targeted toward Grades 5-6)

Design a Reef! (Grades 7-8)

(from the 2003 Gulf of Mexico Deepwater Habitats Expedition)

http://oceanexplorer.noaa.gov/explorations/03mex/background/edu/media/mexdh_aquarium.pdf

Focus: Niches in coral reef ecosystems (Life Science)

Students will compare and contrast coral reefs in shallow water and deep water, describe the major functions that organisms must perform in a coral reef ecosystem, and explain how these functions might be provided in a miniature coral reef ecosystem. Students will also explain the importance of three physical factors in coral reef ecosystems and infer the fundamental source of energy in a deepwater coral reef.

A Piece of Cake (from the 2003 Charleston Bump Expedition)
http://oceanexplorer.noaa.gov/explorations/03bump/background/education/media/03cb_cake.pdf
Focus: Spatial heterogeneity in deepwater coral communities (Life Science)
Students will explain what a habitat is, describe at least three functions or benefits that habitats provide, and describe some habitats that are typical of deepwater hard bottom communities. Students will also explain how organisms, such as deepwater corals and sponges, add to the variety of habitats in areas such as the Charleston Bump.

Alien Invasion!
(from the 2003 Life on the Edge Expedition)
http://oceanexplorer.noaa.gov/explorations/03edge/background/edu/media/aliens.pdf
Focus: Invasive species (Life Science)
Students will compare and contrast "alien species" and "invasive species," explain positive and negative impacts associated with the introduction of non-native species, and give a specific example of species that produce these impacts. Students will also describe at least three ways in which species may be introduced into non-native environments and discuss actions that can be taken to mitigate negative impacts caused by non-native species.

Save A Reef!
(from the Bonaire 2008: Exploring Coral Reef Sustainability with New Technologies Expedition)
http://oceanexplorer.noaa.gov/explorations/08bonaire/background/edu/media/savereef.pdf
Focus: Coral reef conservation (Life Science)
Students will design a public information program to improve understanding of the coral reef crisis, and things individuals can do to reduce stresses on coral reef systems.

Other Resources

See page 217 for Other Resources.

Next Generation Science Standards

Lesson plans developed for Volume 1 are correlated with *Ocean Literacy Essential Principles and Fundamental Concepts* as indicated in the back of this book. Additionally, a separate online document illustrates individual lesson support for the Performance Expectations and three dimensions of the Next Generation Science Standards and associated Common Core State Standards for Mathematics and for English Language Arts & Literacy. This information is provided to educators as a context or point of departure for addressing particular standards and does not necessarily mean that any lesson fully develops a particular standard, principle or concept. Please see: *http://oceanexplorer.noaa.gov/okeanos/edu/collection/wdwe_ngss.pdf.*

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:
oceanexeducation@noaa.gov

For More Information

Paula Keener, Director, Education Programs
NOAA Office of Ocean Exploration and Research
Hollings Marine Laboratory
331 Fort Johnson Road, Charleston SC 29412
843.762.8818 843.762.8737 (fax)
paula.keener-chavis@noaa.gov

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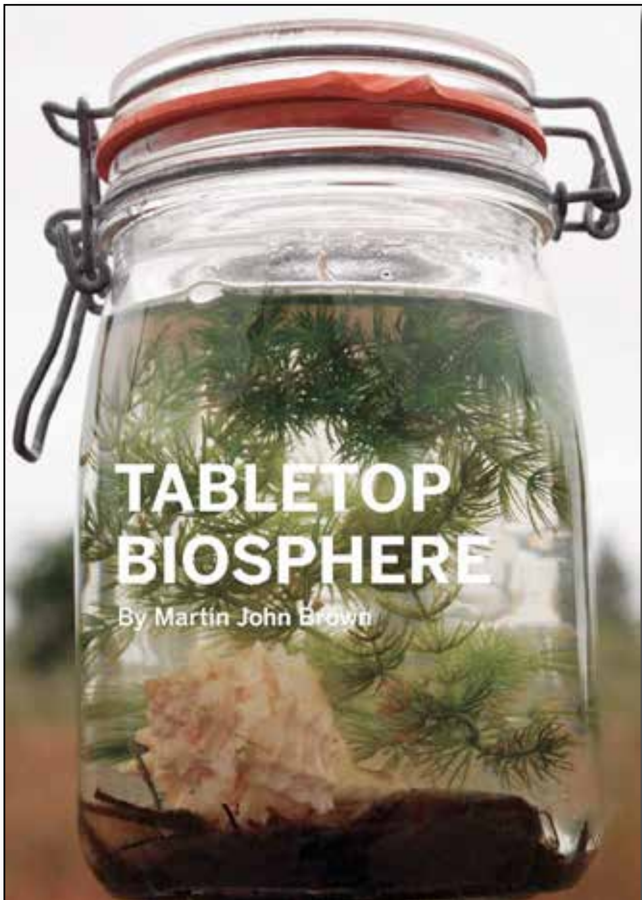
Build Your Own Ecosystem Construction Guide

NOTE: These procedures are adapted from *Ecosystems Engineering*, an article by Martin John Brown that appeared in Volume 10 of *Make* magazine. The article can be downloaded from *http://cachefly.oreilly.com/make/wp_aquanaut.pdf.*



from *Make*, Volume 10

1. Obtain Amano shrimp, snails, hornwort, duckweed, and pond sludge from your teacher.

2. Make Nitrate-Poor Fresh Water (NPFW) by adding dechlorinating solution and mineral solution to a gallon of tap water according to directions on the packages. Your teacher may have you do this step with one or two other groups. The water from the pond or the aquarium store is likely to have a lot of algae and nitrates which would allow algae to take over the system. The use of NPFW helps to prevent this.

3. Rinse your 1-quart canning jar, rocks, and shells in the NPFW.

4. Fill your 1-quart canning jar halfway with NPFW. Put rocks in first, then shells, then the shrimp, snails, hornwort, duckweed, and 2 tablespoons of pond sludge. Be sure not to overload your system with extra animals or plants. Use only the amount specified!

5. Add more NPFW to your jar so that the top of the water is 1-inch below the top edge of the jar. Add 1 tablespoon of calcium carbonate powder (this will make the water cloudy for several hours because it dissolves slowly).

6. Place the cap tightly on the jar.

7. Place your ecosystem in a location that has temperature between 70°F and 80°F, and moderate light for about 12 - 16 hours per day. Do not put your system in direct sunlight.

8. Observe your ecosystem at least once each day, and record your observations in a logbook. Be sure to note what the animals are doing, whether they seem to be growing, and whether anything has died. Some of these ecosystems last for several months…how long will yours last?

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

Section 6: Key Topic – Ocean Health

Stressed Out!

Focus
Threats to ocean health

Grade Level
7-8 (Life Science)

Focus Question
What stresses threaten the health of ocean ecosystems, and what may be done to reduce these stresses?

Learning Objectives
- Students will identify stresses that threaten the health of ocean ecosystems.
- Students will explain natural and human-caused processes that contribute to these stresses.
- Students will discuss actions that may be taken to reduce these stresses.

Materials
- (Optional) Materials for Scientific Posters: see Learning Procedure Note and Step 5)
- (Optional) Materials for Constructing a Tabletop Shrimp Support Module (TSSM): see Learning Procedure Note and Step 6)
  - Copies of *Tabletop Shrimp Support System Construction Guide*, one copy for each student group
  - Materials for constructing TSSM modules:

Materials for one TSSM:
- 1 - 1 quart glass canning jar
- 3 - plastic containers, 1 quart capacity or larger
- 12 (approximately) - River pebbles, about grape-size; enough to cover the bottom of the glass jar in a single layer
- 3-4 - small shells
- 1 - Amano shrimp, *Caridina multidentata* (from an aquarium store)
- 4 - aquatic snails, each less than 1 cm overall length
- 8-inch stem of hornwort (*Ceratophyllum demersum*; from an aquarium store)
- Duckweed, approximately 2 inches x 2 inches (from an aquarium store or local pond)
- 2-8 - Amphipods (from a local pond)

Materials that may be shared by several groups:
- Fishnet or kitchen strainer

- Dechlorinating solution (for treating tap water; from an aquarium store)
- Solution of freshwater minerals (*e.g.*, "cichlid salts;" from an aquarium store)
- Calcium carbonate powder (from an aquarium store)
- Tablespoon measure
- Pond sludge
- Plastic bucket, 1 gallon or larger capacity

Audiovisual Materials

- None

Teaching Time

Two or three 45-minute class periods plus time for student research; additional time will be required for optional activities (see Learning Procedure Note)

Seating Arrangement

Six groups of students

Maximum Number of Students

30

Key Words and Concepts

Ocean health
Overfishing
Habitat destruction
Invasive species
Climate change
Pollution
Ocean acidification

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.

