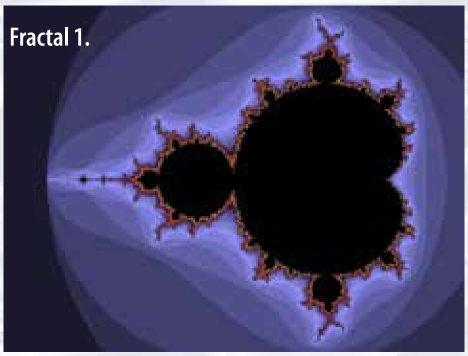
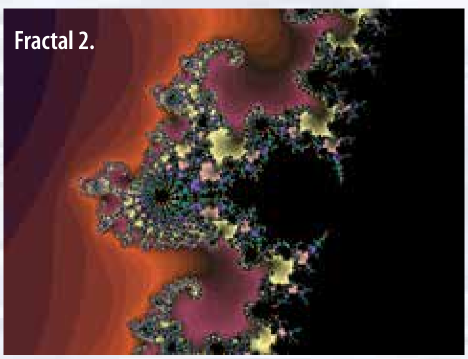
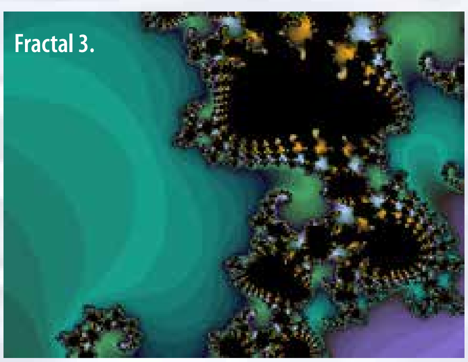
Lesson 1: To Explore Strange New Worlds



Fractal 1. The Mandelbrot set, a famous fractal.





Fractals 2 & 3: Zooming into portions of the Mandelbrot set reveals complex forms that resemble a variety of forms found in nature, including some marine animals. Images courtesy Mel Goodwin. For more information and examples, visit http://fractalfoundation.org/.

This lesson guides student investigations into strategies and technologies used for ocean exploration aboard the NOAA Ship *Okeanos Explorer*. Other lessons for the How Do We Explore? theme guide additional explorations into key topics of Telepresence, Multibeam Mapping, Water Column Investigations, and Underwater Robots.

Focus

Strategies for exploring unknown areas on Earth

Grade Level

Target Grade Level: 7-8; adaptations for grades 5-6 and 9-12 are provided on page 28 (Life Science/Physical Science/Earth Science)

Focus Question

What methods do scientist explorers use to investigate places that have never been seen before?

Learning Objectives

- Students will obtain and communicate information to explain how the exploration strategy used aboard the NOAA Ship *Okeanos Explorer* determines the structure and function of the ship's exploration technologies.
- Students will obtain and communicate information to explain how science, engineering and technology influenced exploration strategies of the Lewis and Clark and HMS *Challenger* Expeditions.
- Students will construct explanations for how fractal geometry can be used to model patterns in natural systems.
- Students will use fractal geometric models to explain how scale influences requirements for ocean exploration technologies.

Materials

- Copies of *Guide for Investigating Exploration Strategies*, one for each student group
- *Koch Curve Construction* scanned to a file for display on a whiteboard, or copied onto an overhead transparency
- Drawing paper
- Ruler for each student group
- Pencils
- Fractal images

Audiovisual Materials

- Interactive white board or overhead projector

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

Seating Arrangement
Groups of two to four students

Maximum Number of Students
30

Key Words and Concepts
Exploration Strategy
Lewis and Clark Expedition
HMS *Challenger* Expedition
Okeanos Explorer
Fractal

Background
Historically, many expeditions of discovery have preceded the voyages of the *Okeanos Explorer*. Two of the most famous are the Lewis and Clark Expedition (1804 – 1806) and the HMS *Challenger* Expedition (1872 – 1876). There are many differences between these expeditions, but several basic questions apply to all three:

- Who will look for discoveries?
- Where will they look?
- How will they look?

For additional discussion, please see the *Introduction to Volume 2: How Do We Explore?* beginning on page 9.

The question of "How to look?" also involves the critical issue of scale: Natural features and processes exist in a wide range of sizes and potential discoveries span the same range. The recent discovery of a fourth giant planet in a distant planetary system that is remarkably similar to our own solar system is an example at a scale of trillions of kilometers; while the discovery of Archaea, a fundamentally unique group of organisms, provides an example at a scale that is a billion trillion (10^{21}) times smaller.

These examples reflect an important characteristic about nature: natural features and processes generally do not become simpler with decreasing size. A useful and intriguing mathematical tool for modeling this characteristic of natural systems involves fractal geometry, which is discussed further in Part B of the Learning Procedure.

