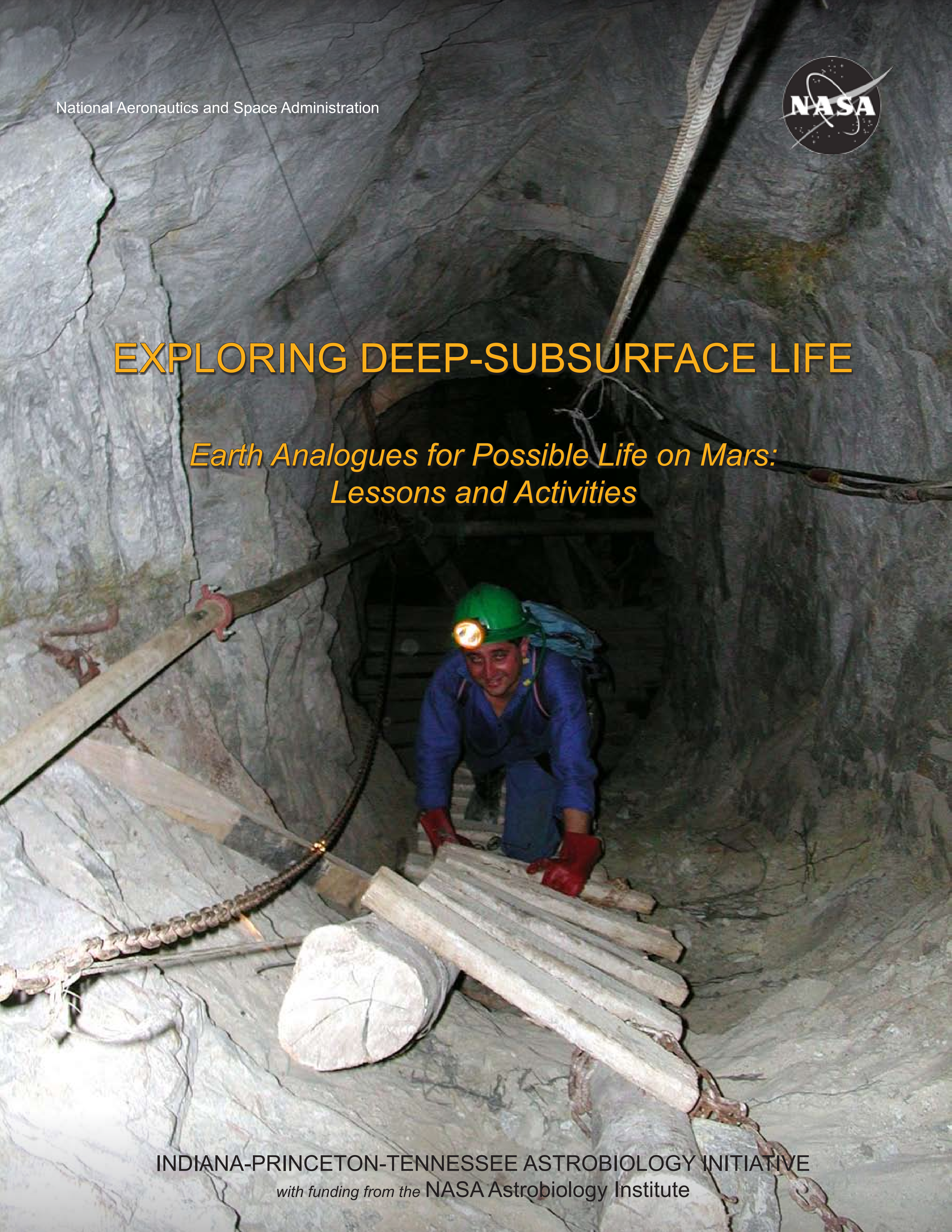

National Aeronautics and Space Administration

EXPLORING DEEP-SUBSURFACE LIFE

Earth Analogues for Possible Life on Mars: Lessons and Activities

INDIANA-PRINCETON-TENNESSEE ASTROBIOLOGY INITIATIVE

with funding from the NASA Astrobiology Institute

THE INDIANA-PRINCETON-TENNESSEE ASTROBIOLOGY INITIATIVE (IPTAI)

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INDIANA UNIVERSITY

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Image credit Peter Suchecki: helicopter delivering supplies to High Lake mine, Nunavut Territories, Canada
Cover image credit Lisa M. Pratt: Dr. Eric Boice ascends a mineshaft at Kloof Gold Mine, Johannesburg, South Africa

Contents:

ON THE DVD: Introduction To The Deep Life Team

Dr. Lisa Pratt (Indiana University)
Dr. Tullis Onstott (Princeton University)
Dr. Susan Pfiffner (University of Tennessee)
Dr. Corien Bakermans (Michigan State University)

Image credit Lisa M. Pratt: headframe, Evander #8 shaft, Harmony Gold Mine, South Africa

9/20/07: False-color image of gully channels in a crater in the southern highlands of Mars, taken by the High Resolution Imaging Science Experiment (HiRISE) camera on the Mars Reconnaissance Orbiter. The gullies emanating from the rocky cliffs near the crater's rim (upper left) show meandering and braided patterns typical of water-carved channels. North is approximately up and illumination is from the left; scale, 26 centimeters per pixel.

A link to the full HiRISE image that includes this view is online at http://hirise.lpl.arizona.edu/PSP_003583_1425

Credit: NASA/JPL/University of Arizona

Preface: Why Astrobiology?

Astrobiology is the search for life and life-like processes across the universe. It is an interdisciplinary science studying the origin, evolution, distribution, and future of life on Earth as well as the potential for life to exist on other bodies in our solar system and beyond. Astrobiology seeks to answer not only the question of how life began on our planet, but if life exists on other planets. How do scientists answer these questions? How do we look for life in places we cannot easily visit? Furthermore, how would we recognize life if we found it?

In these materials we explore the link between life in extreme Earth environments and life on other planets. Our closest planetary neighbor, Mars, has been the main focus of interest in the search for extraterrestrial life. But why Mars? Mars is more like Earth than any other planet in our solar system. It is similar to Earth in size and crustal composition. Like Earth, the Martian atmosphere contains oxygen. In addition, there is abundant evidence of large amounts of water on the surface of Mars in its distant past. Even now, images of Mars indicate that liquid water may be intermittently present in the planet's low gullies and at the margins of the polar ice caps during the Martian summer. Water is crucial to the existence of life as we know it and evidence of water in the planet's past may indicate that water is still present beneath the surface.

Despite these favorable traits, Mars is still an extreme environment. The cold, thin, and extremely dry air on the Red Planet presents a major hurdle to the existence of known living organisms. However, life has found a way to exist in remarkably harsh environments on Earth. The Atacama Desert in Chile is the driest place on our planet, yet still sustains microbial life. Bacteria have been found living in the Siberian Permafrost at temperatures bordering on -20º Celsius. The surface of Mars is only one place where life may exist. On Earth, microorganisms have been found living in rocks deep below the surface. These life forms exist completely independent of sun's energy yet still manage to survive. Similar organisms may be living in the rocks deep within the Martian crust.

Astrobiologists strive to understand life in extreme environments on our own planet so that they might know where and how to look for life on other planets. If we know that life can thrive in hot, dry, cold, or salty places on Earth, then scientists infer that similar environments in our solar system and beyond may also harbor living organisms. Studying the influence of living organisms on their environments also gives us clues as to what "fingerprints" to look for as evidence of life.

Notes to Teachers

We hope you enjoy using these lessons in your classroom as a supplement to your intact curriculum. The activities are designed to be used either in succession or independently, allowing for the most appropriate fit into your curriculum. Each lesson has been linked to the National Science Education Standards and the AAAS Benchmarks for Science Literacy. Our goal is to support teachers by introducing and broadening the study of Astrobiology thereby providing opportunities for new activities in the high school classroom.

The relevant National Standards and Benchmark Standards for this workbook's projects are included in the Standards section beginning on page 59. We have numbered them for the purposes of this workbook, and noted them in the margins on each page for your convenience.

All activity materials are available on the accompanying CD in .doc or .pdf format for class work printing purposes.

Image credit Peter Suchecki: aerial view of landscape, High Lake Mine, Nunavut Territories, Canada

Lesson One: Life Domains

CONTENTS

ON THE DVD: Life Domains

Introduction to the Tree of Life (animation and video):

Professor Lisa Pratt (Indiana University) describes Eukaryotes, Bacteria, Archaea and how they differ

Professor Tullis Onstott (Princeton University) describes the shape and age of Deep Subsurface Organisms (DSSOs)

Image credit Susan Pfiffner (University of Tennessee): Drill rig, High Lake Mine, Nunavut Territories, Canada

Lesson 1

Life's Three Domains

what are the differences?

SUMMARY:
Students explore, compare, discuss and explain the basic differences between organisms assigned to the eukaryotic, bacterial, and archaeal domains. Topics in astrobiology are explored through projects, vocabulary reinforcement, and drawing assignments.

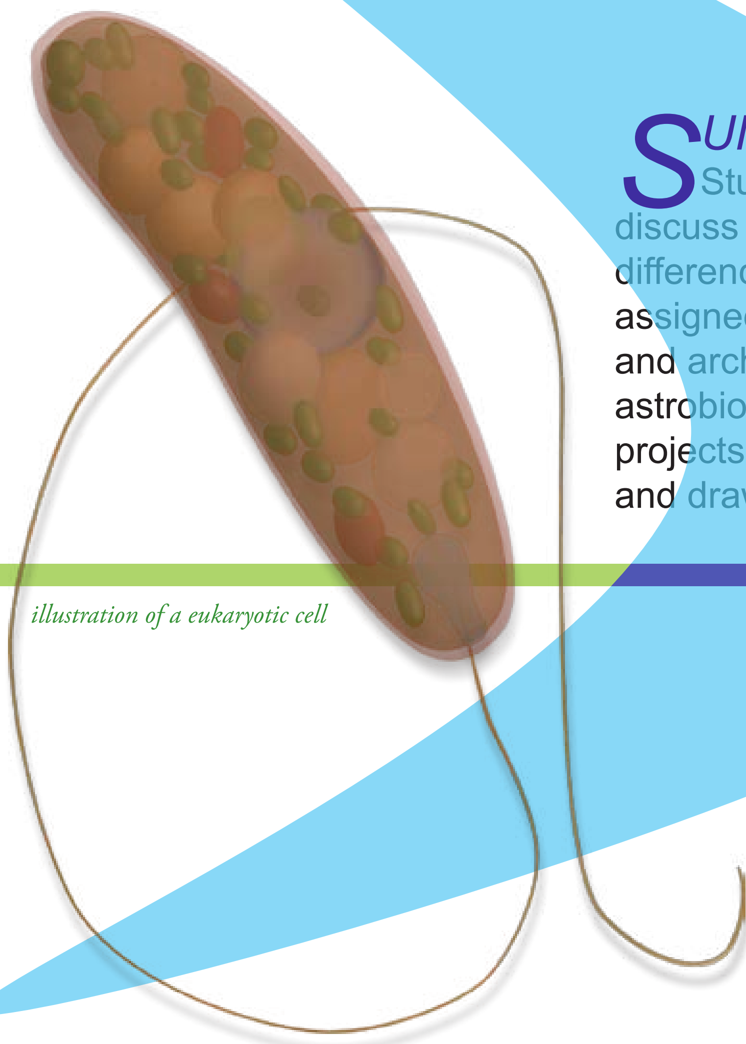


illustration of a eukaryotic cell

The numbers for the relevant National Standards and Benchmark Standards are noted in the margins.