> *"The great mass extinctions of the fossil record were a major creative force that provided entirely new kinds of opportunities for the subsequent explosive evolution and diversification of surviving clades. Today, the synergistic effects of human impacts are laying the groundwork for a comparably great Anthropocene mass extinction in the oceans with unknown ecological and evolutionary consequences. Synergistic effects of habitat destruction, overfishing, introduced species, warming, acidification, toxins, and massive runoff of nutrients are transforming once complex ecosystems like coral reefs and kelp forests into monotonous level bottoms, transforming clear and productive coastal seas into anoxic dead zones, and transforming complex food webs topped by big animals into simplified, microbially dominated ecosystems with boom and bust cycles of toxic dinoflagellate blooms, jellyfish, and disease. Rates of change are increasingly fast and nonlinear with sudden phase shifts to novel alternative community states. We can only guess at the kinds of organisms that will benefit from this mayhem that is radically altering the selective seascape far*

beyond the consequences of fishing or warming alone. The prospects are especially bleak for animals and plants compared with metabolically flexible microbes and algae. Halting and ultimately reversing these trends will require rapid and fundamental changes in fisheries, agricultural practice, and the emissions of greenhouse gases on a global scale."

– Dr. Jeremy Jackson, Scripps Institution of Oceanography, 2008

The health of Earth's ocean is simultaneously threatened by over-exploitation, destruction of habitats, invasive species, rising temperatures, and pollution. Most, if not all, of these threats are the result of human activity. An overview of these issues can be found in Diving Deeper, page 33, and are discussed in greater detail in Allsopp, Page, Johnston, and Santillo (2007) and Jackson (2008). Most of these threats involve entire ocean ecosystems, which are highly complex and are not well-understood. Since Earth's ocean occupies more than 70% of our planet and the entire ocean is being affected, these issues inevitably will affect the human species as well.

Despite their severity, many of the ocean health issues described in Diving Deeper are not widely accepted as pervasive and pressing problems requiring immediate attention. Part of the problem is a phenomenon called "shifting baselines," a term first used by fishery biologist Daniel Pauly. A baseline is a reference point that allows us to recognize and measure change. It's how certain things are at some point in time. Depending upon the reference point (baseline), a given change can be interpreted in radically different ways. For example, the number of salmon in the Columbia River in 2007 was about twice what it was in the 1930s, but only about 20% of what is was in the 1800s. Things look pretty good for the salmon if 1930 is the baseline; but not nearly as good compared to the 1800s. The idea is that some changes happen very gradually, so that we come to regard a changed condition as "normal." When this happens, the baseline has shifted. Shifting baselines are a serious problem, because they can lead us to accept a degraded ecosystem as normal—or even as an improvement (Olson, 2002).

Perceptions of coral reefs offer another example of shifting baselines. Many of Earth's coral reefs appear to be in serious trouble due to causes that include over-harvesting, pollution, disease, and climate change (Bellwood *et al.*, 2004). In the Caribbean, surveys of 302 sites between 1998 and 2000 show widespread recent mortality among shallow- (<5 m depth) and deepwater (> 5 m depth) corals. Remote reefs showed as much degradation as reefs close to human coastal development, suggesting that the decline has probably resulted from multiple sources of long-term as well as short-term stress (Kramer, 2003). Despite these kinds of data and growing concern among marine scientists, visitors continue to be thrilled by the "abundance and diversity of life on coral reefs." So, people who have never seen a coral reef before may still find it to be spectacular, even though many species have disappeared and the corals are severely stressed.

This activity guides a student investigation into stresses that threaten the health of ocean ecosystems, and actions that may be taken to reduce these stresses.

Learning Procedure

NOTE: This lesson includes two optional activities; one involving scientific communication (Step 5) and another involving experiment-based hypothesis testing (Step 6). These activities will add significantly to time requirements, but they are both fundamental elements of modern science and can be related to

Limacina helicina, a free-swimming planktonic snail. These snails, known as pteropods, form a calcium carbonate shell and are an important food source in many marine food webs. As levels of dissolved CO_2 in sea water rise, skeletal growth rates of pteropods and other calcium-secreting organisms will be reduced due to the effects of dissolved CO_2 on ocean acidity. Image credit: Russ Hopcroft, UAF/NOAA.
http://www.noaanews.noaa.gov/stories2006/images/pteropod-limacina-helicina.jpg

According to the Intergovernmental Panel on Climate Change (the leading provider of scientific advice to global policy makers), surface ocean pH is very likely to decrease by as much as 0.5 pH units by 2100, and is very likely to impair shell or exoskeleton formation in marine organisms such as corals, crabs, squids, marine snails, clams and oysters.

Large *Paragorgia* colonies on basalt substrate. From the Mountains in the Sea 2004. Image credit: NOAA.
http://oceanexplorer.noaa.gov/explorations/04mountains/logs/hirez/paragorgia_hirez.jpg

Unusual spiny crab spotted on NW Rota 1 volcano. Crabs are opportunistic predators at vent sites. The body of this crab is ~2 in. (~5 cm) across. Image credit: NOAA.
http://oceanexplorer.noaa.gov/explorations/04fire/logs/hirez/spinycrab_hirez.jpg

many other curriculum elements, which may justify allocating the extra time needed for their completion.

1. To prepare for this lesson:
   - Review introductory information on the NOAA Ship *Okeanos Explorer* at *http://oceanexplorer.noaa.gov/okeanos/welcome.html*. You may also want to consider having students complete some or all of the lesson, *To Boldly Go*. . . .
   - Review *Ocean Health Overview* in Diving Deeper, page 33.
   - If you plan to use the optional scientific communication activity (Step 5), review Scientific Posters, page 204.
   - If you plan to use the optional experiment-based hypothesis testing activity (Step 6), review procedures in the *Tabletop Shrimp Support Modules Construction Guide,* page 205, and decide whether you will assemble the necessary materials or have students do this as part of their assignment. You may also want to review the original article, available online at *http://cachefly.oreilly.com/make/wp_aquanaut.pdf*.

   You may also want to check out Dr. Jeremy Jackson's *Brave New Ocean* presentation at *http://www.esi.utexas.edu/outreach/ols/lectures/Jackson/* (has links to a Webcast of the presentation).

2. If you have not previously done so, briefly introduce the NOAA Ship *Okeanos Explorer*, emphasizing that this is the first Federal vessel specifically dedicated to exploring Earth's largely unknown ocean. Lead a discussion of reasons that ocean exploration is important, which should include understanding ocean health issues.

3. Tell students that their assignment is to research six major topics relevant to ocean health. Assign one of the following topics to each student group:
   Overfishing
   Habitat Destruction
   Invasive Species
   Toxins, Nutrients, Marine Debris
   Climate Change
   Ocean Acidification

   Instruct each group to prepare a report that includes:
   - Description of the problem;
   - Causes of the problem;
   - What needs to be done to correct the problem; and
   - What individuals can do to be part of the solution.

   There are several options for the format of the report, including an oral presentation, written report, PowerPoint™ or video presentation, or scientific poster (see Step 5). You may want to assign one or more of these formats or leave the choice to individual student groups, depending upon available time and resources.

4. Have each group present and discuss results of their research. Since the assigned topics include problems that exist on a global scale, it may be difficult for students to identify solutions and meaningful individual action. If this problem arises, you may want to ask, "How do you eat an elephant?" The answer is, "One bite at a time." The key point is that these problems didn't happen all at once, so we probably shouldn't expect to fix them all at once. It may be helpful to consider specific individual

At NW Eifuku volcano, mussels are so dense in some places that they obscure the bottom. The mussels are ~18 cm (7 in) long. The white galatheid crabs are ~6 cm (2.5 in) long. Image credit: NOAA. *http://oceanexplorer.noaa.gov/explorations/04fire/logs/hirez/mussel_mound_hirez.jpg*

Although much of the debris concentrated in the "garbage patch" is composed of small bits of plastic not immediately visible to the naked eye, large items are occasionally observed. On Aug. 11, Scripps Institution of Oceanography SEAPLEX researchers encountered this large ghost net with tangled rope, net, plastic, and various biological organisms. Image credit: Scripps Institution of Oceanography. *http://oceanexplorer.noaa.gov/okeanos/explorations/ex1006/background/mantanet/media/ghost_net.html* decisions or actions that collectively contribute to the problem, and then how these decisions or actions could be modified to achieve a different outcome.

Sharing the results of this discussion is important! Social networks used by students are an obvious possibility, as are a variety of school-to-school network projects. Please share your ideas with us, and let us know if you need our help (see Send Us Your Feedback, below).