This lesson guides student investigations of exploration strategies used by the Lewis and Clark expedition, HMS *Challenger* expedition, and aboard the NOAA Ship *Okeanos Explorer* (Part A); and into fractal geometry as a tool for modeling natural systems, and how this tool might be used to plan deep-ocean explorations (Part B.).

By necessity, expeditions to explore unknown areas on Earth are based on integration of science, technology, engineering, and mathematics. Examples of this integration can be discussed in Part A, and the application of mathematical concepts to exploration of the real world is investigated in Part B.

Key Images and Video Resources

NOAA Ship *Okeanos Explorer* Slideshow Collection: *http://oceanexplorer.noaa.gov/okeanos/media/slideshow/flash_slideshow.html*

NOAA Ship *Okeanos Explorer* Video Playlist: *http://oceanexplorer.noaa.gov/okeanos/media/exstream/exstream_playlist.html*

INDEX-SATAL 2010 Expedition Photo and Video Log: *http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/photolog/photolog.html*

Ocean Exploration Careers

For information about the exciting career opportunities in ocean exploration, see Appendix A starting on page 179.

The NOAA Ocean Explorer OceanAGE web page (*http://oceanexplorer.noaa.gov/edu/oceanage/welcome.html*) is a unique online educational resource that enables users to learn more about a variety of ocean careers available to those interested in work on or in the ocean.

You may also want to check out the special issue of *Current* entitled *A Closer Look at Ocean Careers through the NOAA Ship Okeanos Explorer: A Case Study*, Volume 28, No. 1, 2012 (*http://oceanexplorer.noaa.gov/edu/oceanage/current_careers.pdf*).

Learning Procedure

[Note: Part A of this lesson is adapted from the *Exploring the Unknown* lesson from the INDEX-SATAL 2010 Expedition (*http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/edu/media/unknown.pdf*).]

Part A. Voyages of Discovery

1. To prepare for this lesson:
   (a) Review:
   - Mission Plan for the INDEX-SATAL 2010 Expedition (*http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/plan/plan.html*);
   - "NOAA Ship *Okeanos Explorer*, 'America's Ship for Ocean Exploration' " (*http://oceanexplorer.noaa.gov/okeanos/welcome.html#*);
   - "NOAA Ship *Okeanos Explorer* Maximizing Operations" (*http://oceanexplorer.noaa.gov/okeanos/explorations/ex1006/welcome.html*);
   - "Exploration or Research Science - Where Do We Draw the Line?" (*http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/july22/july22.html*);

   (b) Review information about the importance of deep-ocean exploration in the Background section of the "Earth's Ocean is 95% Unexplored: So What?" lesson (*http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/edu/media/so_what.pdf*);
   (c) Make copies of the *Guide for Investigating Exploration Strategies*.
   (d) You may also want to review the Ocean Exploration Panel Web site (*http://oceanservice.noaa.gov/websites/retiredsites/oceanpanel.pdf*), which includes background information that was used to develop a national strategy for a new era of ocean exploration. The Ocean Exploration Panel was convened by the U.S. Department of Commerce at the direction of President Clinton in June 2000. The Panel's final report entitled "Discovering Earth's Final Frontier: A U.S. Strategy for Ocean Exploration" is an historic accomplishment because it is the only national strategy proposed for exploration of the global oceans by any country in the world. The executive summary of the final report is included on the Web site.

2. Briefly introduce the INDEX-SATAL 2010 Expedition. Point out that this expedition was the maiden voyage of the NOAA Ship *Okeanos Explorer*, which is the only U.S. ship whose sole assignment is to systematically explore Earth's largely unknown ocean for the purposes of discovery and the advancement of knowledge. Ask students for their ideas about why this kind of exploration might be important, and highlight some of the reasons referenced in Step 1b. Be sure students understand that discoveries of deep-sea chemosynthetic communities during the last 30 years are major scientific events that have changed many assumptions about life in the ocean and have opened up many new fields of scientific investigation.

3. Tell students that their assignment is to investigate strategies used by other expeditions to explore unknown territories, and to invent a strategy that might guide the *Okeanos Explorer* on its voyages of discovery. Provide each student or student group with a copy of the *Guide for Investigating Exploration Strategies*. For Part A, you may want to have individual students or groups focus on only the Lewis and Clark Expedition or the HMS *Challenger* Expedition, or have them answer questions about both expeditions.

   These voyages of discovery all involve aspects of science, technology, engineering, and mathematics. Have students describe how these four elements are integrated in the activities of each expedition as part of their investigations.

4. Lead a discussion of students' responses to questions about previous expeditions to explore the unknown. The following points should be included:

Lewis and Clark Expedition

- Thomas Jefferson's primary motivation for exploring the American West was developing commerce, specifically finding the most direct and practicable routes for water transport across the continent. Related to this mission was the requirement that the explorers should contact and develop friendly relations with native American tribes. Jefferson was also a keen citizen scientist, and his instructions for the Expedition also stated that observations should be made of soils, plants, animals, minerals, geologic formations, and climatic conditions.