Lesson 1

Pre-Activity Exercise

assessing prior knowledge and misconceptions

Below are three boxes. In the box labeled "K," write down everything you currently know about the topic. In the "W" box, make a list of things you do not know about the topic, but would like to learn. Leave the "L" box blank for now. After completing the exercises, fill in what you have learned from the background reading and activities.

TOPIC

Classification of Life – Please describe everything you know about how organisms are placed into groups. You may include information on what traits biologists use to classify living things, categories or classification structure, and differences between major groups of organisms.

K

W

L

Lesson 1

Pre-Activity Exercise

assessing prior knowledge and misconceptions

Pre-Activity Questions

Directions: Read the background and introduction titled "What is Life?" and "Life Domains." Answer the questions below in the space provided.

1 What is the fundamental unit that provides the cell information on how to grow, reproduce, acquire nutrients, and maintain the processes necessary for life? Answer: ***DNA***

2 What role does mRNA play? Answer: ***Used as a copy of the DNA molecule (transcribed) to then help build proteins at the ribosome.***

3 What are the three domains into which all living things are classified? Answer: ***Bacteria, Archaea, Eukarya***

4 What are some of the major characteristics of eukaryotic cells? What are some things that bacteria and archaea have in common? What are some characteristics that are shared between eukaryotes and archaea?
Answer: ***Eukarya have membrane-bound organelles, store genetic information in linear structures called chromosomes and use histones to organize and pack DNA.***

5 What are the major differences in cell membrane structure between the three domains? (Make sure you mention all three in your answer)
Answer: ***Eukarya and bacteria have lipids that are ester linked. Archaea have lipids that are ether linked.***

Questions for Discussion

1 Why do you think scientists use cell structure to classify living organisms?

2 What group do you think plants, animals, fungi, and protists belong to? Why?

3 Can you think of any other things scientists could use to classify organisms besides cellular structure?

Lesson 1 What is life?

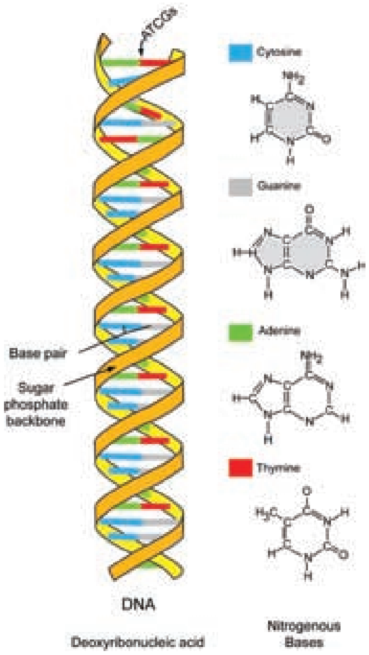


Figure 1.1: Structure of DNA

It seems like a simple question, but defining what it is to be alive can be a complicated endeavor. What are the characteristics of something that is living? Must it move? Grow? Reproduce? Does it have to eat? Scientists agree that the smallest unit that can qualify as life as we know it on Earth is the cell. By definition, the cell is the simplest collection of matter that can be said to live. While defining life continues to be a constant source of debate among researchers, most can agree on the minimum aspects required for something to qualify as living matter. It must be able to reproduce, and therefore must have DNA to provide instructions on how to do so. It must be able to metabolize material and extract energy from it. Finally, life must in some way respond to stimuli from its environment. These characteristics taken together encompass our current understanding and definition of life on our planet.

A cell is life's fundamental unit of structure and function. All cells contain deoxyribonucleic acid (DNA) – a complex, double-stranded molecule made up of the nucleotides adenine (A), guanine (G), cytosine (C,) and thymine (T). These nucleotides, or bases, are why a length of DNA is often shown as a span of A's, G's, C's and T's. Encoded in the DNA are genes, or units of heritable information. These genes consist of a specific nucleotide sequence. Genes are the blueprint for making all the machinery, structures, and products that a given cell will need over the course of its life.

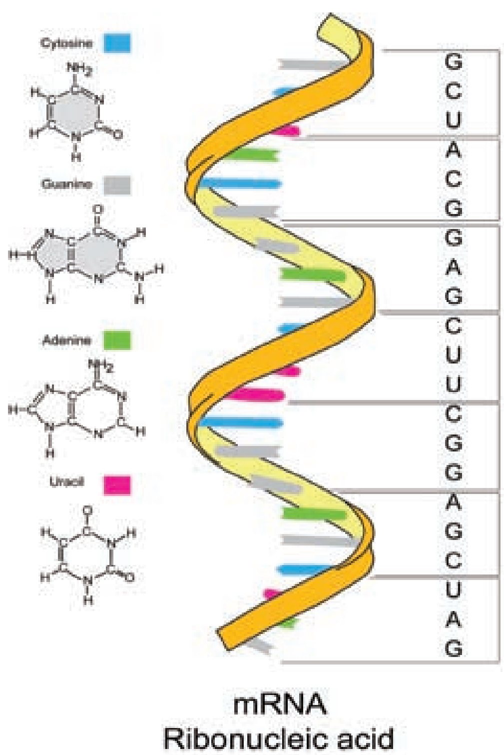


Figure 1.2: Structure of messenger RNA

The complete set of a cell's genetic information is called a genome. The information contained in a cell's genome is very precious: it only has one copy of the instructions required to make the components it needs to survive. Therefore, in order to use the information encoded in the cell's genome without jeopardizing its DNA, the genes are transcribed from DNA to messenger ribonucleic acid (mRNA). mRNA is similar in structure to DNA, but consists of different nucleic bases and is single stranded. The mRNA message is sent out to the ribosomes, complex organelles consisting of both proteins and specialized RNA molecules (different from the mRNA) that assemble amino acid building blocks into new protein products. The mRNA is read by the ribosome like a set of instructions and the sequence of the RNA is translated into a chain of amino acids that are then folded into the final protein. In this manner, all living organisms use information from the DNA to make the wide variety of proteins required for life.

NSES
C-3
C-4
C-7

Images adapted from: National Human Genome Research Institute, Talking Glossary of Genetic Terms. Available at: www.genome.gov/Pages/Hyperion//DIR/VIP/Glossary/Illustration/ma.shtml

AAAS
5.B.3
5.C.3
5.C.4

Lesson 1 Life Domains

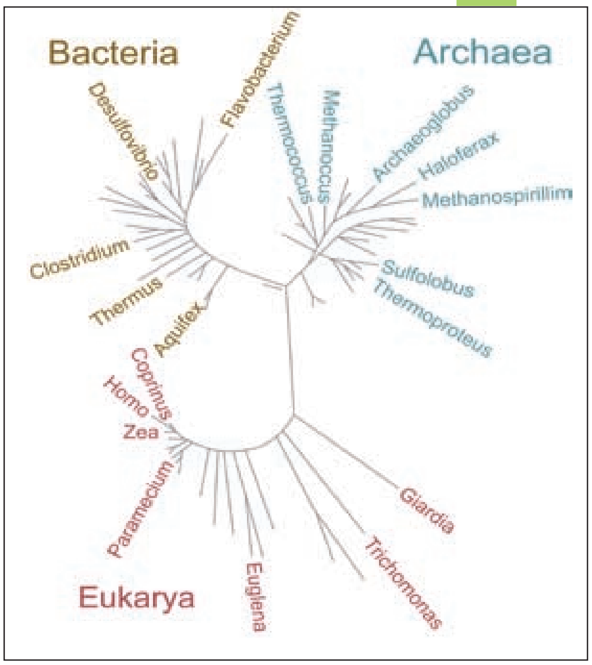


Figure 1.3: Professor Karl Woese's 3-domain tree of life diagram as constructed by Professor Norman Pace

All life on Earth is divided into three broad domains: eukarya, bacteria and archaea. The eukarya represent a wide variety of life on this planet, from tiny, single-celled paramecia to more complex organisms such as fungi, plants and animals. Eukaryotic cells not only have a membrane that encloses them but also have membrane-bound internal compartments such as the nucleus (which houses and protects their DNA) and metabolic organelles (cell parts that help to produce energy for the cell) such as mitochondria and chloroplasts. Eukarya store their genetic information in linear structures called chromosomes and use proteins called histones to organize and pack their DNA. Additionally, genes in eukaryotic cells must be "turned on" by certain proteins called transcription factors before the product of the gene can be made. Transcription factors in eukaryotes help initiate transcription of specific genes. This allows a tighter control over what is being expressed, leading to greater adaptability.

The other two main domains of life, bacteria and archaea, have several characteristics in common, a fact that for many years resulted in their being grouped together in one domain: the prokarya. Both bacteria and archaea lack internal membrane structures (they have no nucleus) and their entire genome is in the form of a single, circular chromosome. Both groups can use plasmids, or self-replicating circles of DNA, to pass information from one cell to another. Archaea and bacteria also have the ability to live in very extreme and hostile environments, a trait that makes them of great importance to astrobiologists. However, there are many characteristics of the archaea that are actually more similar to the eukaryotes than bacteria. Like eukarya, archaea package their DNA with histones and require transcription factors to "turn on" their genes, a trait that could explain why many archaea have adapted to thrive in extreme environments. Other characteristics of the archaea are unlike either bacteria or eukarya. The archaea include the only microorganisms that produce methane as a product of metabolism. The lipids, or fats, that make up the membranes of archaeal cells are ether-linked, as opposed to the ester linkages seen in the other two domains. Bacteria also have unique abilities that separate them from the archaea and eukarya. They are the only domain with muramic acid cell walls and are the only life capable of nitrification (the conversion of ammonia to nitrate.) In light of these differences, researchers divide all life into three distinct groups that arose from a single common ancestor.

NSES
C-3
C-4
C-7
C-14

AAAS
1.A.3
1.A.2
5.A.2
5.B.3
5.C.3
5.C.4
5.F.2

The domains of eukarya, bacteria and archaea represent the most basic way to categorize life as we know it on Earth. It is important to remember that while this three-branch model is built on our current understanding, research is constantly expanding our body of knowledge. As new organisms are discovered they may be so different that they do not fit into the established domains of eukarya, bacteria, or archaea. In this event, new domains would be created to encompass new organisms. The pace of discovery is rapid, and as biologists make new discoveries they continue to revise the domains of life based on their findings.

Lesson 1 project overview

NOTES TO TEACHERS

Before beginning "Lesson 1: Life's Three Domains," students should be introduced to the concept of cell theory and have background knowledge of DNA and how life on Earth is classified. The background information provided in this lesson is intended for enrichment and review.