5. (Optional) Have student groups prepare scientific posters about ocean health issues. See Page 204 for information about scientific posters. Arrange for students to present their posters to one or more audiences, such as other classes, parent groups, teachers, or community groups. Prior to beginning this activity, explain to students that communication is a fundamental part of modern science, and is essential for scientists to be able to learn and build on the results of others. In the case of ocean health issues, communication to non-scientific audiences is particularly important, because most people are unaware of these problems, and because most solutions involve public policy decisions that can be stimulated by large numbers of people expressing concern, or (even better) demanding that specific action be taken.

6. (Optional) The *Tabletop Shrimp Support Modules Construction Guide* is based on the Tabletop Shrimp Support Module (TSSM) described in an article titled *Ecosystems Engineering* by Martin John Brown, which appeared in Volume 10 of *Make* magazine. You can download a pdf of Brown's original article from *http://cachefly.oreilly.com/make/wp_aquanaut.pdf*. In a followup comment about the article, Brown says:

   "Most of the questions I've gotten have to do with switching ingredients or adding extra animals. The short answer is, DON'T. Making a bottle ecosystem is not the same as just throwing some stuff from the local pond in a jar, and it is nothing like running a regular fish tank. There is a reason for everything in the article."

   The concept of this activity is to investigate the reasons for some of the individual components in the TSSM through experimental manipulation. The objectives of this activity are to give students experience in formulating and testing hypotheses, as well as identifying critical functions in aquatic ecosystems.

   Prior to beginning this activity, you will need to decide whether students will be required to obtain their own materials for constructing their TSSMs, or whether you will provide some or all of them. You will also need to decide whether students will work individually or in pairs. Larger groups are not recommended, because this will limit the number of replicate and control systems available, and these are essential to a well-designed experimental procedure.

   Begin the activity with a class discussion that reviews TSSMs and the functions of individual components. Explain to students that you want to conduct a class experiment that tests hypotheses about one or more of these functions. Since the TSSM as described in the *Tabletop Shrimp Support Module Construction Guide* and in the original article by Brown is supposed to be a balanced system, hypotheses about the functions of components will be tested through experimental manipulations that alter this balance. Guide a class discussion to define one or more hypotheses and experimental manipulations that can test each hypothesis. Be sure to include controls, replicates, and avoid manipulating more than one variable at a time. A class of 30 students working in pairs would provide 15 TSSM systems, that could be allocated to 5 replicate controls and two sets of 5 replicate experimental systems to test two levels of a particular manipulation (*e.g.*, half as much calcium carbonate and no calcium carbonate). Plan to allow systems to equilibrate for at least one week after they are assembled before beginning experimental manipulations.

Randomly assign the systems to experimental and control groups. One technique for doing this is to give each system a number, beginning with "01," then "02," and so on. Then select a page from a telephone book and read the last two digits of the telephone numbers beginning at the top of the page. When the last two digits match the number of one of the systems, that system is assigned as a control. The next match is assigned to the first experimental group. The third match is assigned to the second experimental group. The fourth match is assigned as a control, and so on, consecutively assigning systems to control and experimental groups in rotation until all systems have been assigned.

Hypotheses and predictions should be based on students' knowledge of processes that occur in the TSSM system, such as photosynthesis and respiration. For example, students should realize that respiration produces carbon dioxide, and dissolved carbon dioxide will lower the pH of surrounding water (see Diving Deeper, page 41, for a demonstration of this). So, predictions about the function of calcium carbonate and/or shells might involve fluctuations in pH that could be measured in experimental and control systems. Here are a few other ideas:

- Keep experimental systems in the dark for 24 hours, then check pH & compare to pH of systems after 12 hours darkness & 12 hours light.
- Omit calcium carbonate and shells from some systems and repeat above, comparing results with systems that have calcium carbonate and shells.
- Double the amount of plant material.
- If you have an electronic dissolved oxygen meter, measure oxygen as well as pH in the above comparison.

Once data are collected, students should perform simple statistical analyses to evaluate the significance of any differences observed, and state whether the experimental results support or reject the hypothesis. After a particular hypothesis has been tested, you may have students restore all of the TSSMs to the "balanced" design, allow the systems to equilibrate, and test another hypothesis. Again, systems should be randomly assigned to experimental and control groups.

The BRIDGE Connection

www.vims.edu/bridge/ – Scroll over "Ocean Science Topics," "Human Activities," then "Environmental Issue" for links to resources about pollution, conservation, bycatch, sustainability, and policy.

The "Me" Connection

Have students write a brief essay describing how they could have a personal impact on an issue affecting ocean health.

Connections to Other Subjects

English/Language Arts, Social Sciences, Physical Science, Mathematics

Assessment

Students' reports and class discussions provide opportunities for assessment.

Extensions

1. Follow events aboard the *Okeanos Explorer* at *http://oceanexplorer.noaa.gov/okeanos/welcome.html*.

Multimedia Discovery Missions

http://www.oceanexplorer.noaa.gov/edu/learning/welcome.html Click on the links to Lessons 12 and 14 for interactive multimedia presentations and Learning Activities on Food, Water, and Medicine from the Sea; and Seamounts.

Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

(The following Lesson Plans are targeted toward Grades 7-8)

Treasures in Jeopardy (from the 2007 Cayman Island Twilight Zone Expedition)
http://oceanexplorer.noaa.gov/explorations/07twilightzone/background/edu/media/treasures.pdf
Focus: Conservation of deep-sea coral communities (Life Science)
Students will compare and contrast deep-sea coral communities with their shallow-water counterparts and explain at least three benefits associated with deep-sea coral communities. Students will also describe human activities that threaten deep-sea coral communities and describe actions that should be taken to protect resources of deep-sea coral communities.

Boom and Bust (from the 2003 Mountains in the Sea Expedition)
http://oceanexplorer.noaa.gov/explorations/03mountains/background/education/media/mts_boombust.pdf
Focus: Fishery management
Students will describe stages in a commercial fishery that eventually becomes severely depleted, interpret basic data to predict when a fishery stock is beginning to show signs of overexploitation, and describe the potential consequences of overexploitation on fish populations, marine habitats, and fishing businesses. Students will also describe and discuss potential management policies that could avoid or remediate overexploitation in commercial fisheries.

Other Resources

See page 217 for Other Resources.

Next Generation Science Standards

Lesson plans developed for Volume 1 are correlated with *Ocean Literacy Essential Principles and Fundamental Concepts* as indicated in the back of this book. Additionally, a separate online document illustrates individual lesson support for the Performance Expectations and three dimensions of the Next Generation Science Standards and associated Common Core State Standards for Mathematics and for English Language Arts & Literacy. This information is provided to educators as a context or point of departure for addressing particular standards and does not necessarily mean that any lesson fully develops a particular standard, principle or concept. Please see: *http://oceanexplorer.noaa.gov/okeanos/edu/collection/wdwe_ngss.pdf.*

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:
oceanexeducation@noaa.gov

For More Information

Paula Keener, Director, Education Programs
NOAA Office of Ocean Exploration and Research
Hollings Marine Laboratory
331 Fort Johnson Road, Charleston SC 29412
843.762.8818   843.762.8737 (fax)
paula.keener-chavis@noaa.gov

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

Scientific Posters

Scientific posters are an increasingly popular way to communicate results of scientific research and technical projects. There are a number of reasons for this, including limited time at conferences for traditional "public speaking"-style presentations, better options for interacting one-on-one with people who are really interested in your work, opportunities for viewers to understand the details of your work (even if you aren't present), and having a more relaxed format for those who dislike speaking in public. In addition, posters are more durable that one-time presentations; once they are created they can be used in many different settings, over and over again. For more discussion of pros and cons, as well as examples of good and bad posters, visit

http://colinpurrington.com/tips/academic/posterdesign
http://www.ncsu.edu/project/posters/NewSite/