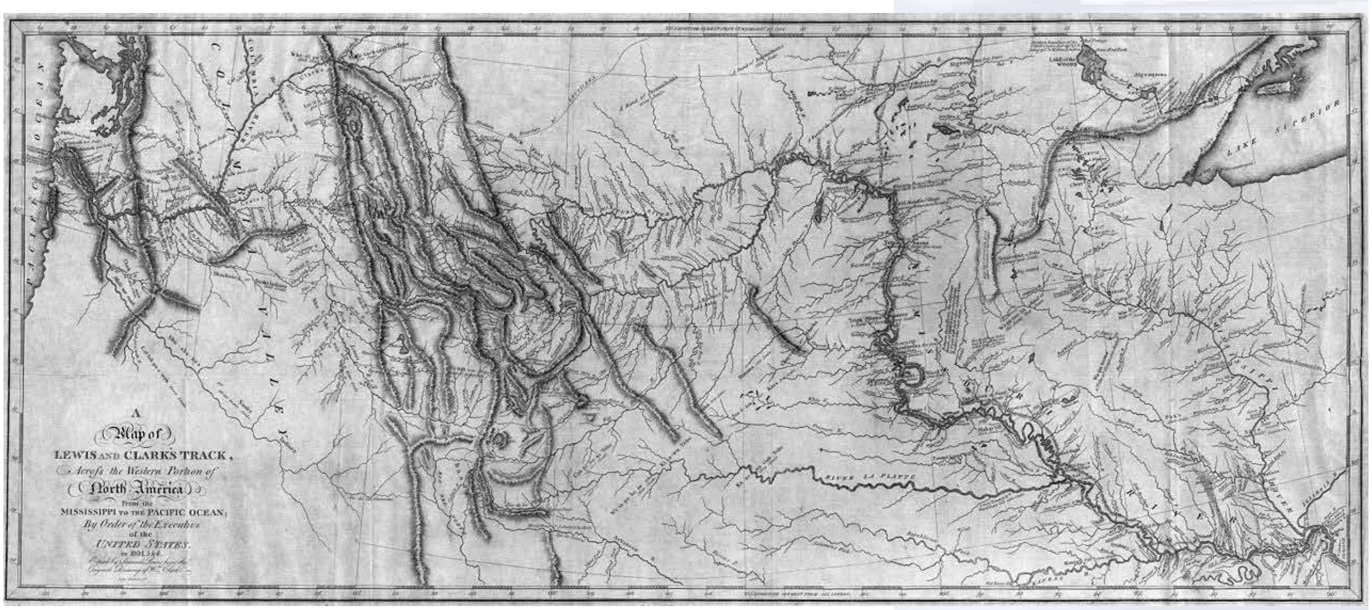
- The overall plan for the Expedition's route was to follow the Missouri River upstream as far as possible, and then find a route to the Pacific Ocean. Since much of the Missouri River was unexplored, Lewis and Clark had no idea how close the headwaters of the Missouri would be to the Pacific, nor whether any route between them actually existed.

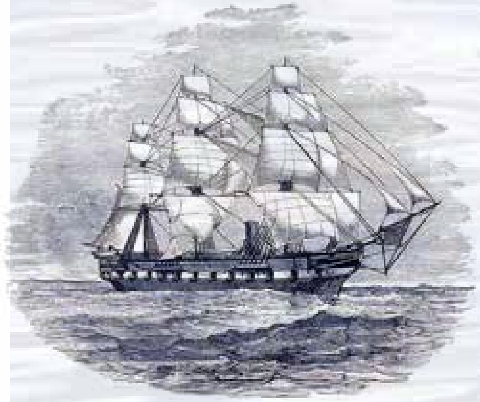
- The Expedition made extensive observations and collections in keeping with the broad instructions described above, with particular emphasis on detailed maps.

- Technical instruments included a mariner's compass and surveying instruments, portable microscope, and hydrometers. Information about natural history was collected primarily by visual observation and recorded as drawings, notes, and specimens.

The official report of the Expedition required eight years to complete after the explorers returned, and includes two volumes totalling 992 pages.

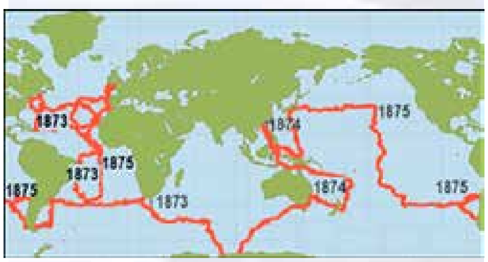
Map of Lewis and Clark's Track, Across the Western Portion of North America. Uncolored map showing topography and rivers in the region as well as towns, native American villages, and population figures. Originally published in 1814. The map and the written account of the expedition changed American mapping of the northwest by giving the first accurate depiction of the relationship of the sources of the Missouri, the sources of the Columbia, and the Rocky Mountains. The map was copied by Samuel Lewis from William Clark's original drawing, and was engraved by Samuel Harrison.