Student learning objectives for this lesson are:

- To understand what constitutes a living organism
- To understand the three domains of life on Earth, their characteristics, and how they differ from one another
- To explore and understand the function, structure, and components of the phospholipid bilayer

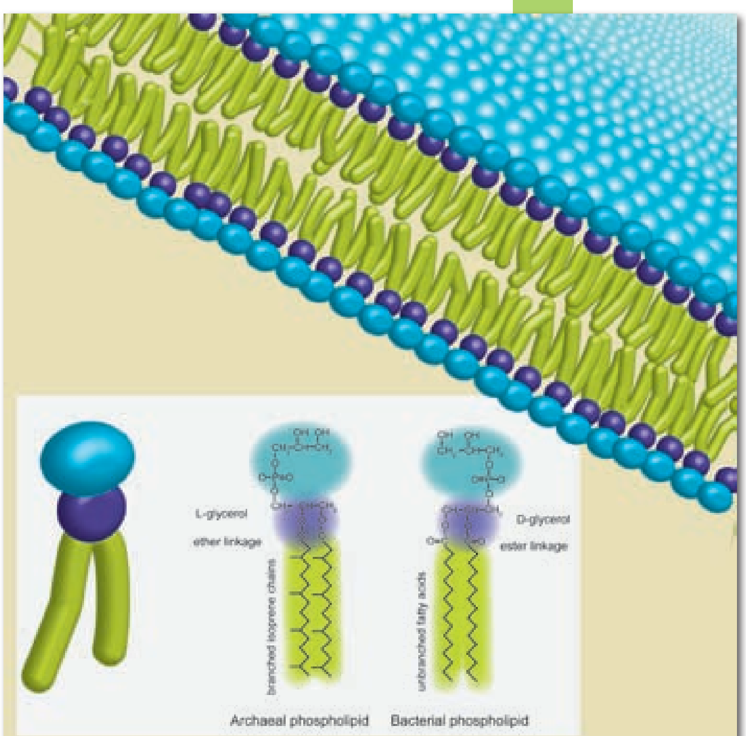


Figure 1.4: Illustration of a membrane lipid bilayer, showing archaeal and bacterial phospholipids.

The cell's plasma membrane is the boundary that separates cellular components from the environment and allows control over what enters and leaves the organism. This selectively permeable boundary is present in all cells of all domains of life. The membrane is composed of units of phospholipids- long chains of lipids, or fats, bound to a phosphorus-containing molecule. The "phospho" head region is hydrophilic (or "water loving") - it has an affinity for water and is soluble in it. The "lipid" tail component is hydrophobic (or "water fearing"). Like all fats, the lipids want to be away from water and are soluble in oils. When membranes assemble, two layers of phospholipids line up into a bilayer. The hydrophobic fats of each half sandwich together on the inner portion of the membrane structure and the hydrophilic regions face outward. The hydrophilic regions interact with both the cytoplasm inside the cell and environment outside of it. The membrane itself is fluid.

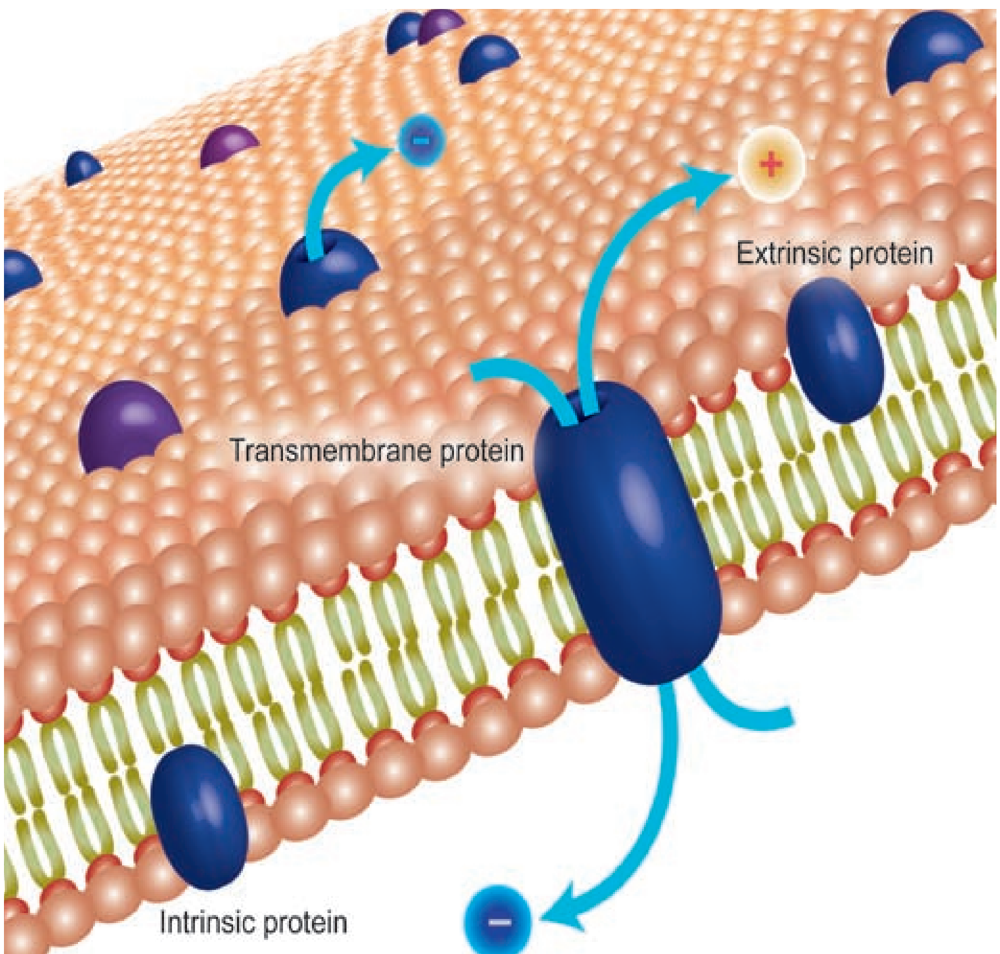
NSES
B-11
C-1
C-2

AAAS
5.C.1
5.C.2
5.C.8

activity 1 project overview

SPECIAL MACHINERY

In addition to being a boundary, the membrane has special functions that are integral to the life of the cell. The plasma membrane is the mechanism through which all nutrients enter the cell and all waste leaves. The membrane also allows the cell to interact and respond to its surroundings. To accomplish these tasks, there are many components of the membrane that are not phospholipids. Transmembrane channels made of protein are required to move water molecules and ions across the membrane. Transporter proteins work to actively move larger molecules (such as sugars and fats) from one side of the membrane to another. Additionally, signaling receptor proteins are present in the membrane to monitor the cell's environment. These molecules can then signal the cellular machinery to do certain actions or even turn on certain genes. Still other proteins decorate only the surface of the membrane. These markers help identify the cell to other cells. All these tasks are accomplished by the cell's first line of defense: the membrane.



NSES
B-11
C-1
C-23

AAAS
5.C.1
5.C.2
5.C.8

Figure 1.5: Illustration of a membrane cross-section.

activity 1 building membranes

PROJECT

Students will construct a three dimensional cut-away model of a cell membrane. Using craft items, students will model the lipid bilayer and associated proteins.

FEATURES OF THE MEMBRANE

The model should include the phospholipids necessary for overall membrane structure as well as accessory proteins. Students should research on their own the kinds of proteins, channels and molecules that may be present in a membrane as well as the difference between membranes across life's domains. Structures should be clearly labeled and students should be able to identify and describe the various components.

Students should work together in small groups to assemble their membranes.

PLANNING THE MODEL

Before beginning, students should be shown the membrane figure from these materials and encouraged to find other images of membrane structures on their own.

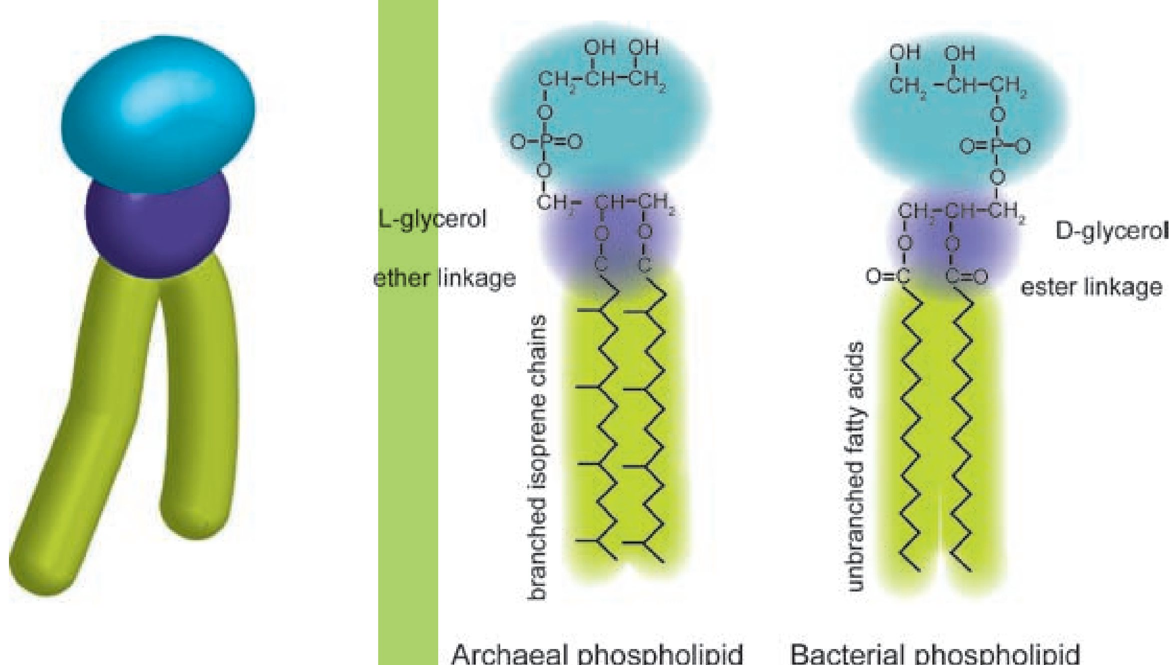


Figure 1.6: Illustration of archaeal and bacterial phospholipid structures.

NSES
A-4
B.11
C-1

AAAS
5.C.1
5.C.2
5.C.8

activity 1 building membranes

MATERIALS AND METHODS

1 Pipe cleaners to represent elongate lipid tails

2 Pom-Poms (large and small sizes, different colors) to represent the phosphate group heads (large) and the glycerol attachments (small)

3 Velcro® dots (small) to stick pom-poms together into a grid structure

4 Flexible straws to represent membrane-bound proteins

NSES
A-4
C-1

AAAS
5.C.1
5.C.8

The student activity materials are available on the accompanying CD as Microsoft Word and Acrobat PDF documents for classroom copying purposes only.

activity 1 drawing assignment

PLANNING SHEET

Use the space below to draw a sketch of your membrane model.
Label the parts using the following terms:

- Phospholipid
- Extracellular space
- Cytoplasm
- Hydrophobic region
- Hydrophilic region
- Signalling proteins
- Ion channels

QUESTIONS FOR THOUGHT AND DISCUSSION

1 What were some of the differences between the membranes that you noticed from your research? What were some differences between cells within the same domain?

2 What changes might an organism make to its membrane that would allow it to survive in harsh environments?

3 Assume that we find life on another planet. To which domain of life do you think the organism would belong? Why do you think that?

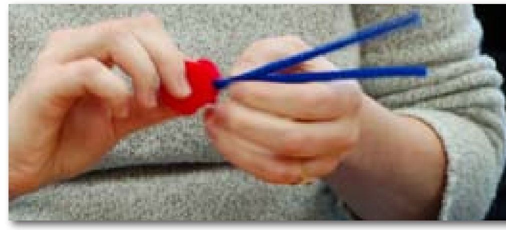
NSES
A-4
C-1
C-2

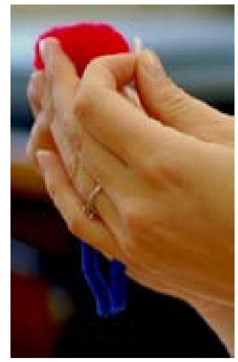
AAAS
5.C.1
5.C.2
5.C.8
12.D.1

activity 1 building membranes

NOW BUILD YOUR MODEL!