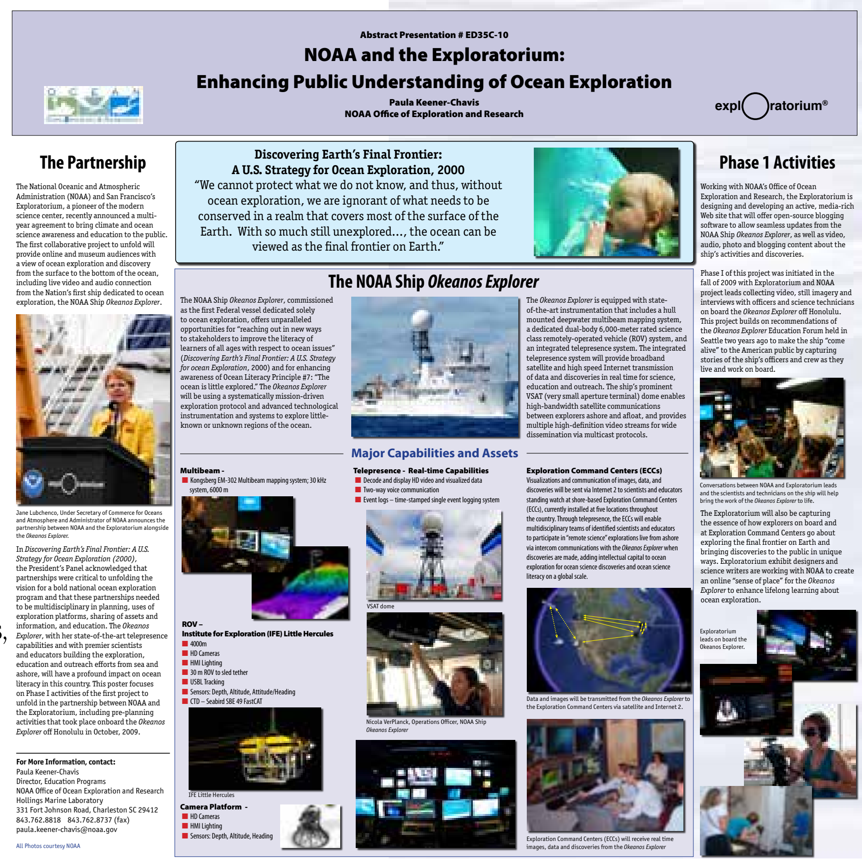
Scientific posters usually contain the same elements as traditional written reports: title, introduction, materials and methods, results, conclusions, literature cited (key citations only!), acknowledgments, and contact points for further information. Good posters do NOT usually have an abstract, though an abstract is often required as part of the submission process and may be included in a printed program.

Another similarity to traditional reports is that the best posters almost always go through several drafts. You should always expect that the first draft of your poster will change significantly before it emerges in final form. Be sure to allow enough time for others to review your first draft and for you to make needed changes.

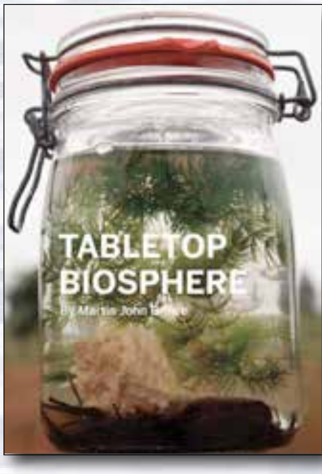
An important difference (and advantage) that posters have compared to written reports is that posters can be much more flexible in terms of layout and where these elements appear, as long as there is still a clear and logical flow to guide viewers through your presentation. Here are a few more tips for good scientific posters (see the Web sites listed above for many other ideas):

- Posters should be readable from 6 feet away;
- Leave plenty of white space (35% is not too much) -- densely packed posters can easily repel potential viewers;
- The top and right columns of your poster are prime areas for vital material, while the bottom edge will receive much less attention;
- Serif fonts (*e.g.*, Times) are easier to read than sans serif fonts (*e.g.*, Helvetica), so use sans serif fonts for titles and headings, and serif fonts for body text (usually no more than two font families on a single poster)
- Text boxes are easiest to read when they are about 40 characters wide

Below: An example of a scientific poster.



Tabletop Shrimp Support Module Construction Guide



From *Make*, Volume 10

NOTE: These procedures are adapted from *Ecosystems Engineering*, an article by Martin John Brown that appeared in Volume 10 of *Make* magazine. The article can be downloaded from *http://cachefly.oreilly.com/make/wp_aquanaut.pdf.*

Materials

Materials (for one module)

- 1 - 1 quart glass canning jar
- 3 - plastic containers, 1 quart capacity or larger
- 12 (approximately) - River pebbles, about grape-size; enough to cover the bottom of the glass jar in a single layer
- 3-4 - small shells
- 1 - Amano shrimp, *Caridina multidentata* (from an aquarium store)
- 4 - aquatic snails, each less than 1 cm overall length
- 8-inch stem of hornwort (*Ceratophyllum demersum*; from an aquarium store)
- Duckweed, approximately 2 inches x 2 inches (from an aquarium store or local pond)
- 2-8 - Amphipods (from a local pond)
- Pond sludge (from a local pond)
- Plastic bucket, 1 gallon or larger capacity

These materials may be shared by several groups:

- Fishnet or kitchen strainer
- Dechlorinating solution (for treating tap water; from an aquarium store)
- Solution of freshwater minerals (*e.g.*, "cichlid salts;" from an aquarium store)
- Calcium carbonate powder (from an aquarium store)
- Tablespoon measure

Procedure

1. Your teacher may provide some or all of the materials for your Tabletop Shrimp Support Module (TSSM), or you may be on your own. If you are responsible for rounding up the materials, you can obtain Amano shrimp, snails, hornwort, duckweed from an aquarium store. You can also obtain the dechlorinating and mineral solutions from an aquarium store, but you may want to partner with other groups since you don't need very much of either solution for one TSSM.

   You can get pond sludge from (you guessed it!) a local pond. Try to find one that has a shallow end where you can easily reach the bottom. Make your collection late in the afternoon, because this is when dissolved oxygen should be highest, and acidity lowest. The best places for collecting will be near aquatic plants and have a mixture of substrates such as sand, rock, and decaying wood. Collect the sludge from the pond bottom, and drag a fine-mesh net through the water as well. Ideally, you will collect a mixture of amphipods, copepods, and ostracods along with the sludge.

2. Make Nitrate-Poor Fresh Water (NPFW) by adding dechlorinating solution and mineral solution to a gallon of tap water according to directions on the packages. Your teacher may have you do this step with one or two other groups. The water from the pond or the aquarium store is likely to have a lot of algae and nitrates which would allow algae to take over the system. The use of NPFW helps to prevent this.

3. Rinse your 1-quart canning jar, rocks, and shells in the NPFW.

4. Fill your 1-quart canning jar halfway with NPFW. Put rocks in first, then shells, then the shrimp, snails, hornwort, duckweed, and 2 tablespoons of pond sludge. Be sure not to overload your system with extra animals or plants. Use only the amount specified!

5. Add more NPFW to your jar so that the top of the water is 1-inch below the top edge of the jar. Add 1 tablespoon of calcium carbonate powder (this will make the water cloudy for several hours because it dissolves slowly).

6. Place the cap tightly on the jar.

7. Place your ecosystem in a location that has temperature between 70°F and 80°F, and moderate light for about 12 - 16 hours per day. Do not put your system in direct sunlight.

8. Your TSSM is complete! Allow your system to equilibrate for at least a week before beginning any experiments.

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*

Section 6: Key Topic – Ocean Health

Off Base

Focus
pH, buffers, and ocean acidification

Grade Level
9-12 (Biology/Chemistry/Earth Science)

Focus Question
What factors tend to resist changes in pH of the ocean, and why is the ocean becoming more acidic?

Learning Objectives
- Students will define pH.
- Students will define a buffer, and explain in general terms the carbonate buffer system of seawater.
- Students will explain Le Chatelier's Principle, and will predict how the carbonate buffer system of seawater will respond to a change in concentration of hydrogen ions.
- Students will identify how an increase in atmospheric carbon dioxide might affect the pH of the ocean, and will discuss how this alteration in pH might affect biological organisms.

Materials
- Copies of *Ocean Acidification Investigation Guide*; one for each student group
- Protective goggles and gloves; one set for each student and one for the teacher
- 100 ml glass beaker; one for each student group
- 100 ml graduated cylinder; one cylinder may be shared by several student groups, but have separate cylinders for distilled water and seawater
- 500 ml glass beaker
- 2 - 1 liter beakers or Erlenmeyer flasks for mixing solutions
- Glass stirring rod; one for each student group
- Sodium hydroxide pellets, approximately 50 grams (see Learning Procedure Step 1)
- Solid citric acid (to neutralize sodium hydroxide spills); approximate 450 grams
- Distilled water; approximately 150 ml for each student group, plus 1.5 liters for making solutions (see Learning Procedure Step 1)
- Artificial seawater; approximately 150 ml for each student group, plus approximately 250 ml for demonstration
- pH test paper, wide range; one roll for each student group
- Dilute acetic acid solution in dropper bottles; one bottle containing approximately 50 ml for each student group (see Learning Procedure Step 1)

Ocean Exploration and Research

- 0.1 M sodium hydroxide solution in dropper bottles; one bottle containing approximately 50 ml for each student group (see Learning Procedure Step 1)

Audiovisual Materials

- Marker board, blackboard, or overhead projector with transparencies, or digital equivalent

Teaching Time

Two 45-minute class periods, plus time for student research

Seating Arrangement

Groups of 2-4 students

Maximum Number of Students

32

Key Words and Concepts

Buffer
pH
Calcium carbonate
Ocean acidification

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.