The HMS *Challenger*.
http://www.19thcenturyscience.org/HMSC/HMSC-INDEX/index-linked.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 courtesy of NOAA.
http://www.19thcenturyscience.org/HMSC/HMSC-INDEX/group.jpg



The route of HMS *Challenger*. The expedition lasted 1,000 days and covered more than 68,000 nautical miles. Image courtesy of NOAA.
http://oceanexplorer.noaa.gov/explorations/03mountains/background/challenger/media/route.html

HMS *Challenger* Expedition

- The HMS *Challenger* Expedition was organized and funded to examine the deep seafloor and address specific scientific objectives:
  - To investigate depth, temperature, circulation, specific gravity and penetration of light in the deep sea;
  - To determine the chemical composition of seawater at various depths from the surface to the bottom, the organic matter in solution and the particles in suspension;
  - To ascertain the physical and chemical character of deep-sea deposits and the sources of these deposits; and
  - To investigate the distribution of organic life at different depths and on the deep seafloor.

  In addition, the Expedition was instructed to obtain photographs of "native races," and the information that was recorded about the indigenous people proved to be extremely valuable, because many island cultures changed rapidly in subsequent years.

  You may also want to point out that commercial interest in the deep ocean was being stimulated by the desire to lay submarine telegraph cables, and that there was scientific controversy over whether there was any life at all in the ocean below 549 m (1800 feet).

- The Expedition's route included the North and South Atlantic, Indian, and Pacific Oceans (*http://oceanexplorer.noaa.gov/explorations/03mountains/background/challenger/media/route.html*). Along this route, 362 official stations were established at which data were collected.

- A standard set of data was collected at each of 362 stations along their route. Samples and data were carefully returned to Scotland for systematic analysis and documentation. The standard set of observations made and samples taken at each station was:
  - water depth
  - temperature at various depths
  - weather conditions
  - water conditions at surface and sometimes at depth
  - seafloor samples
  - water samples for later chemical analysis
  - samples of plant and animal life collected with dredges, trawls, and sometimes plankton nets from various depths

- Primary technical instruments were weighted ropes for measuring depth; dredges and nets; thermometers; hydrometers; and water sampling bottles.

The final reports from the HMS *Challenger* Expedition occupy 50 volumes with a total of 29,552 pages, and required 19 years to complete after the Expedition ended.

Discuss some of the ways in which science, technology, engineering, and mathematics are integrated in the activities of each expedition. For example:

- The first part of the Lewis and Clark Expedition used a custom-built keelboat designed by Thomas Jefferson and Meriwether Lewis. The initial design was extensively modified based upon experiments with prototypes during the vessel's construction in the spring and summer of 1803 (a good example of the Engineering Design Process in action. See sidebar).
- Surveying and navigation activities of all three expeditions are based on mathematical principles and methods.
- HMS *Challenger* and *Okeanos Explorer* embody many aspects of sophisticated engineering and applied mathematics. Neither vessel was originally constructed for ocean exploration, and both required an extensive retrofit to incorporate specialized exploration technologies.

5. Discuss some of the basic requirements shared by expeditions to explore unknown territories. In addition to material requirements such as appropriate transportation and technology, students should understand that modern ocean exploration depends upon many of the same human character traits that were needed by the Lewis and Clark and HMS *Challenger* Expeditions:
   - Courage to face uncertainties;
   - Willingness to take risks;
   - Ability to face physical challenges; and
   - An acceptance of the likelihood of adverse circumstances and willingness to adapt to unexpected events.

   Note that "risk-taking" does not imply reckless behavior; rather, it involves a willingness to try new things, work through difficulties, and learn from failures.

   Discuss similarities between human character traits needed for ocean exploration and engineering habits of mind, which include:
   - systems thinking;
   - creativity;
   - optimism;
   - collaboration;
   - communication; and
   - attention to ethical considerations.

   In modern ocean exploration, science, technology, engineering, and mathematics are so closely integrated that it can be hard to separate one element from the others. Scientific questions drive the Engineering Design Process, which produces technology that provides data to answer the questions. Mathematics helps translate scientific questions into engineering design problems, provides tools that help create technological solutions, and assists with interpreting and analyzing data obtained with technology to answer scientific questions. Electronics are involved in every aspect of ocean exploration, including ship operations, telepresence, data acquisition, and scientific analysis. Many devices used for these activities include microcontrollers; tiny computers that are also found in home appliances, automobiles, marine engines, televisions, media players, interactive games, toys and many other products.