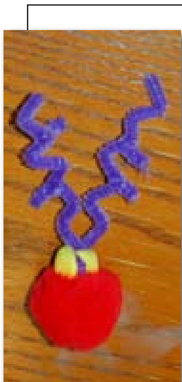
The phospholipids are best modeled by twisting pipe cleaners around a large pom-pom base, and twisting a small pom-pom of another color on top.



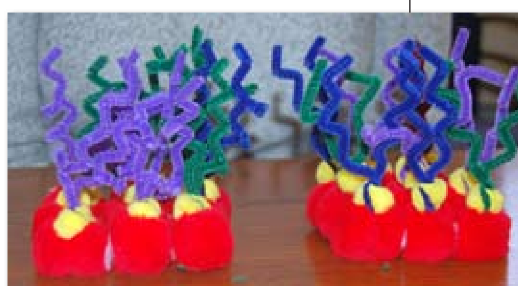


The large bottom pom-pom represents the hydrophilic phosphate group component of the membrane and the smaller, top pom-pom represents the glycerol it's attached to. Pipe cleaners are the hydrophobic lipid component.

Attach small velcro dots to the sides of the 'phospholipid' structure and stick them to each other in a square.



Bacteria have non-branched tails



To represent the branched lipid tails of the Archaea, cut pipe cleaners into smaller pieces and attach them to the tails.

To represent proteins present in the membrane, long, tubular straws are ideal. Encourage students to research the types of proteins associated with the lipid bilayer and brainstorm craft items that could represent them in their model.

When adding the straw proteins, be sure to represent those types of proteins that span the entire lipid membrane and provide conduits for transfer of molecules from the outside to the inside of the cell.

Image credit: Ruth Droppo

NSES
A-4
C-1

AAAS
5.C.1
5.C.2
5.C.8

activity 1 vocabulary exercise

Wordbank			
Aerobic	Bacteria	DNA	Phospholipid
Amino Acid	Biomass	Eukarya	RNA
Anaerobic	Cell Membrane	Extremophile	rDNA
Archaea	Chemolithotroph	Guanine	Ribosome
Astrobiology	Cytosine	Organelles	Thermophiles
Autotroph		Peptides	

Use the wordbank to complete these sentences. You will not use all words, and some words may be used more than once.

1 All life on Earth is assigned to one of three domains: **Archaea**, **Eukarya**, and **Bacteria**.

2 The majority of Extremophiles are found in the domain **Archaea**, but eukaryotic and bacterial extremophiles are known.

3 Proteins are made from chains of **amino acid** building blocks called **peptides**.

4 A single-stranded helical compound, **mRNA** is used by cells to convert genetic information into proteins.

5 A double-stranded helical compound, **DNA** stores the cells' genetic information.

6 **Astrobiology** is the study of the possibility of extraterrestrial life and the potential distribution of life in the universe.

7 **rDNA** is extracted from cells and is used to determine the placement of an organism within the phylogenetic tree of life.

8 Unlike bacteria and archaea, eukaryotic cells contain a nucleus and **organelles**.

9 All cells are enclosed by a **cell membrane**, a semifluid boundary made up of **phospholipids**.

Lesson Two: Cellular Metabolism

CONTENTS

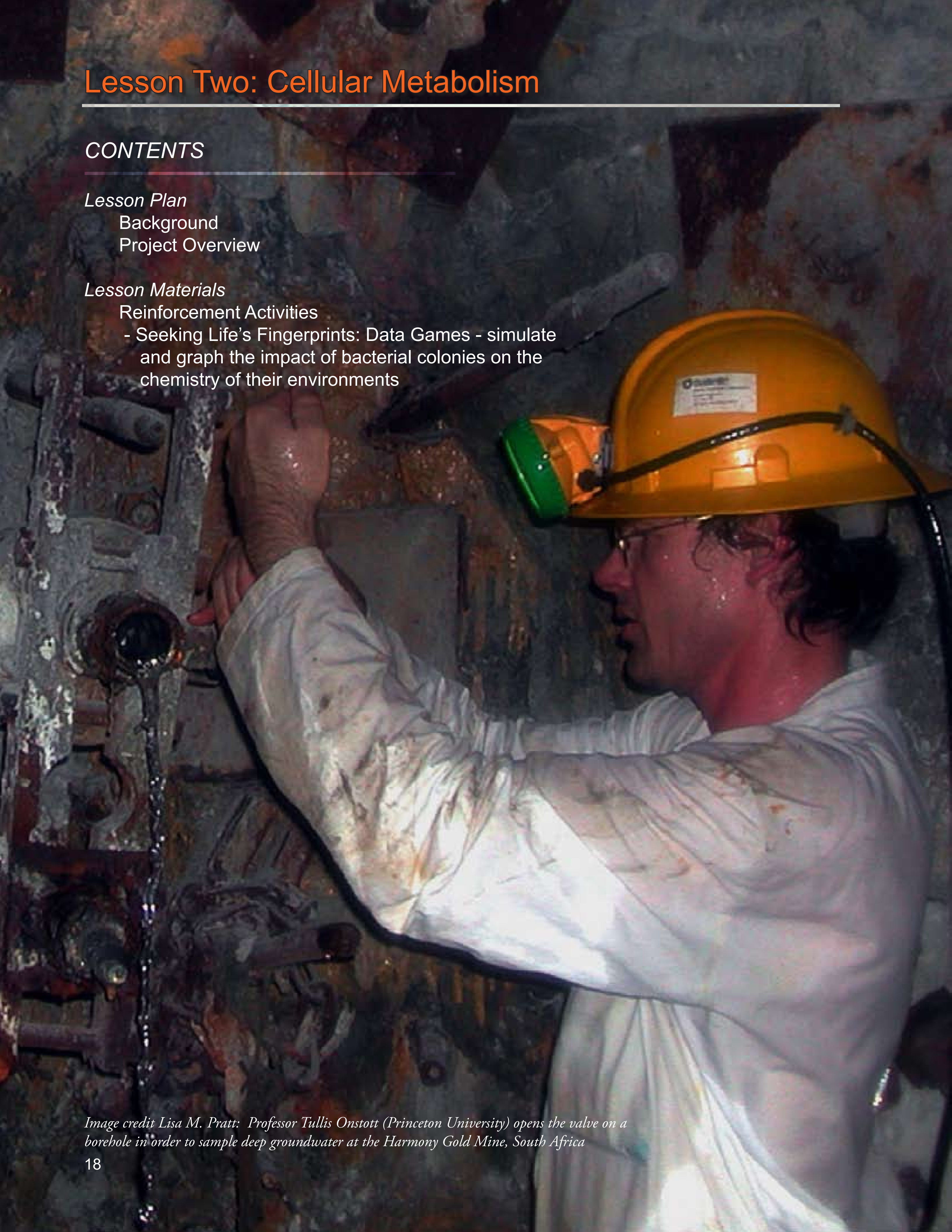


Image credit Lisa M. Pratt: Professor Tullis Onstott (Princeton University) opens the valve on a borehole in order to sample deep groundwater at the Harmony Gold Mine, South Africa

ON THE DVD: Cellular Metabolism

Dan McGown and Mark Davidson (Princeton University) describe how they look for evidence of microbes

Meet the Bacteria: Scanning Electron Microscope (SEM) images of South African deeplife bacteria

Image credit Susan Pfiffner: Dr. Corien Bakermans (Michigan State University) using a portable glove bag to transfer permafrost samples into culture tubes at High Lake Mine, Canada

Lesson 2

Cellular Metabolism

seeking life's fingerprints

Illustration of an archaeal cell

SUMMARY :

Students examine processes in cellular metabolism. They explore both direct and indirect evidence for fingerprints of life.

The numbers for the relevant National Standards and Benchmark Standards are noted in the margins.

Lesson 2

Pre-Activity Exercise

assessing prior knowledge and misconceptions

Below are three boxes. In the box labeled "K," write down everything you currently know about the topic. In the "W" box, make a list of things you do not know about the topic, but would like to learn. Leave the "L" box blank for now. After completing the exercises, fill in what you have learned from the background reading and activities.

TOPIC

Cell Metabolism & Chemistry – Please describe everything you know about atoms, ions, and bonding. In addition, write down any information you know about cellular metabolism.

K

W

L

Lesson 2

Pre-Activity Exercise

assessing prior knowledge and misconceptions

Pre-Activity Questions

Directions: Read the background materials titled "Lesson 2: Project Overview" and "Activity 2: Introduction to Data Games."

Answer the questions below in the space provided.

1 Due to the extreme conditions in which some DSSOs live, it is difficult to detect them with traditional lab techniques (microscopes, culturing, etc.). Given that fact, how can scientists detect their presence? Answer: ***Their presence must be inferred from the influence of metabolism on the environment.***

2 What happens to atoms when they become ions? When will an ion be negative? Positive? Answer: ***Ions will be negative if they gain electrons and positive if they lose electrons. They lose or gain electrons so they have an unequal number of protons and electrons.***

3 When sulfate accepts electrons it converts to the product **sulfide**.

4 A system can support a stable population of microbes when a **balance** is reached.

Questions for Discussion

1 What do you think metabolism is? Why do you think cells need to conduct metabolic processes?

2 Waste products of an organism can be used to detect the presence of a living organism. If you were walking in the woods, even if you couldn't see the many animals that are present how could you tell they were there?

3 Balance within ecosystems is really important. What do you think would happen to populations if that balance was disturbed?

Lesson 2 Background

Figure 2.1: Lisa Pratt (Indiana University) backflushing cells on filters to collect biomass samples from deep groundwater in Lupin gold mine, Nunavut Territories, Canada. Note the use of gloves to minimize contamination from hands. Image credit: Lisa M. Pratt

Individual bacteria and archaea are too small to see with the naked eye. On Earth's surface scientists often collect samples of bacteria and/or archaea, and grow them using specialized culturing techniques. Once scientists have a sufficient colony of organisms it is easy to study them under a microscope. Although some Deep-Subsurface Organisms (DSSOs) can be grown, there are many that cannot be cultured in a laboratory. Low levels of nutrients and energy are available to organisms in the deep subsurface. Populations of DSSOs are often orders of magnitude lower than in surface environments. Environmental conditions in the deep subsurface are markedly different from the surface. Scientists are often unable to replicate ideal environmental conditions for DSSOs in the laboratory, and that prevents DSSOs from growing and reproducing.

Many regions of the subsurface are inaccessible, and sample collecting is not possible. For example, DSSOs tightly attached to rock and mineral surfaces in an underground fissure may stay attached and hidden even if water in the fissure is sampled. If scientists cannot directly sample DSSOs, then the existence of DSSOs must be inferred from the influence of metabolism on the environment. The consumption of specific nutrients or addition of waste products will change the environment and indicate the presence of hidden life. The following student activity illustrates this point.

NSES
A-7
A-9
C-2
C-23
C-24
E-1
E-2
E-3
G-4
AAAS
1.A.1
1.B.1
1.B.3
1.B.4
5.C.7
5.D.1
5.D.2

activity 2 project overview

ASTROBIOLOGY

In the search for life on other planets, it is important to know what we should be looking for. Since we are familiar with life on this planet it follows that studying organisms in similar environments here might give us an idea of what kind of clues might be left by extraterrestrial life. Other planets in our solar system, such as Mars, are very harsh environments for life. On our planet, similarly harsh environments are inhabited by extremophiles: organisms that thrive in hot, dry, salty, alkaline, acidic, or very cold conditions. While most extremophiles are found in the bacterial or archaeal domains, there are eukaryotic species that survive in these environments as well. Though much less common, ciliates such as *Metapus contortus* have been discovered living in the hot and acidic environments of deep sea hydrothermal vents. By studying the extremophiles and their effect on their surroundings on our planet, we have an idea about where to look for life on other planets, as well as how to identify signs of life when we encounter it.