Carbon dioxide (CO_2) concentrations in Earth's atmosphere have increased by 36% since the Industrial Revolution (from approximately 280 parts per million (ppm) in pre-industrial times to 391 ppm in December of 2011; NOAA Earth Systems Research Laboratory, *http://www.esrl.noaa.gov/gmd/ccgg/trends/index.html#global*). According to the Intergovernmental Panel on Climate Change, present CO_2 concentrations are higher than any time in at least the last 800,000 years, and almost all of this increase is due to human activities (Lüthis *et al.*, 2008; Tans, 2008).

While there has been much discussion about the impacts of increased atmospheric CO_2 on global climate, these changes have also caused another change: ocean acidification. Each year, the ocean absorbs approximately 25% of the CO_2 added to the atmosphere by human activities. When CO_2 dissolves in seawater, carbonic acid is formed, which raises acidity. Ocean acidity has increased by 30% since the beginning of the Industrial Revolution, causing seawater to become corrosive to the shells and skeletons of many marine organisms as well as affecting the reproduction and physiology of others.

Ocean acidification is a result of increased CO_2 emissions, and is not directly related to climate change. There are many uncertainties about the causes, extent, and impacts of global climate change; but these do not apply to ocean acidification which can be observed happening right now and is highly predictable into the future. Measures to reduce global temperatures or the concentration of other greenhouse gases will have no effect on ocean acidification. Only a reduction in atmospheric CO_2 concentrations will affect the acidification problem.

Dry ice, a pH indicator, and water can be used in the classroom to demonstrate the acidifying effects of carbon dioxide in ocean water. For a similar demonstration using human respiration instead of dry ice, see page 41. Image credit: NOAA/CRCP

At NW Eifuku volcano, mussels are so dense in some places that they obscure the bottom. The mussels are ~18 cm (7 in) long. The white galatheid crabs are ~6 cm (2.5 in) long. Image credit: NOAA. *http://oceanexplorer.noaa.gov/explorations/04fire/logs/hirez/mussel_mound_hirez.jpg*

Limacina helicina, a free-swimming planktonic snail. These snails, known as pteropods, form a calcium carbonate shell and are an important food source in many marine food webs. As levels of dissolved CO_2 in sea water rise, skeletal growth rates of pteropods and other calcium-secreting organisms will be reduced due to the effects of dissolved CO_2 on ocean acidity. Image credit: Russ Hopcroft, UAF/NOAA. *http://www.noaanews.noaa.gov/stories2006/images/pteropod-limacina-helicina.jpg*

According to the Intergovernmental Panel on Climate Change (the leading provider of scientific advice to global policy makers), surface ocean pH is very likely to decrease by as much as 0.5 pH units by 2100, and is very likely to impair shell or exoskeleton formation in marine organisms such as corals, crabs, squids, marine snails, clams and oysters.

Large *Paragorgia* colonies on basalt substrate. From the Mountains in the Sea 2004. Image credit: NOAA. *http://oceanexplorer.noaa.gov/explorations/04mountains/logs/hirez/paragorgia_hirez.jpg*

Unusual spiny crab spotted on NW Rota 1 volcano. Crabs are opportunistic predators at vent sites. The body of this crab is ~2 in. (~5 cm) across. Image credit: NOAA. *http://oceanexplorer.noaa.gov/explorations/04fire/logs/hirez/spinycrab_hirez.jpgl*

Research is just beginning on the impacts of ocean acidification on marine organisms and ecosystems (more than 60% of the research papers on this subject have been published since 2004). Impacts have been observed in many species, however, and range from interference with calcification processes to reduced resistance to other environmental stresses such as increasing temperatures and pollution.

This lesson guides a student investigation into some properties of the ocean's carbonate buffer system, and how changes in atmospheric carbon dioxide levels may affect ocean pH and biological organisms that depend upon calcification.

Learning Procedure

1. To prepare for this lesson:
   - Review introductory information on the NOAA Ship *Okeanos Explorer* at *http://oceanexplorer.noaa.gov/okeanos/welcome.html*. You may also want to consider having students complete some or all of the lesson, *To Boldly Go*. . . .
   - Review the introductory essay *Exploring the "C's": Climate Change and Cold-Water Corals* for the *Lophelia* II 2009 Expedition (*http://oceanexplorer.noaa.gov/explorations/09lophelia/background/climatechange/climatechange.html*)
   - Review procedures and questions on the *Ocean Acidification Investigation Guide*; and
   - Prepare solutions for student inquiries:

   (a) 4 M sodium hydroxide solution: Dissolve 40 g NaOH in 100 ml water, then dilute to 250 ml.

   (b) 0.1 M sodium hydroxide solution: Dilute 25 ml of 4 M sodium hydroxide solution to a volume of 1 liter. Transfer the solution to dropper bottles, one bottle for each student group.

   [NOTE: Be careful! Concentrated sodium hydroxide is dangerous. Use goggles and protective rubber gloves when working with solid chemicals and solutions, and be sure the surfaces of gloves and bottles are dry to avoid accidental slippage when bottles are handled. Any chemical that contacts the skin should be immediately washed off with copious quantities of water. Then apply dilute vinegar solution to neutralize traces of the alkali. Spills of alkalis should be diluted as above before mopping up. For large spills, solid citric acid should be used as a neutralizer.]

   (c) Dilute acetic acid solution: Transfer white vinegar to dropper bottles, one bottle for each student group.

   (d) Artificial seawater: Follow directions on package to prepare required quantity (see Materials; typically, 1 liter will require about two tablespoons of the dry powder).

2. If you have not previously done so, briefly introduce the NOAA Ship *Okeanos Explorer*, emphasizing that this is the first Federal vessel specifically dedicated to exploring Earth's largely unknown ocean. Lead a discussion of reasons why ocean exploration is important, which should include understanding and maintaining ocean health.

3. Review the concept of acids, bases, pH, and Le Chatelier's Principle (If a system that is in equilibrium is changed, the system will react in such a way as to undo the effect of the change). Ask students what might cause significant pH changes in the ocean. If students do not identify increased atmospheric carbon dioxide as a potential cause, do not prompt them on this point right now.

   Tell students that their assignment is to investigate some of the aspects of pH in seawater, and impacts of reduced pH caused by increased concentrations of atmospheric carbon dioxide. Provide each student group with a copy of the *Ocean Acidification Investigation Guide* and the materials listed in Part 2 of the worksheet.

4. When students have completed the procedures described in the *Investigation Guide*, lead a discussion of their results.

Answers for Background Research & Analysis Questions

1. About 25% of the CO_2 added to the atmosphere from human activities is absorbed by the ocean each year.
2. When CO_2 dissolves in seawater, carbonic acid is formed.
3. Ocean acidification may affect shell and skeleton formation, physiology, and/or reproduction in marine organisms.
4. Polar regions of Earth's ocean are expected to be first to become acidic enough to dissolve some shells.
5. Ocean acidity has increased 30% since the Industrial Revolution.
6. An episode of ocean acidification 65 million years ago is linked to mass extinctions of marine organisms.
7. The present increase in ocean acidification is happening 100 times faster than any other acidification event in at least 20 million years.
8. Current CO_2 emissions are higher than the "worst case scenario" developed by the Intergovernmental Panel on Climate Change in the 1990's.
9. Ocean acidification is a result of CO_2 emissions, not climate change.
10. The only measures that will reduce ocean acidification are those that reduce atmospheric CO_2.
11. As a result of ocean acidification, by the middle of this century, coral calcification rates will decline by one-third and erosion of corals will exceed new growth. By 2100, 70% of cold-water corals will be exposed to corrosive waters that are sufficiently acidic to damage coral skeletons.
12. Economic impacts expected from ocean acidification include impacts on marine food webs that include commercially fished species, which threaten the food security of millions of people. In addition, impacts on coral reefs will affect shoreline protection and tourism.
13. Ocean acidification has a "feedback" effect on climate change, because decreasing pH reduces the ocean's capacity to absorb CO_2, which will make it more difficult to stabilize atmospheric CO_2 concentrations.
14. Atmospheric CO_2 concentrations can be stabilized with technology that is presently available or will soon be available. The cost of stabilizing atmospheric CO_2 at a level that will avoid most of the negative impacts of ocean acidification is less than the cost of doing nothing.