Engineering Design Process

The Engineering Design Process is a series of steps that engineers use to create solutions to problems. There are many versions of the Process, but the basic steps include:

- Define the problem
- Gather relevant information
- Brainstorm possible solutions
- Analyze possible solutions and select the most promising
- Test the solution by building a prototype
- Revise and improve the solution
- Repeat previous steps until results are acceptable
- Report the design process and results

These steps involve several key skills:

- Obtaining, evaluating, and communicating information;
- Analyzing and interpreting data;
- Using mathematics, information and computer technology, and computational thinking; and
- Using evidence to discuss the strengths and weaknesses of ideas and designs.

Most problems will include certain constraints that may relate to cost, size, environmental conditions, or other specific requirements. Some constraints may be identified in the statement of the problem, but most problems need additional analysis to be certain that all constraints are understood. Often, constraints will force designers to make trade-offs in their solutions. For example, the strongest material may be too expensive, or too heavy to meet cost and size constraints. Identifying the solution that meets all of the constraints with the best combination of trade-offs is called optimization. Models are frequently used to help designers visualize possible solutions, and may be two-dimensional illustrations, three-dimensional physical shapes, or mathematical calculations that predict how well a potential solution will do what is necessary to solve the problem. Each step of the Engineering Design Process involves systematically examining information that is needed to move to the next step. This kind of examination is called analysis.

Lead a discussion about exploration strategies that might guide *Okeanos Explorer* missions. Have students present their ideas, then relate these to the following points from the exploration strategy discussion in the *Introduction to Volume 2: How Do We Explore?* starting on page 12:

- The overall *Okeanos Explorer* strategy is based on finding anomalies;
- This strategy involves Underway Reconnaissance, Water Column Exploration, and Site Characterization;
- Key technologies involved with this strategy include Telepresence, Multibeam Sonar Mapping, CTD and other electronic sensors, and a Remotely Operated Vehicle (ROV); and
- The *Okeanos Explorer* is a ship of discovery, focused on exploration rather than research.

Be sure students realize that the recognition of anomalies may be affected by a variety of factors, including:

- The scale at which observations are made;
- Who is making the observations; and
- How the observations are made.

For example:

- If observations of chemical and physical seawater properties are made at 10 m intervals, anomalies are more likely to be missed than if these observations are made at intervals of 1 m (which is possible with CTD equipment aboard *Okeanos Explorer*);
- The significance of a bottom feature imaged by multibeam sonar may be interpreted differently by a biologist and a geologist (this is also a good example of the importance of telepresence in the *Okeanos Explorer* exploration strategy);
- Finding anomalies in the deep ocean is highly dependent upon the technology that is available to make observations, and even with state-of-the-art technology it is likely that some anomalies will be missed because they can only be observed with instruments that are not yet available to ocean explorers.

Decisions about the scale at which observations are to be made, and which technologies will be used to make these observations are strongly influenced by our basic assumptions about natural systems. One of these assumptions, the "geometry of nature," is explored in the following investigation.

Part B. The Fractal Geometry of Nature

1. To prepare for this lesson:
   (a) Scan the *Koch Curve Construction* on page 32 to a file for display on a whiteboard, or copy it onto an overhead transparency.
   (b) Download examples of fractals in nature and "fractal forgeries of nature" from *http://classes.yale.edu/fractals/Panorama/welcome.html*. Select categories from the "Contents" menu on the left side of the page. Useful categories include "Forgeries of Nature," "Fractal Planets, Simulated," and "Mountains, Simulated." There are also several hundred videos about fractals in nature available on You Tube.

2. Background

"Clouds are not spheres, mountains are not cones, coastlines are not circles, and bark is not smooth, nor does lightning travel in a straight line."

~ Benoit Mandelbrot
The Fractal Geometry of Nature

Pueblo, Colorado lies just east of the Rocky Mountains. Looking west from Pueblo, you see the jagged, complex topography of the Rockies. If you drive 40 miles or so to the base of the Rockies, you no longer see as much of the overall topography, but now you can distinguish many trees and smaller rock formations; different from the view at Pueblo, but just as complex. Climb a mile up the slope of the nearest mountain, and you see details of individual trees and rocks; again, different from the previous views, but still complex. Move closer to a single tree and more details become evident, but the overall view does not become simpler. Pick a single leaf or piece of bark, chop it up, look at a single fragment under a microscope, and…you know what happens.