Figure 2.2: Microbial colonies sampled from hot springs in Warner Valley Oregon showing distinct differences in pigment colors. Image credit: Ruth Droppo

PURPOSE

This lesson is designed to introduce students to how scientists can use evidence of cellular metabolism to detect life. The lesson attempts to present the material in a straightforward way. Cellular structure and metabolism are basic concepts students need to explore in order to understand modern astrobiology. How life functions on Earth is one of the guiding principles for determining how to search for life on other planets. Students should be able to distinguish the basic structural differences between eucarya, bacteria, and archaea, as well as explain how scientists use chemical signatures to determine if life is active in an environment.

Figure 2.3: Green filamentous colonies of microbes from hot springs in Warner Valley Oregon. Image credit: Ruth Droppo

activity 2 project overview

NOTES TO TEACHERS:

Figure 2.4: Marina Antonio, a graduate student in Dr. Carl Bauer's lab in the Biology Department at Indiana University, samples individual colonies of Eschericia coli (E. Coli). Image credit: Ruth Droppo.

Before beginning "Lesson 2: Cellular Metabolism," students should be familiar with basic chemistry concepts (ions, molecules) as well as the broad concepts of cellular metabolism. The background information provided in this lesson is intended for enrichment and review.

It is probably best to introduce the basic characteristics of a cell and its metabolic functions before presenting the materials included here. Vocabulary exercises will allow students to discuss and correlate ideas throughout the lesson.

Alternative assignments and vocabulary worksheets introduce students to ideas presented in the DVD, and give them a way to work through concepts like cellular structure, which are often more straightforward than metabolic needs and energy recruitment.

Questions in these assignments attempt to help students understand the basics of cellular structure and metabolism. In a simple, hands-on approach, the activity simulates bacterial preference for a particular nutrient in the form of an ion in solution. Most lithotrophic organisms are highly selective of the basic chemical compounds they use as energy or carbon sources.

Student learning objectives for this lesson are:

- To learn what deep-subsurface organisms are and why they are important
- To explore how scientists study these organisms
- To learn about the metabolic "fingerprints" left by living organisms and why they are important to astrobiology

In this activity the students "consume" ions in a manner simulating bacterial selectivity. By examining changes in abundance ratios, students are able to collect data similar to the type of data astrobiologists use in determining the presence or absence of life. The lab requires students to calculate, create graphs and record data, and make predictions about their results.

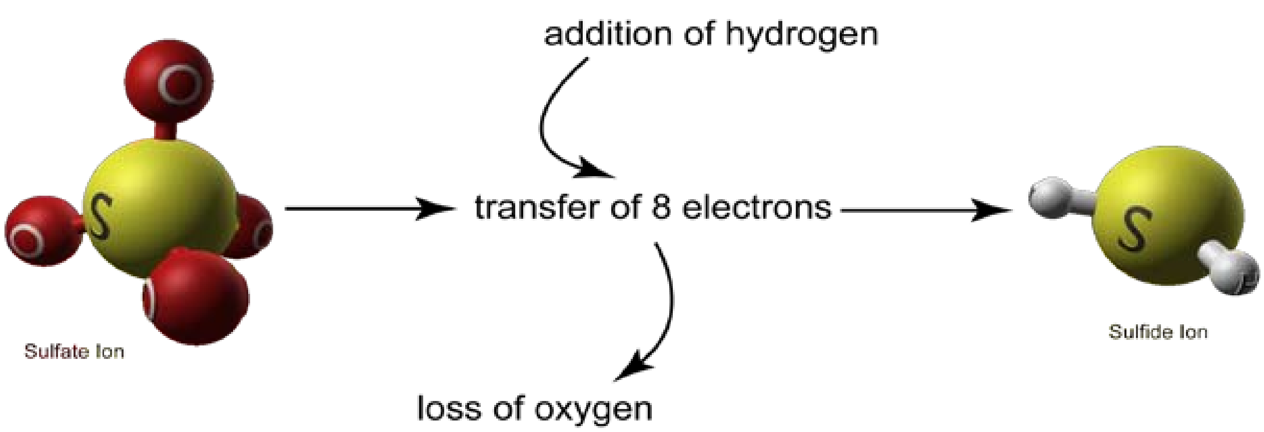
activity 2 data games

INTRODUCTION

Ions are atoms with slight electrical charges. These charges occur because ions have an unequal number of protons and electrons. Protons have a positive charge and electrons have a negative charge. If an ion has more electrons than protons it will have a negative charge. If it has fewer electrons than protons it will have a positive charge. Ions often bond with atoms or other ions to form either ionic compounds or molecules. Ionic compounds retain a net electrical charge. In a molecule, charges are balanced and there is no net charge.

Ionic compounds are used by microbes to power the reactions required to build and repair cellular structures. Microbes use different compounds in different ways. Cells can extract energy by transferring electrons from one ion to another, changing its chemical properties and converting it into a different ion. A common example of this type of reaction is the reduction of sulfate to sulfide. In this case, sulfate (SO_4^{2-}) accepts electrons which convert it into the product, sulfide (H_2S). In sulfate ions, the sulfur atom is stabilized by the presence of four oxygen atoms. As the ion takes up electrons, the oxygen bonds become weakened and the sulfur atom becomes

NSES
B-1
B-2
B-7
B-11
B-13
C-1
C-2
C-15
C-17
C-18
C-23
D-5



stabilized by bonding to two hydrogen atoms. This reduced product is called sulfide (H_2S). As sulfate is reduced, energy is released that the microorganism can then use to drive other necessary cellular processes. A balance is reached when compounds are converted back and forth by two or more groups of microbes. Once the balance is reached, relatively stable concentrations of both compounds are maintained and the system supports a stable population of microbes. The following activity illustrates this point.

AAAS
4.D.1
4.D.2
4.D.7
4.G.3
5.C.5
5.E.2

Figure 2.3: illustration of ion transfer between sulfate and sulfide

activity 2 data games

MATERIALS

1 40 small marbles, each of two different colors and 50 of a third color. Other possible choices: cereal, colored candies, game chips.

2 One 1/8 cup measure (27.57 ml)

3 One small paper bag

4 Data tables and graphs (supplied with this lesson, or students can record and graph their data on a computer using an Excel spreadsheet or other graphing software).

Note: In these instructions we use 50 yellow, 40 green, and 40 red marbles as examples. Other colors may be substituted.

INTRODUCTION

Each of you will represent a bacterial population in the Earth's Deep Subsurface environment. Just like any other living organism you require energy and cannot live in an environment without your food source.

Bacteria A: The player who represents Bacteria A consumes sulfate and through its metabolic process produces sulfide.

Bacteria B: The player who represents Bacteria B consumes sulfide and through its metabolic process produces sulfate.

THE GAME'S ENVIRONMENT

Sulfate and sulfide are ionic compounds utilized as nutrients by microbial communities. Chloride ions are common in aqueous environments but are not nutrients. The game environment will start out with all sulfate and no sulfide ions. Therefore, Bacteria B cannot survive the game environment until there is enough sulfide to support Bacteria B.

The 40 green marbles will represent sulfate, 40 red marbles will represent sulfide, and 50 yellow marbles will represent chloride ions.

Start by separating out all the red marbles and setting them aside. Put all the green and yellow marbles into the paper bag. Shake the bag so the marbles are well mixed.

AAAS
5.E.2
5.E.3
4.D.9

activity 2 data games

HOW TO PLAY THE GAME

- 40 green marbles = 40 sulfate ionic compounds.
  50 yellow marbles = 50 chloride ions.
  These 90 marbles will be added to the bag provided to start the game.

- **Bacteria A (Player A)** will scoop out marbles using the measuring device provided. Since Bacteria A metabolizes sulfate into sulfide, Bacteria A will replace the green marbles with the same number of red marbles.

- Return the marbles to the bag.

UPDATE YOUR DATA TABLE

Update the data table: record any changes in the numbers of marbles of different colors in the bag. If 4 green marbles were removed and replaced with 4 red marbles, then the data table should read 36 green, 50 yellow, and 4 red marbles.

NEXT ROUNDS

- **Bacteria B (Player B)** will scoop out marbles with the measuring device provided. Since Bacteria B consumes sulfide, any red marbles that are pulled out will be removed. In addition, Bacteria B produces sulfate so the number of red marbles pulled out will be replaced with green marbles.

- Update your data table: Subtract the number of red marbles removed and add the number of green marbles put back.

The game continues in the same way, with the players updating their data tables after each turn.

activity 2 scorecard - table 1

UPDATE YOUR DATA TABLE

Update your data table:
The game continues in the same way, with the players updating their data tables after each turn.

Round		Number of Marbles in Bag		
		Green	Yellow	Red
1	player A's turn			
	player B's turn			
2	player A's turn			
	player B's turn			
3	player A's turn			
	player B's turn			
4	player A's turn			
	player B's turn			
5	player A's turn			
	player B's turn			
6	player A's turn			
	player B's turn			
7	player A's turn			
	player B's turn			
8	player A's turn			
	player B's turn			
9	player A's turn			
	player B's turn			
10	player A's turn			
	player B's turn			
Ending Amounts				

NSES
A-2
A-3
A-10

AAAS
2.B.1
12.D.7

activity 2 scorecard - table 2

YOU CAN DISRUPT THE ECOSYSTEM

- Record the ending amount for each category from the previous table.

- Remove 90% of the marbles that are either red or green (sulfide or sulfate), NOT yellow, and observe what happens to the colony.