Discussion of Results of Hands-on Activity

Students should have found that seawater is much more resistant to changes in pH than distilled water, and consequently is a good buffer. Write the following equation on a marker board or overhead transparency so that it is visible to all students:

The Carbonate Buffer System Equation

CO_2	+	H_2O	↔	H_2CO_3	↔	H^+	+	HCO_3^-	↔	$2H^+$	+	CO_3^{2-}
carbon dioxide		water		carbonic acid		hydrogen ion		bicarbonate ion		2 hydrogen ions		carbonate ion

This equation shows that carbon dioxide dissolves in seawater to form carbonic acid, a weak acid. Most of the carbonic acid normally dissociates to form hydrogen ions, bicarbonate ions, and carbonate ions. Carbon dioxide, carbonic acid, bicarbonate ions, and carbonate ions are all present in normal seawater, although not in the same concentrations (about 87% of inorganic carbon is bicarbonate, about 12% is carbonate, and carbonic acid and carbon dioxide combined are about 1%). When these chemicals are in equilibrium, the pH of seawater is about 8.1 – 8.3 (slightly basic). More dissolved carbon dioxide causes an increase in hydrogen ions and a lower ocean pH. But the pH change in seawater is less than if the same amount of carbon dioxide were dissolved in fresh water because the carbonate buffer system in seawater removes some of the added hydrogen ions from solution.

Considering Le Chatelier's Principle, students should realize that if hydrogen ions are added to normal seawater the system will react in a way that tends to remove hydrogen ions from solution, so the reactions will proceed to the left. Similarly, if a very basic solution is added to normal seawater students should predict that the system will react in a way that tends to add more hydrogen ions, and so the reactions will proceed to the right.

The BRIDGE Connection

www.vims.edu/bridge/ – Scroll over "Ocean Science Topics," then click "Chemistry," or "Atmosphere" for links to resources about ocean chemistry or climate change.

The "Me" Connection

Have students write a brief essay describing how buffer systems are of personal benefit, and how a change in ocean pH might have personal impacts.

Connections to Other Subjects

English/Language Arts, Social Sciences, Mathematics

Assessment

Students' responses to *Investigation Guide* questions and class discussions provide opportunities for assessment.

Extensions

1. Follow events aboard the *Okeanos Explorer* at *http://oceanexplorer.noaa.gov/okeanos/welcome.html*.
2. Have student groups prepare scientific posters about the ocean acidification issue. See *http://oceanexplorer.noaa.gov/explorations/09bioluminescence/background/edu/media/ds_09_livinglight.pdf* for information about scientific posters, and "Other Resources" for additional sources of information about ocean acidification.

Multimedia Discovery Missions

http://www.oceanexplorer.noaa.gov/edu/learning/welcome.html Click on the links to Lessons 3, 5, and 6 for interactive multimedia presentations and Learning Activities on Deep-Sea Corals, Chemosynthesis and Hydrothermal Vent Life, and Deep-Sea Benthos.

Other Resources

See page 217 for Other Resources.

Next Generation Science Standards

Lesson plans developed for Volume 1 are correlated with *Ocean Literacy Essential Principles and Fundamental Concepts* as indicated in the back of this book. Additionally, a separate online document illustrates individual lesson support for the Performance Expectations and three dimensions of the Next Generation Science Standards and associated Common Core State Standards for Mathematics and for English Language Arts & Literacy. This information is provided to educators as a context or point of departure for addressing particular standards and does not necessarily mean that any lesson fully develops a particular standard, principle or concept. Please see: *http://oceanexplorer.noaa.gov/okeanos/edu/collection/wdwe_ngss.pdf.*

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:
oceanexeducation@noaa.gov

For More Information

Paula Keener, Director, Education Programs
NOAA Office of Ocean Exploration and Research
Hollings Marine Laboratory
331 Fort Johnson Road, Charleston SC 29412
843.762.8818 843.762.8737 (fax)
paula.keener-chavis@noaa.gov

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Ocean Acidification Investigation Guide

A buffer is a solution that tends to resist changes in pH. Your assignment is to investigate some of the pH buffering capabilities of seawater.

Part 1. Background Research & Analysis

Obtain a copy of *Ocean Acidification: A Summary for Policymakers from the Second Symposium on the Ocean in a High-CO_2 World* (*http://ocean-acidification.net/OAdocs/SPM-lorezv2.pdf*), and find answers to the following questions:

1. About how much of the CO_2 added to the atmosphere from human activities is absorbed by the ocean each year?

____

2. When CO_2 dissolves in seawater, what compound is formed?

____

3. How may ocean acidification affect marine organisms and ecosystems?

____

____

____

4. Which regions of Earth's ocean will be first to become acidic enough to dissolve some shells?

____

____

____

5. How much has ocean acidity increased since the Industrial Revolution?

____

____

6. In geologic history, has ocean acidification ever been linked to mass extinctions of marine organisms, and if so, when and how?

____

____

____

7. Ocean pH is known to fluctuate. How is the present increase in acidity different from past fluctuations?

____

____

____

8. In the 1990's the Intergovernmental Panel on Climate Change (IPCC) developed a "worst case scenario" for projected CO_2 emissions. How do current CO_2 emissions compare with the "worst case scenario?"

9. Is ocean acidification another result of climate change? Why or why not?

10. Will initiatives to combat climate change also reduce ocean acidification? Why or why not?

11. What impacts is ocean acidification expected to have on reef-building corals?

12. What are some economic impacts expected from ocean acidification?

13. Does ocean acidification have any "feedback" effect on climate change? If so, describe.

14. Practically speaking, what needs to be done to avoid the negative impacts associated with decreasing ocean pH?

Part 2. Hands-On Activity

Materials

- Distilled water, approximately 150 ml
- Artificial seawater, approximately 150 ml
- pH test paper
- Dilute acetic acid solution in dropper bottle
- 0.1 M sodium hydroxide solution in dropper bottle
- 100 ml glass beaker
- 100 ml graduated cylinder
- Glass stirring rod

Procedure

Wear eye protection and gloves throughout this activity!
Wash your hands thoroughly when you are finished!
Do not eat, drink, or chew anything while you are in the laboratory!

1. Measure 50 ml of distilled water into a 100 ml glass beaker. Test the pH by dipping a strip of pH test paper into the water and comparing the color of the paper to the chart on the test paper container. Record the pH on the data chart on the following page.

2. Add one drop of dilute acetic acid to the beaker, stir with a glass stirring rod, test the pH, and record the result on the data chart.

3. Repeat Step 3 until 20 drops of dilute acetic acid have been added, testing and recording the pH after each drop.

4. Rinse the beaker, then repeat Steps 1 through 3 using seawater instead of distilled water. Be sure to use a separate graduate cylinder for measuring the seawater.

5. Rinse the beaker and repeat Steps 1 through 3 with distilled water and seawater (use a different graduated cylinder for each!), but use 0.1 M sodium hydroxide solution instead of dilute acetic acid.

6. **Wash your hands thoroughly!**

Data Chart for Buffer Properties of Seawater

Drops Added	Test with Added Acetic Acid: Distilled Water pH	Test with Added Acetic Acid: Seawater pH	Test with Added Sodium Hydroxide: Distilled Water pH	Test with Added Sodium Hydroxide: Seawater pH
0				
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				

Analysis

1. What do your data suggest about the buffer system of seawater compared to distilled water?

2. Recall Le Chatelier's Principle. What do you think would happen if hydrogen ions were added to normal seawater?

3. What do you think would happen if a very basic solution (which tends to remove hydrogen ions from solution) were added to normal seawater?

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

Other Resources

General

Goodwin, M. 2006. *Discover Your World with NOAA: An Activity Book* [Internet]. NOAA [cited November 16, 2010]. Available from: http://celebrating200years.noaa.gov/edufun/book/welcome.html#book. A free printable book for home or school introduced in 2004 to celebrate the 200th anniversary of NOAA; nearly 200 pages of activities focusing on the exploration, understanding, and protection of Earth as a whole system.

Gopnik, A., A.N. Meltzoff, and P.K. Kuhl. 2001. *The Scientist in the Crib. What Early Learning Tells Us About the Mind*. HarperCollins, 279p.

Ocean Explorer [Internet]. n.d. NOAA Office of Ocean Exploration and Research [cited November 16, 2010]. Available from: http://oceanexplorer.noaa.gov. Web site of NOAA's Ocean Explorer Program.