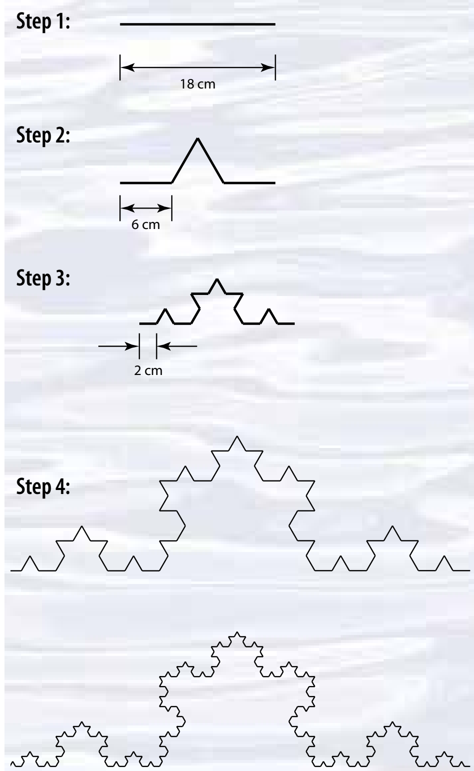
This illustrates an important characteristic about nature in general: natural features and processes generally do not become simpler with decreasing size. This characteristic has important implications for decisions about the scale of exploration observations.

Most mathematics curricula emphasize the regular geometric shapes described by Euclid (a Greek mathematician who lived around 300 B.C.). Young children (and some highly-paid "primitive" artists) use these shapes to depict nature (*e.g.*, trees as straight lines topped by circles). In fact, the artist Paul Cézanne is widely reported to have said, "Everything in nature takes its form from the sphere, the cone and the cylinder."

Despite this emphasis, we know that nature rarely assumes the classic Euclidian forms. A basic wilderness survival strategy, for example, is that signals made with straight lines, circles, squares or triangles are easily seen by rescuers because these regular shapes are almost never found in natural landscapes.

In 1982, Benoit Mandelbrot published *The Fractal Geometry of Nature*, in which he proposed that many natural features can be modeled with geometric structures that he called fractals. The Koch Curve, named after Swedish mathematician Niels Fabian Helge von Koch, is a well-known example that provides a useful starting point for exploring fractals.

Koch Curve Construction



3. Show several simple geometric forms such as circles, square, triangles, etc., and ask students where they can find these forms in nature. Students may name various objects that are approximately circular (e.g., the moon), but should realize that if one looks closely enough there are many irregularities that prevent the objects from being exactly circular.

   Use the Pueblo example described above to introduce the idea of complexity at multiple scales. Tell students that they are going to create a simple example of a structure that can be increasingly complex at an infinite number of scales.

   Instruct students to begin by drawing a line measuring 18 cm (Step 1 of "Koch Curve Construction"). Next, divide the line into three equal segments (6 cm), and replace the middle segment with two sides of a triangle whose sides are 6 cm long as shown in Step 2. Now repeat this process, dividing each segment into three equal segments (2 cm), and replacing the middle segment with two sides of a triangle whose sides are 2 cm long as shown in Step 3. If you repeat this an infinite number of times, you produce the Koch Curve. Step 4 shows the results of two more repetitions. Tell students that it obviously is not possible to repeat the process infinitely, so our drawing is only an approximation of the Koch Curve; but it helps to illustrate two defining features of fractals:
   - Self-similarity; and
   - Fractional dimensions.

   Self-similarity means that the segments of the Koch Curve are made of repeating units that look the same, regardless of how much we magnify any portion of the curve. In other words, the Koch Curve is equally complex at multiple scales.

   Fractional dimension refers to the way objects occupy space. A line is a one-dimensional object. A square, triangle or other flat shape is a two-dimensional object. A cube, pyramid, sphere, or other solid is a three-dimensional object. The Koch Curve is not a one-dimensional object (a line), nor is it a two-dimensional object (square, triangle, circle, ellipse, etc). It is something in between a one- and two-dimensional object; so it has a fractional dimension. This dimension can be calculated to be approximately 1.2619 (optional: see *http://math.rice.edu/~lanius/frac/* for further discussion about how this calculation can be done).

4. Show students images downloaded in Step 1d, and discuss the idea that fractals provide useful models of nature; more accurate, in many cases, than Euclidean shapes. Point out (if students do not mention it) that the fractal characteristic of similarity at multiple scales is similar to our own experiences with nature (such as the Pueblo example). Discuss how this characteristic might be useful to explorers planning a strategy for exploring the deep ocean. Students should realize that if we observe complexity in natural features at one scale, the "fractal geometry of nature" concept suggests that we will also find similar complexity at other scales. So, if we observe deep-ocean features over a wide area (for example, with multibeam sonar), we can find areas where features seem to be relatively complex (such as seamounts, underwater volcanoes, deep reefs). We can then observe these relatively complex areas at different scales with different tools (such as video cameras on an ROV) to look for other features, organisms, or anomalies. The idea is that detecting complexity over large areas gives us a way to narrow our search to places that have a relatively high probability for anomalies.