- Continue play as normal and observe what happens

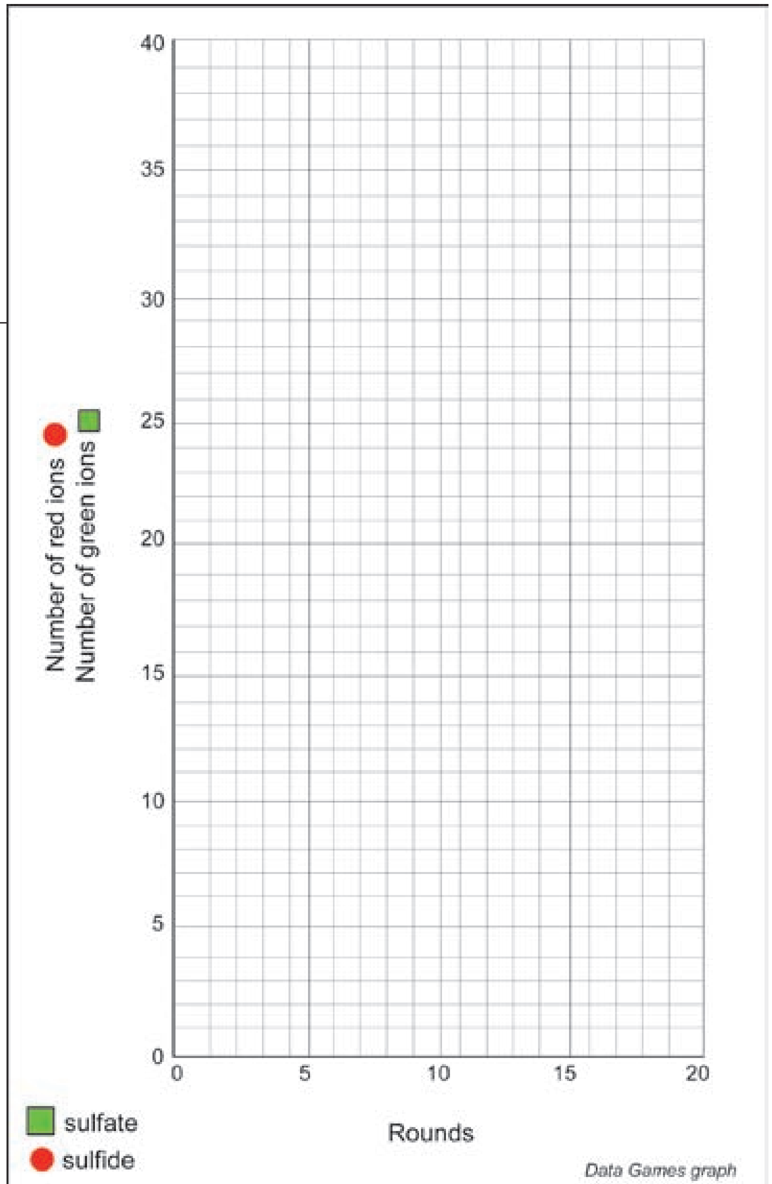
Round		Number of Marbles in Bag		
		Green	Yellow	Red
Ending Amounts from Table 1				
1	player A's turn			
	player B's turn			
2	player A's turn			
	player B's turn			
3	player A's turn			
	player B's turn			
4	player A's turn			
	player B's turn			
5	player A's turn			
	player B's turn			
6	player A's turn			
	player B's turn			
7	player A's turn			
	player B's turn			
8	player A's turn			
	player B's turn			
9	player A's turn			
	player B's turn			
10	player A's turn			
	player B's turn			

NSES
A-2
A-3
A-10

AAAS
2.B.1
12.D.7

activity 2 graph it!

MAKE TWO GRAPHS



- Use all data collected from both tables 1 and 2 to make two graphs
- If Excel is accessible to you, create an Excel file with a worksheet for each of the data tables.
- Next, create a graph of the tables, using different colored lines for the sulfide and sulfate ions. Print your Excel graphs and tables and turn them in. If Excel or a computer is not available, use the paper graph that is supplied with your materials.
- The first graph should show the changes in the number of marbles of each color over time. This graph depicts the chemistry of the system.
- The second graph should show the changes in the number of bacteria.
- On both graphs mark the point at which the ecosystem disruption occurred

NSES
A-2
A-9
A-10

AAAS
2.B.1
12.B.5
12.D.7
12.E.2

activity 2 thought questions

QUESTIONS FOR THOUGHT AND DISCUSSION

1 What happened to the numbers of red and green marbles? Describe below.

2 What you described above is called equilibrium. Equilibrium is a stable situation in which products and reactants are balanced. In our game environment, this means the number of sulfate and sulfide ions are relatively stable. Why do you think equilibrium is important in this environment?

3 How long did it take to reach equilibrium again after the disruption?

4 What role do you think chloride plays in this ecosystem?

5 Sulfate tends to be more prevalent than sulfide in marine (ocean) sediments. If you collected ocean sediments that contained a lot of sulfide but little sulfate, what might that suggest?

6 Suppose you started out with 80 chloride ions and only 20 sulfate compounds. How would that affect the growth of the system? Do you think it would take more or less time for the system to stabilize? Why? If possible, test this and see if your prediction was correct.

NSES
A-10
A-11
C-15
C-17
C-18
C-14
G-4

AAAS
12.B.5
12.D.7

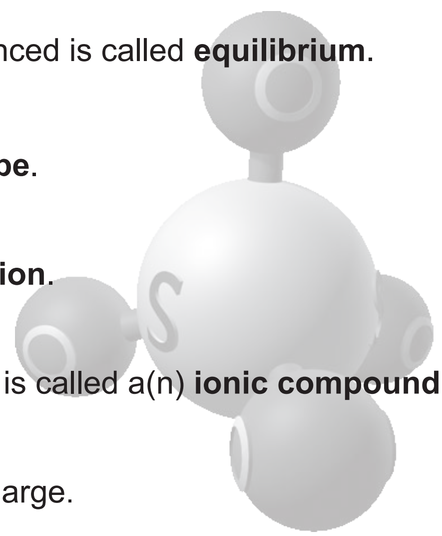
activity 2 vocabulary exercise/answer key

Wordbank

Aerobic	Bacteria	Electrons	Membrane
Amino Acid	Biomass	Equilibrium	Microbe
Anaerobic	Cell Membrane	Flagella	Oxygen
Archaea	Cytosine	Heterotroph	Protons
ATP	DNA	Ion	Sulfate
Autotroph		Ionic Compound	Sulfide

Use the wordbank to complete these sentences. You will not use all words, and some words may be used more than once.

1 A stable situation in which products and reactants are balanced is called **equilibrium**.



2 A general term for any microscopic organism is a(n) **microbe**.

3 When an atom has lost or gained electrons it is called a(n) **ion**.

4 A charged molecule formed by an ion bonded to other ions is called a(n) **ionic compound**.

5 The **electron** is a subatomic particle that has a negative charge.

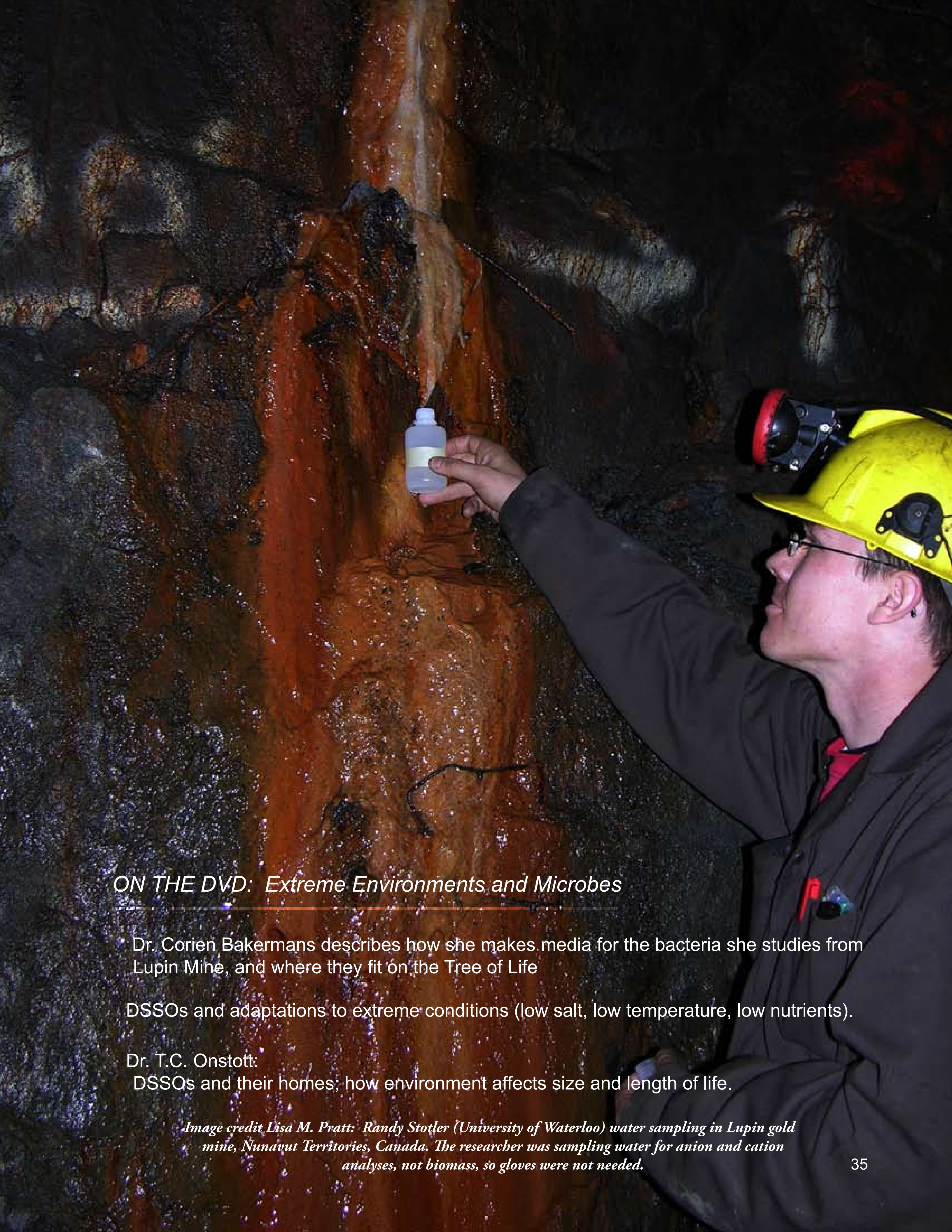
6 Sulfate is converted to **sulfide** through the transfer of eight **electrons**.

7 When sulfate converts to sulfide hydrogen is added and **oxygen** is lost.

LESSON 3: EXTREME ENVIRONMENTS AND MICROBES

CONTENTS

Image credit Lisa M. Pratt: Water sampling in Lupin gold mine, Nunavut Territories, Canada.
The researcher was sampling water for anion and cation analyses, not biomass, so gloves were not needed.



ON THE DVD: Extreme Environments and Microbes

- Dr. Corien Bakermans describes how she makes media for the bacteria she studies from Lupin Mine, and where they fit on the Tree of Life

DSSOs and adaptations to extreme conditions (low salt, low temperature, low nutrients).

Dr. T.C. Onstott:
DSSOs and their homes; how environment affects size and length of life.

Image credit Lisa M. Pratt: Randy Stotler (University of Waterloo) water sampling in Lupin gold mine, Nunavut Territories, Canada. The researcher was sampling water for anion and cation analyses, not biomass, so gloves were not needed.

Lesson 3

Extreme Environments and Microbes

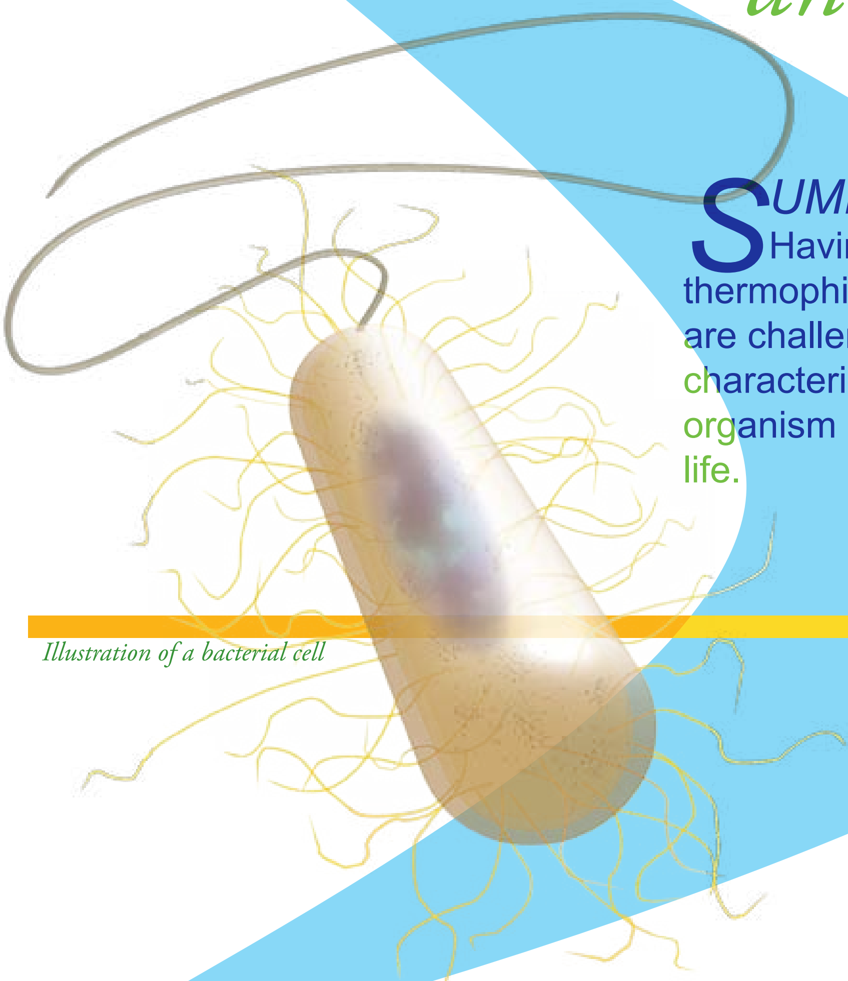


Illustration of a bacterial cell

SUMMARY:
Having just discovered a new thermophilic organism, students are challenged to describe its characteristics and place that organism in the phylogenetic tree of life.