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Ocean Literacy Essential Principles and Fundamental Concepts

Version 2: March 2013

Grades 5-8

	To Boldly Go	Journey to the Unknown	Come On Down!	The Methane Circus	Where Have All the Glaciers Gone?	Animals of the Fire Ice	Oceans of Energy	Microfriends	What Killed the Seeds?	Build Your Own Ocean Ecosystem	Stressed Out!
EP 1. The Earth has one big ocean with many features.											
FC a. The ocean is the defining physical feature on our planet Earth—covering approximately 70% of the planet's surface. There is one ocean with many ocean basins, such as the North Pacific, South Pacific, North Atlantic, South Atlantic, Indian, Southern, and Arctic.	•						•			•	•
FC b. Ocean basins are composed of the seafloor and all of its geological features (such as islands, trenches, mid-ocean ridges, and rift valleys) and vary in size, shape and features due to the movement of Earth's crust (lithosphere). Earth's highest peaks, deepest valleys and flattest plains are all in the ocean.					•						
FC c .Throughout the ocean there is one interconnected circulation system powered by wind, tides, the force of Earth's rotation (Coriolis effect), the Sun and water density differences. The shape of ocean basins and adjacent land masses influence the path of circulation. This "global ocean conveyor belt" moves water throughout all of the ocean basins, transporting energy (heat), matter, and organisms around the ocean. Changes in ocean circulation have a large impact on the climate and cause changes in ecosystems.	•						•				
FC d. Sea level is the average height of the ocean relative to the land, taking into account the differences caused by tides. Sea level changes as plate tectonics cause the volume of ocean basins and the height of the land to change. It changes as ice caps on land melt or grow. It also changes as sea water expands and contracts when ocean water warms and cools.					•						
FC e .Most of Earth's water (97%) is in the ocean. Seawater has unique properties. It is salty, its freezing point is slightly lower than fresh water, its density is slightly higher, its electrical conductivity is much higher, and it is slightly basic. Balance of pH is vital for the health of marine ecosystems, and important in controlling the rate at which the ocean will absorb and buffer changes in atmospheric carbon dioxide.	•										•
FC f. The ocean is an integral part of the water cycle and is connected to all of Earth's water reservoirs via evaporation and precipitation processes.											
FC g. The ocean is connected to major lakes, watersheds, and waterways because all major watersheds on Earth drain to the ocean. Rivers and streams transport nutrients, salts, sediments, and pollutants from watersheds to coastal estuaries and to the ocean.											
FC h. Although the ocean is large, it is finite, and resources are limited.	•				•	•	•			•	•
EP 2. The ocean and life in the ocean shape the features of the Earth.											
FC a. Many earth materials and biogeochemical cycles originate in the ocean. Many of the sedimentary rocks now exposed on land were formed in the ocean. Ocean life laid down the vast volume of siliceous and carbonate rocks.					•						
FC b. Sea level changes over time have expanded and contracted continental shelves, created and destroyed inland seas, and shaped the surface of land.											
FC c. Erosion—the wearing away of rock, soil and other biotic and abiotic earth materials—occurs in coastal areas as wind, waves, and currents in rivers and the ocean, and the processes associated with plate tectonics move sediments. Most beach sand (tiny bits of animals, plants, rocks, and minerals) is eroded from land sources and carried to the coast by rivers; sand is also eroded from coastal sources by surf. Sand is redistributed seasonally by waves and coastal currents.											
FC d. The ocean is the largest reservoir of rapidly cycling carbon on Earth. Many organisms use carbon dissolved in the ocean to form shells, other skeletal parts, and coral reefs.					•						•
FC e. Tectonic activity, sea level changes, and the force of waves influence the physical structure and landforms of the coast.											

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EP 3. The ocean is a major influence on weather and climate.											
FC a. The interaction of oceanic and atmospheric processes controls weather and climate by dominating the Earth's energy, water, and carbon systems.	•				•						
FC b. The ocean moderates global weather and climate by absorbing most of the solar radiation reaching Earth. Heat exchange between the ocean and atmosphere drives the water cycle and oceanic and atmospheric circulation.	•										
FC c. Heat exchange between the ocean and atmosphere can result in dramatic global and regional weather phenomena, impacting patterns of rain and drought. Significant examples include the El Niño Southern Oscillation and La Niña, which cause important changes in global weather patterns because they alter the sea surface temperature patterns in the Pacific.					•						
FC d. Condensation of water that evaporated from warm seas provides the energy for hurricanes and cyclones. Most rain that falls on land originally evaporated from the tropical ocean.							•				
FC e. The ocean dominates Earth's carbon cycle. Half of the primary productivity on Earth takes place in the sunlit layers of the ocean. The ocean absorbs roughly half of all carbon dioxide and methane that are added to the atmosphere.	•										
FC f. The ocean has had, and will continue to have, a significant influence on climate change by absorbing, storing, and moving heat, carbon, and water. Changes in the ocean's circulation have produced large, abrupt changes in climate during the last 50,000 years.	•				•						
FC g. Changes in the ocean-atmosphere system can result in changes to the climate that in turn, cause further changes to the ocean and atmosphere. These interactions have dramatic physical, chemical, biological, economic, and social consequences.	•				•						•
EP 4. The ocean made Earth habitable.											
FC a. Most of the oxygen in the atmosphere originally came from the activities of photosynthetic organisms in the ocean. This accumulation of oxygen in Earth's atmosphere was necessary for life to develop and be sustained on land.										•	•
FC b. The ocean is the cradle of life; the earliest evidence of life is found in the ocean. The millions of different species of organisms on Earth today are related by descent from common ancestors that evolved in the ocean and continue to evolve today.				•							
FC c. The ocean provided and continues to provide water, oxygen, and nutrients, and moderates the climate needed for life to exist on Earth (Essential Principles 1, 3, and 5).					•					•	
EP 5. The ocean supports a great diversity of life and ecosystems.											
FC a. Ocean life ranges in size from the smallest living things, microbes, to the largest animal on Earth, blue whales.								•			
FC b. Most of the organisms and biomass in the ocean are microbes, which are the basis of all ocean food webs. Microbes are the most important primary producers in the ocean. They have extremely fast growth rates and life cycles, and produce a huge amount of the carbon and oxygen on Earth.								•		•	
FC c. Most of the major groups that exist on Earth are found exclusively in the ocean and the diversity of major groups of organisms is much greater in the ocean than on land.				•				•	•		
FC d. Ocean biology provides many unique examples of life cycles, adaptations, and important relationships among organisms (symbiosis, predator-prey dynamics, and energy transfer) that do not occur on land..				•		•					
FC e. The ocean provides a vast living space with diverse and unique ecosystems from the surface through the water column and down to, and below, the seafloor. Most of the living space on Earth is in the ocean.		•		•				•			

Ocean Literacy Essential Principles and Fundamental Concepts

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Grades 5-8

EP 5. The ocean supports a great diversity of life and ecosystems. (continued)	To Boldly Go	Journey to the Unknown	Come On Down!	The Methane Circus	Where Have All the Glaciers Gone?	Animals of the Fire Ice	Oceans of Energy	Microfriends	What Killed the Seeds?	Build Your Own Ocean Ecosystem	Stressed Out!
FC f. Ocean ecosystems are defined by environmental factors and the community of organisms living there. Ocean life is not evenly distributed through time or space due to differences in abiotic factors such as oxygen, salinity, temperature, pH, light, nutrients, pressure, substrate, and circulation. A few regions of the ocean support the most abundant life on Earth, while most of the ocean does not support much life.				•						•	•
FC 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.		•				•		•			
FC h. Tides, waves, predation, substrate, and/or other factors cause vertical zonation patterns along the coast; density, pressure, and light levels cause vertical zonation patterns in the open ocean. Zonation patterns influence organisms' distribution and diversity.											
FC i. Estuaries provide important and productive nursery areas for many marine and aquatic species.											
EP 6. The ocean and humans are inextricably interconnected.											
FC a. The ocean affects every human life. It supplies freshwater (most rain comes from the ocean) and nearly all Earth's oxygen. The ocean moderates the Earth's climate, influences our weather, and affects human health.	•				•					•	•
FC b. The ocean provides food, medicines, and mineral and energy resources. It supports jobs and national economies, serves as a highway for transportation of goods and people, and plays a role in national security.	•	•			•	•	•	•	•	•	•
FC c. The ocean is a source of inspiration, recreation, rejuvenation, and discovery. It is also an important element in the heritage of many cultures.					•						
FC d. Humans affect the ocean in a variety of ways. Laws, regulations, and resource management affect what is taken out and put into the ocean. Human development and activity leads to pollution (point source, nonpoint source, and noise pollution), changes to ocean chemistry (ocean acidification), and physical modifications (changes to beaches, shores, and rivers). In addition, humans have removed most of the large vertebrates from the ocean.	•				•					•	•
FC e. Changes in ocean temperature and pH due to human activities can affect the survival of some organisms and impact biological diversity (coral bleaching due to increased temperature and inhibition of shell formation due to ocean acidification).	•	•			•					•	•
FC f. Much of the world's population lives in coastal areas. Coastal regions are susceptible to natural hazards (tsunamis, hurricanes, cyclones, sea level change, and storm surges).											
FC 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.	•	•		•	•	•		•		•	•