5. *Optional:* Discuss how the fractal geometry of nature influences diversity in natural habitats. Ecologists have found that the number of species in various habitats often correlates with the physical complexity of the habitat and the variety of resources available in that habitat. They have also found that habitat complexity often exists at multiple scales. So, for example, a coral reef is complex at the scale of an entire coastline, also complex at the scale of individual fishes, similarly complex at the scale of smaller organisms that live in the space between corals and coral branches, and still complex at the scale of microorganisms that live on the surfaces of corals and other organisms on the reef. For other examples, see Wiens (1989).

   See *http://oceanexplorer.noaa.gov/explorations/06davidson/background/edu/fleas.pdf* for another activity that explores the fractal nature of habitat complexity.

Adaptations for Other Grade Levels

Considerations for Grades 5-6 – Activities and information about the Lewis and Clark, HMS *Challenger*, and *Okeanos Explorer* expeditions are appropriate to all grades. Expectations for students' responses to the *Guide for Investigating Exploration Strategies* questions should be similar to expectations that would apply to other student reports at this grade level. Most students at the grade 5-6 level will not be familiar with many of the mathematical concepts involved with fractal geometry, but experience suggests that the overall idea of fractals and their potential as models of natural features and process are well within the grasp of students in these grades. Lanius (see Other Resources) provides additional discussion and ideas about how fractal concepts can be taught to elementary and middle school students.

Considerations for Grades 9-12 – Students in these grades should be expected to provide more detailed information in response to *Guide for Investigating Exploration Strategies* questions. Individual *Guide* questions may be assigned to specific student groups as topics for group reports. Mathematics knowledge among students at this level should be sufficient to allow more in-depth exploration of fractals, including calculation of fractal dimensions. Frame, Mandelbrot, and Neger (see Other Resources) offer ideas for laboratory exercises and lesson plans, as well as extensive background information and examples from many fields including fine art, architecture, and natural history.

The BRIDGE Connection

www.vims.edu/bridge/ – Scroll over "Ocean Science Topics" in the menu on the left side of the page, then "Human Activities" then click on "Maritime Heritage" for activities and links about the HMS *Challenger* and other ocean exploration expeditions.

The "Me" Connection

Have students write a brief essay discussing how they use (or might use) anomalies to explore an unfamiliar area.

Connections to Other Subjects

English/Language Arts, Mathematics, Social Studies

Assessment

Answers to *Guide for Investigating Exploration Strategies* questions and class discussions provide opportunities for assessment.

Extensions

Visit *http://oceanexplorer.noaa.gov/explorations/lewis_clark01/lewis_clark01.html* and *http://oceanexplorer.noaa.gov/explorations/03mountains/background/challenger/challenger.html* for more information about connections between modern ocean exploration and the Lewis and Clark and HMS *Challenger* Expeditions.

Multimedia Discovery Missions

http://www.oceanexplorer.noaa.gov/edu/learning/welcome.html Click on the links to Lessons 1, 3, 5, 6, and 12 for interactive multimedia presentations and Learning Activities on Plate Tectonics, Deep-Sea Corals, Chemosynthesis and Hydrothermal Vent Life, Deep-Sea Benthos, and Food, Water, and Medicine from the Sea.

Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

Journey to the Unknown (Grades 5-6)
(from *The NOAA Ship* Okeanos Explorer *Education Materials Collection Volume 1: Why Do We Explore?*)
http://oceanexplorer.noaa.gov/okeanos/edu/collection/media/wdwe_journey.pdf
Focus: Ocean Exploration (Life Science/Earth Science)
Students will experience the excitement of discovery and problem-solving to learn what organisms could live in extreme environments in the deep ocean, and will understand the importance of ocean exploration.

Come on Down! (Grades 7-8)
(from *The NOAA Ship* Okeanos Explorer *Education Materials Collection Volume 1: Why Do We Explore?*)
http://oceanexplorer.noaa.gov/okeanos/edu/collection/media/wdwe_comedown.pdf
Focus: Ocean Exploration (Physical Science)
Students will research the development and use of research vessels/vehicles used for deep-ocean exploration; and calculate the density of objects by determining the mass and volume.

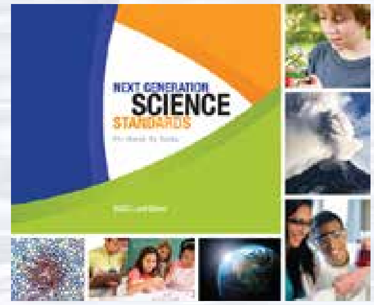
Big Fleas Have Little Fleas (Grades 7-8)
(from the 2006 Davidson Seamount: Exploring Ancient Coral Gardens Expedition)
http://oceanexplorer.noaa.gov/explorations/06davidson/background/edu/fleas.pdf
Focus: Physical structure in benthic habitats (Life Science)
Students recognize that natural structures and systems often display recurrent complexity over many scales of measurement, infer the importance of structural complexity to species diversity and abundance in benthic habitats, and discuss ways that octocorals may modify seamount habitats to make these habitats more suitable for other species.