The numbers for the relevant National Standards and Benchmark Standards are noted in the margins.

Lesson 3

Pre-Activity Exercise

assessing prior knowledge and misconceptions

DIRECTIONS

Below are three boxes. In the box labeled "K," write down everything you currently know about the topic. In the "W" box, make a list of things you do not know about the topic, but would like to learn. Leave the "L" box blank for now. After completing the exercises, fill in what you have learned from the background reading and activities.

TOPIC

Phylogenetic Trees – Write down any information you know about how biologists determine organisms' relationships to each other. Think about what structures or traits might they use to determine relatedness.

K

W

L

Lesson 3

Pre-Activity Exercise

assessing prior knowledge and misconceptions

Pre-Activity Questions

Directions: Read Lesson 3 Background: Extremophiles and Lesson 3 Background: Phylogenetic Trees.

Answer the questions below in the space provided.

1 Give at least three types of extremophiles and describe why they are listed as extremophiles. Answer: ***Could be any of the various bulleted points under Lesson 3 Background: Extremophiles.***

2 When a new extremophile is discovered what do they do with its genetic code? Answer: ***Use it to determine the similarity or difference between this organism and other known organisms.***

3 Why do biologists use DNA sequences to determine how related two organisms are to one another and not some other molecule such as RNA? Answer: ***Because the DNA sequences are all of the directions needed to build the cell's proteins.***

4 What are the three major limbs that make up the phylogenetic tree of all living organisms? Answer: ***Bacteria, Archaea, Eukarya.***

5 Why do scientists use rDNA to sequence for phylogenetic trees? Answer: ***Genes that code for ribosomes (rDNA) are present in all living things and due to the fact that they all share this set of DNA we can use differences in the sequence to tell how long two species have been divergent.***

6 What is the LUCA? Answer: ***The Last Universal Common Ancestor, now extinct, is an ancestor species to two or more living species.***

Questions for Discussion

1 What might cause one species to break into two species instead of just evolving into one other species?

2 When we say "two organisms are related" what do you think we are actually referring to?

3 Why do you think it is important for biologists to build phylogenetic trees?

Lesson 3

Background: Extremophiles

Our understanding of the conditions needed to support life has changed considerably in the past thirty years. Scientists are now looking for microbes in environments previously assumed to be too hot, cold, acidic, alkaline, salty or dry to support life, and new forms of life are being discovered with surprising frequency. These new life forms are called extremophiles.

Some examples of extremophiles are:

- Thermophiles – organisms found living at temperatures between 60ºC (140ºF) and 80ºC (176ºF).
- Hyperthermophiles – organisms that can live at temperatures above 80ºC (176ºF). The upper limit for a hyperthermophile is uncertain, but organisms have been discovered that can live at temperatures in excess of 120ºC (248ºF) if there is enough pressure to keep water from boiling.
- Acidophiles – organisms that live in acidic environments with pH below 3.
- Alkaliphiles – organisms that live in alkaline environments with pH above 9.
- Halophiles – organisms that live in sea water environments.
- Barophiles – organisms that live under great pressure. Sometimes called piezophiles.
- Psychrophile – organisms that live at or near the freezing point of water. Sometimes called cryophiles.
- Xerophiles – organisms that live in persistently dry environments.

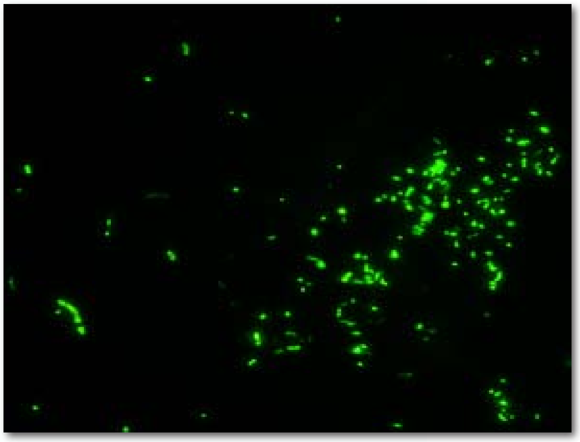


Figure 3.1. Intact prokaryotic cells recovered by filtration of ground water at a depth of 1130 meters below the surface in the Lupin gold mine, Nunavut Territories Canada. Cells occur in clumps and exhibit diverse morphologies. Cells were enumerated using a green fluorescent dye.

There are also polyextremophiles, which can withstand more than one extreme condition. *Deinoccocus radiodurans*, for example, can survive extreme heat, cold, acidity and radiation, including up to 1,000 times the amount of UV radiation normally fatal to humans.

When scientists discover a new extremophile, the genetic code is used to determine the similarity or difference between this organism and other known organisms. Surprisingly, many extremophiles appear to be genetically similar to previously known, non-extremophilic organisms. It is possible that, by comparing specific genetic sequences in extremophiles with their non-extremophilic relatives, genes can be identified for tolerance to heat, cold, acidity or other conditions. When analyzing an organism's genetic code, scientists look at the sequence of nucleotides. These are the basic structural units of DNA and RNA. Nucleotide sequences are the directions to build proteins. Because the sequence of nucleotides directs all cell functions, biologists use DNA sequences to determine how related two organisms are to one another. Even small differences in a nucleotide sequence will result in substantial differences in a protein's shape and function.

NSES
C-3
C-4
C-7
D-5
D-6

AAAS
5.C.4
5.C.7
5.C.8
5.F.4

Lesson 3

Background: Phylogenetic Trees

Archaea, bacteria, and eukarya make up the major limbs of the phylogenetic tree, a branching diagram that represents a hypothesis about evolutionary relationships. The tree of life organizes all living things based on their similarity or difference. The closer together two organisms are on the tree of life, the more closely they are related. The question is how do we construct this tree? Do we use physical characteristics? Chemical characteristics? To construct a phylogenetic tree, scientists use the DNA sequence of specific genes. Since all living things must synthesize proteins, living cells must contain ribosomes. The cells have to make their own ribosomes, therefore the genes that encode for the RNA components of these organelles must be present in all organisms. This ribosomal DNA (rDNA) is present in the cell's genome and small variations in its genetic code, or mutations, can be analyzed to determine the difference between species. The sequence of bases is statistically compared to determine the level of similarity or difference between two studied organisms. Organisms that have similar rDNA sequences are little changed from a common ancestor and have not accumulated mutations that greatly alter their rDNA. Organisms that have very different rDNA are more divergent and will have more mutations in their sequences. The distance between two organisms along the phylogenetic tree of life is proportional to the difference between their rDNA sequences.

NSES
C-3
C-7
C-10
C-11
C-13
C-14

AAAS
5.A.2
5.C.4
5.F.1
5.F.2
5.F.4
5.F.8
5.F.9

It is worth noting that in this case our tree appears to be rootless. That is, the archaea, eukarya, and bacteria all diverge from a common point. This indicates the presence of a last universal common ancestor (or LUCA). The LUCA is an organism that is the precursor from which all the known domains, and therefore all life, is descended. Although this ancestor no longer exists as an identifiable species, we know that it must have had characteristics shared by the three existing domains. In simplest terms, the LUCA would have been a single-celled organism surrounded by a membrane and possessing the instructions for making proteins in its DNA. The LUCA is, in fact, the organism from which all life on Earth evolved. Remember, the tree reflecting our current knowledge of life has three domains: the eukarya, the bacteria, and the archaea. As of now, these domains include all life as we know it on our planet. The eukarya are distinguished by the presence of a nuclear membrane around their DNA and by the way they store and retrieve information from their genomes. The bacteria and archaea do not have internal membranes and store their genetic information in a continuous circular molecule of DNA. However, the archaea are unique in that they utilize their DNA in a way that more closely resembles eukaryotic cells than bacterial cells.

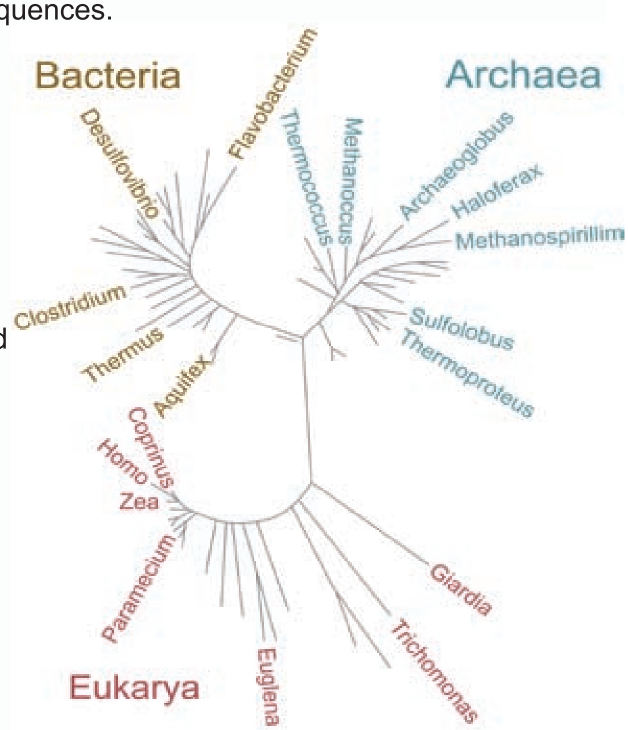


Figure 3.2: Dr. Karl Woese's 3-domain tree of life diagram as constructed by Dr. Norman Pace

activity 3 project overview

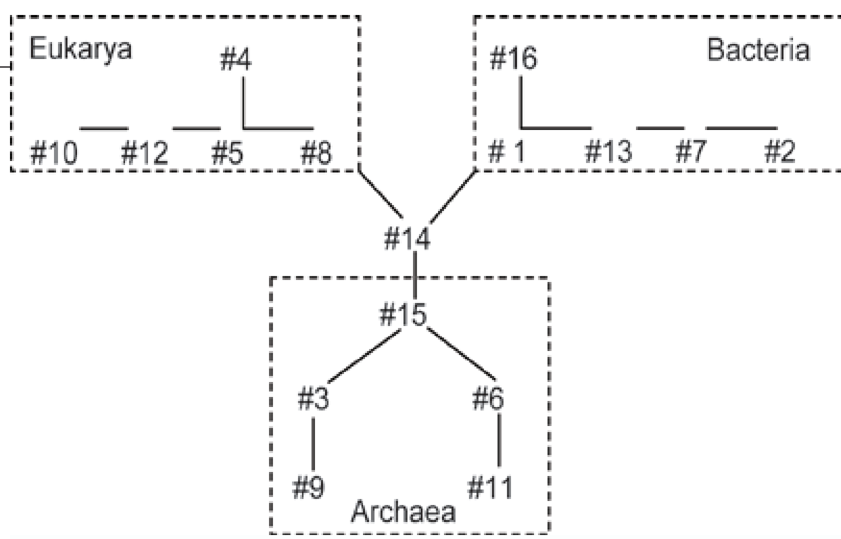
NOTES TO TEACHERS

Before beginning "Lesson 3: Extreme Environments and Microbes," students should be familiar with basic microbiology and genetics. Students should also know that life evolves and changes over time.