Ocean Literacy Essential Principles and Fundamental Concepts

Version 2: March 2013

Grades 5-8

EP 7. The ocean is largely unexplored.	To Boldly Go	Journey to the Unknown	Come On Down!	The Methane Circus	Where Have All the Glaciers Gone?	Animals of the Fire Ice	Oceans of Energy	Microfriends	What Killed the Seeds?	Build Your Own Ocean Ecosystem	Stressed Out!
FC a. The ocean is the largest unexplored place on Earth—less than 5% of it has been explored. The next generation of explorers and researchers will find great opportunities for discovery, innovation, and investigation.	•	•	•		•	•	•	•	•	•	•
FC b. Understanding the ocean is more than a matter of curiosity. Exploration, experimentation, and discovery are required to better understand ocean systems and processes. Our very survival hinges upon it.	•	•	•	•	•	•	•	•		•	•
FC c. Over the last 50 years, use of ocean resources has increased significantly; the future sustainability of ocean resources depends on our understanding of those resources and their potential.	•	•			•	•	•			•	•
FC d. New technologies, sensors, and tools are expanding our ability to explore the ocean. Scientists are relying more and more on satellites, drifters, buoys, subsea observatories, and unmanned submersibles.	•	•	•		•	•					
FC e. Use of mathematical models is an essential part of understanding the ocean system. Models help us understand the complexity of the ocean and its interactions with Earth's interior, atmosphere, climate, and land masses											
FC f. Ocean exploration is truly interdisciplinary. It requires close collaboration among biologists, chemists, climatologists, computer programmers, engineers, geologists, meteorologists, physicists, animators, and illustrators. And these interactions foster new ideas and new perspectives for inquiries.	•	•	•	•	•	•	•	•		•	•

Ocean Literacy Essential Principles and Fundamental Concepts

Version 2: March 2013

Grades 9-12

	Calling All Explorers	History's Thermometers	What's the Big Deal?	Watch the Screen	Off Base
EP 1. The Earth has one big ocean with many features.					
FC a. The ocean is the defining physical feature on our planet Earth—covering approximately 70% of the planet's surface. There is one ocean with many ocean basins, such as the North Pacific, South Pacific, North Atlantic, South Atlantic, Indian, Southern, and Arctic.					
FC b. Ocean basins are composed of the seafloor and all of its geological features (such as islands, trenches, mid-ocean ridges, and rift valleys) and vary in size, shape and features due to the movement of Earth's crust (lithosphere). Earth's highest peaks, deepest valleys and flattest plains are all in the ocean.					
FC c .Throughout the ocean there is one interconnected circulation system powered by wind, tides, the force of Earth's rotation (Coriolis effect), the Sun and water density differences. The shape of ocean basins and adjacent land masses influence the path of circulation. This "global ocean conveyor belt" moves water throughout all of the ocean basins, transporting energy (heat), matter, and organisms around the ocean. Changes in ocean circulation have a large impact on the climate and cause changes in ecosystems.					
FC d. Sea level is the average height of the ocean relative to the land, taking into account the differences caused by tides. Sea level changes as plate tectonics cause the volume of ocean basins and the height of the land to change. It changes as ice caps on land melt or grow. It also changes as sea water expands and contracts when ocean water warms and cools.					
FC e .Most of Earth's water (97%) is in the ocean. Seawater has unique properties. It is salty, its freezing point is slightly lower than fresh water, its density is slightly higher, its electrical conductivity is much higher, and it is slightly basic. Balance of pH is vital for the health of marine ecosystems, and important in controlling the rate at which the ocean will absorb and buffer changes in atmospheric carbon dioxide.					•
FC f. The ocean is an integral part of the water cycle and is connected to all of Earth's water reservoirs via evaporation and precipitation processes.					
FC g. The ocean is connected to major lakes, watersheds, and waterways because all major watersheds on Earth drain to the ocean. Rivers and streams transport nutrients, salts, sediments, and pollutants from watersheds to coastal estuaries and to the ocean.					•
FC h. Although the ocean is large, it is finite, and resources are limited.		•	•	•	•
EP 2. The ocean and life in the ocean shape the features of the Earth.					
FC a. Many earth materials and biogeochemical cycles originate in the ocean. Many of the sedimentary rocks now exposed on land were formed in the ocean. Ocean life laid down the vast volume of siliceous and carbonate rocks.					
FC b. Sea level changes over time have expanded and contracted continental shelves, created and destroyed inland seas, and shaped the surface of land.					
FC c. Erosion—the wearing away of rock, soil and other biotic and abiotic earth materials—occurs in coastal areas as wind, waves, and currents in rivers and the ocean, and the processes associated with plate tectonics move sediments. Most beach sand (tiny bits of animals, plants, rocks, and minerals) is eroded from land sources and carried to the coast by rivers; sand is also eroded from coastal sources by surf. Sand is redistributed seasonally by waves and coastal currents.					
FC d. The ocean is the largest reservoir of rapidly cycling carbon on Earth. Many organisms use carbon dissolved in the ocean to form shells, other skeletal parts, and coral reefs.		•			•
FC e. Tectonic activity, sea level changes, and the force of waves influence the physical structure and landforms of the coast					

Ocean Literacy Essential Principles and Fundamental Concepts

Version 2: March 2013

Grades 9-12

	Calling All Explorers	History's Thermometers	What's the Big Deal?	Watch the Screen	Off Base
EP 3. The ocean is a major influence on weather and climate.					
FC a. The interaction of oceanic and atmospheric processes controls weather and climate by dominating the Earth's energy, water, and carbon systems.			•		
FC b. The ocean moderates global weather and climate by absorbing most of the solar radiation reaching Earth. Heat exchange between the ocean and atmosphere drives the water cycle and oceanic and atmospheric circulation.					
FC c. Heat exchange between the ocean and atmosphere can result in dramatic global and regional weather phenomena, impacting patterns of rain and drought. Significant examples include the El Niño Southern Oscillation and La Niña, which cause important changes in global weather patterns because they alter the sea surface temperature patterns in the Pacific.					
FC d. Condensation of water that evaporated from warm seas provides the energy for hurricanes and cyclones. Most rain that falls on land originally evaporated from the tropical ocean.					
FC e. The ocean dominates Earth's carbon cycle. Half of the primary productivity on Earth takes place in the sunlit layers of the ocean. The ocean absorbs roughly half of all carbon dioxide and methane that are added to the atmosphere.			•		•
FC f. The ocean has had, and will continue to have, a significant influence on climate change by absorbing, storing, and moving heat, carbon, and water. Changes in the ocean's circulation have produced large, abrupt changes in climate during the last 50,000 years.		•	•		•
FC g. Changes in the ocean-atmosphere system can result in changes to the climate that in turn, cause further changes to the ocean and atmosphere. These interactions have dramatic physical, chemical, biological, economic, and social consequences.			•		•
EP 4. The ocean made Earth habitable.					
FC a. Most of the oxygen in the atmosphere originally came from the activities of photosynthetic organisms in the ocean. This accumulation of oxygen in Earth's atmosphere was necessary for life to develop and be sustained on land.					
FC b. The ocean is the cradle of life; the earliest evidence of life is found in the ocean. The millions of different species of organisms on Earth today are related by descent from common ancestors that evolved in the ocean and continue to evolve today.					
FC c. The ocean provided and continues to provide water, oxygen, and nutrients, and moderates the climate needed for life to exist on Earth (Essential Principles 1, 3, and 5).					
EP 5. The ocean supports a great diversity of life and ecosystems.					
FC a. Ocean life ranges in size from the smallest living things, microbes, to the largest animal on Earth, blue whales.				•	
FC b. Most of the organisms and biomass in the ocean are microbes, which are the basis of all ocean food webs. Microbes are the most important primary producers in the ocean. They have extremely fast growth rates and life cycles, and produce a huge amount of the carbon and oxygen on Earth..				•	
FC c. Most of the major groups that exist on Earth are found exclusively in the ocean and the diversity of major groups of organisms is much greater in the ocean than on land.				•	
FC d. Ocean biology provides many unique examples of life cycles, adaptations, and important relationships among organisms (symbiosis, predator-prey dynamics, and energy transfer) that do not occur on land.	•				
FC e. The ocean provides a vast living space with diverse and unique ecosystems from the surface through the water column and down to, and below, the seafloor. Most of the living space on Earth is in the ocean.				•	•
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