Calling All Explorers… (Grades 9-12)
(from *The NOAA Ship* Okeanos Explorer *Education Materials Collection Volume 1: Why Do We Explore?*)
http://oceanexplorer.noaa.gov/okeanos/edu/collection/media/wdwe_callingex.pdf
Focus: Ocean Exploration - Recent explorers of deep-sea environments and the relationship between science and history (Life Science/Earth Science)

Students learn what it means to be an explorer, both modern and historic; recognize that not all exploration occurs on land; understand the importance of curiosity, exploration, and the ability to document what one studies; gain insight into the vastness of unexplored places in the deep sea; and gain appreciation of science mentors and role models.

Next Generation Science Standards

Lesson plans developed for Volume 2 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/hdwe_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 *Next Generation Science Standards* (National Academies Press 2013). 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

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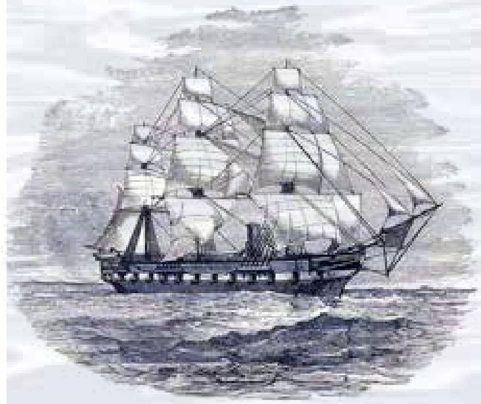
Part A: Guide for Investigating Exploration Strategies

Lessons from Previous Voyages of Discovery

Two of the most famous expeditions to explore unknown territory are the Lewis and Clark Expedition and the HMS *Challenger* Expedition. Both of these expeditions are generally considered to have been successful, and produced a great deal of information that provided vital guidance for subsequent explorations and scientific studies. Exploration strategies used by these expeditions may offer some useful ideas for modern-day voyages of discovery. The following questions will help guide your investigation into these strategies.

1. Exploration strategies usually are strongly influenced by the underlying purpose of the expedition. What was the overall mission of the expedition?
2. What was the overall plan for the expedition's route?
3. What scientific measurements or observations did the expedition make?
4. What technical instruments did the expedition have available?
5. How long was the expedition?
6. How many people were involved in the expedition?
7. How much area did the expedition cover?



The HMS *Challenger*.
http://www.19thcenturyscience.org/HMSC/HMSC-INDEX/index-linked.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 courtesy of NOAA.
http://www.19thcenturyscience.org/HMSC/HMSC-INDEX/group.jpg

NOAA Ship *Okeanos Explorer*

In 2000, the President's Panel for Ocean Exploration issued its report, *Discovering Earth's Final Frontier* (available from: *http://oceanservice.noaa.gov/websites/retiredsites/supp_oceanpanel.html*). The report called for a new national Ocean Exploration Program, noting that 1) previous efforts to explore the ocean had "ended before a significant portion of the oceans was visited in even a cursory sense; and 2) marvelous new tools now exist that permit exploration in spatial and temporal dimensions that were unachievable 50 years ago. For these reasons, we must go where no one has ever gone before, 'see' the oceans through a new set of technological 'eyes,' and record these journeys for posterity."

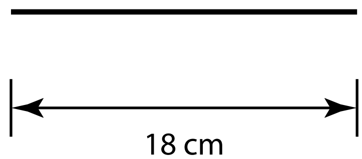
In August 2008, the NOAA Ship *Okeanos Explorer* was commissioned as the only U.S. ship whose sole mission is to systematically explore our largely unknown ocean for the purposes of discovery and the advancement of knowledge. List some ideas for exploration strategies that could be used to fulfill this mission. In particular, consider:

- What kind of measurements or observations should be made?
- What technologies could be used to make these measurements or observations?

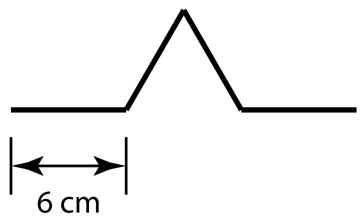
NOAA Ship *Okeanos Explorer:* America's Ship for Ocean Exploration. Image courtesy of NOAA. For more information, see the following Web site: *http://oceanexplorer.noaa.gov/okeanos/about.html*

Part B. Koch Curve Construction

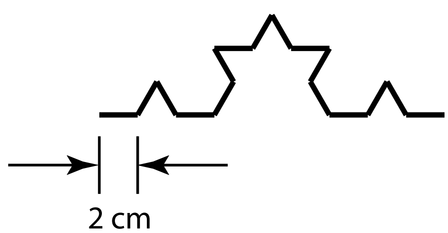
Step 1.



Step 2.



Step 3.



Step 4.