Student learning objectives for this lesson are:

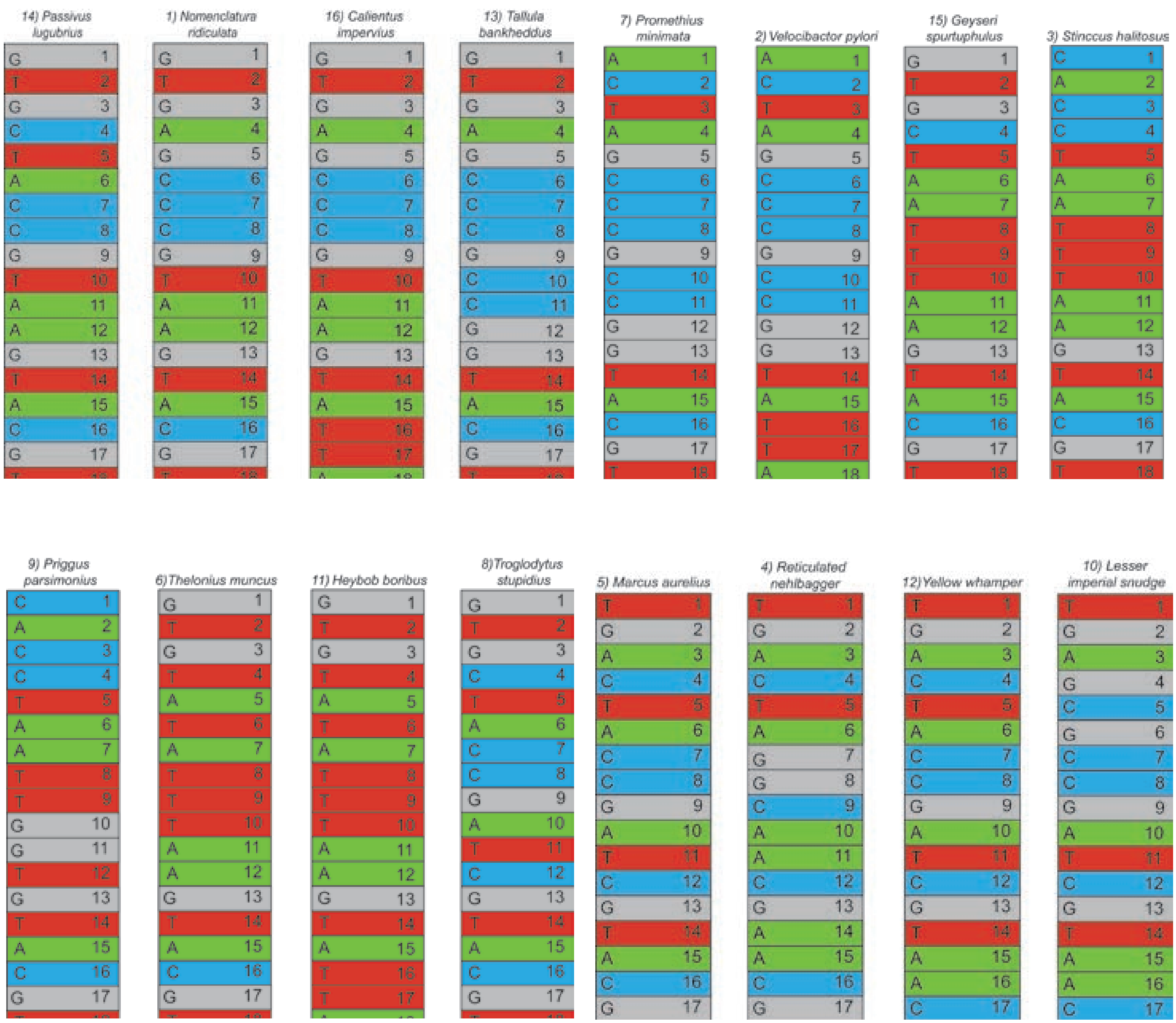
- To learn about extremophiles and their importance to astrobiology
- To learn and understand how scientists determine evolutionary relationships
- To understand what a phylogenetic tree is and how it is constructed

- Print out the file "Extremophiles_chart.pdf" (found in "Supplemental Materials" on the accompanying CD). You will need one chart for each student.
- The students should color the sequences according to the Extremophiles 1, 2, 3, and 4 models on page 42 of this workbook. The original models are also included as .pdf documents in your Supplemental Materials CD, if you wish to print them on a color printer.
- Separate the 16 different rDNA sequences by cutting between them, keeping the name and number of the organism with the sequence. (The numbers were assigned randomly and have no relationship to their placement within the tree of life.)
- Start by giving the organisms 1-15 to the students. Once they have arranged these organisms on the tree of life template—this will likely take 25 to 30 minutes—and answered the first two questions, give them the sequence for *Calientus impervius* (16) and have them complete the assignment.
- The completed tree should look like the tree below. The numbers refer to the number of the organism.



activity 3 project overview

rDNA SEQUENCE MODELS



activity 3 build a tree of life

EVALUATIONS

Organisms can evolve in straight lines:

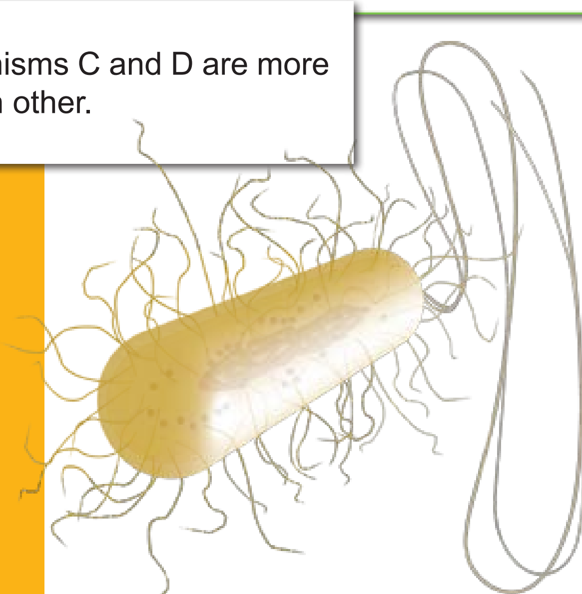
Organism A → Organism B → Organism C → Organism D

Or by branching:

Organism A → Organism B → Organism C

Organism B → Organism D

In the branching example Organisms C and D are more closely related to B than to each other.



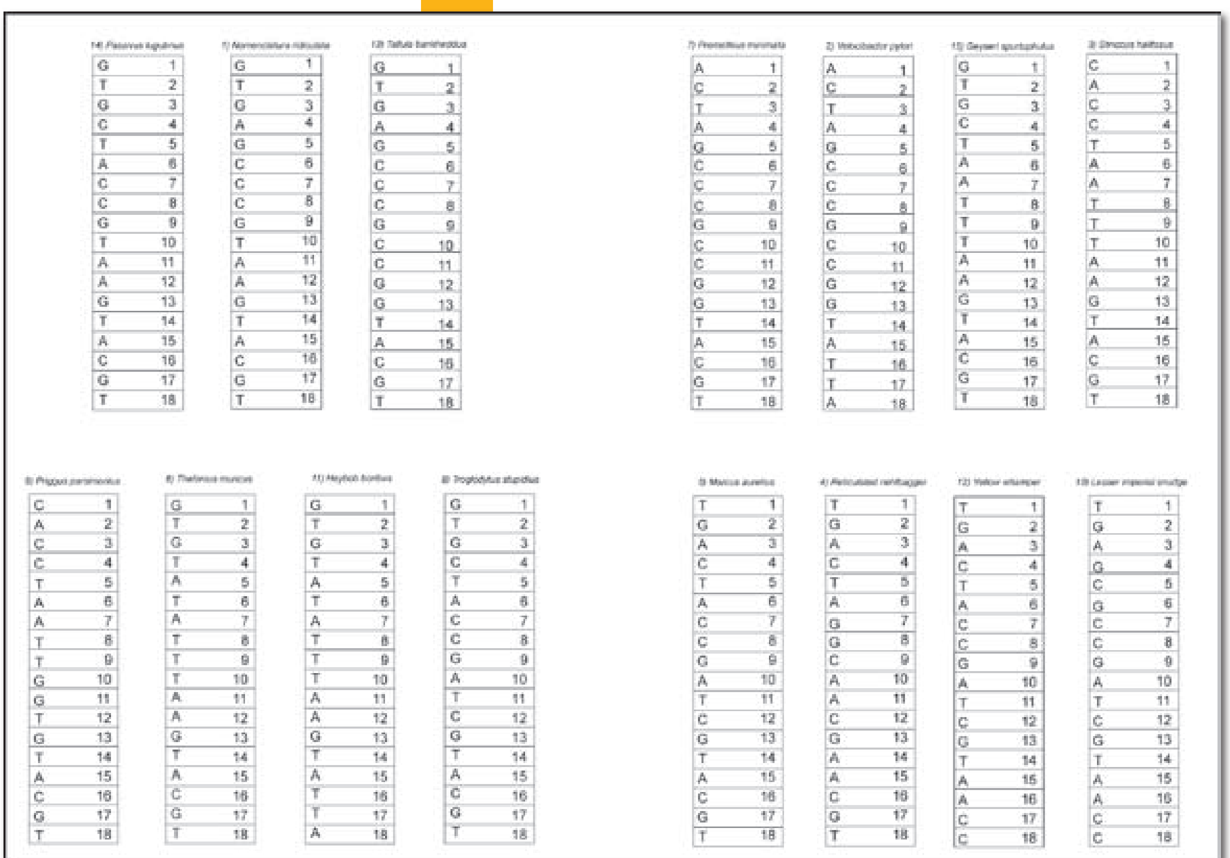
NSES
C-10
C-14

AAAS
5.F.1
5.F.2
5.F.8
5.F.9

activity 3 build a tree of life

YOUR ASSIGNMENT

1 You will receive rDNA sequences for 15 different organisms from your teacher. Arrange the organisms into a “Tree of Life” according to similarities in their rDNA code. Your “tree” will look similar to, but much simpler than, the Tree of Life shown on the DVD and in earlier lessons. Organisms with similar rDNA should be close together in the tree, and organisms with dissimilar rDNA should be farther apart. (The numbers next to the name of the organism were assigned randomly and have no relationship to their placement within the tree of life.) Color your DNA sequences as follows: grey = G, blue = C, red = T, green = A. Next, cut out your DNA sequences.

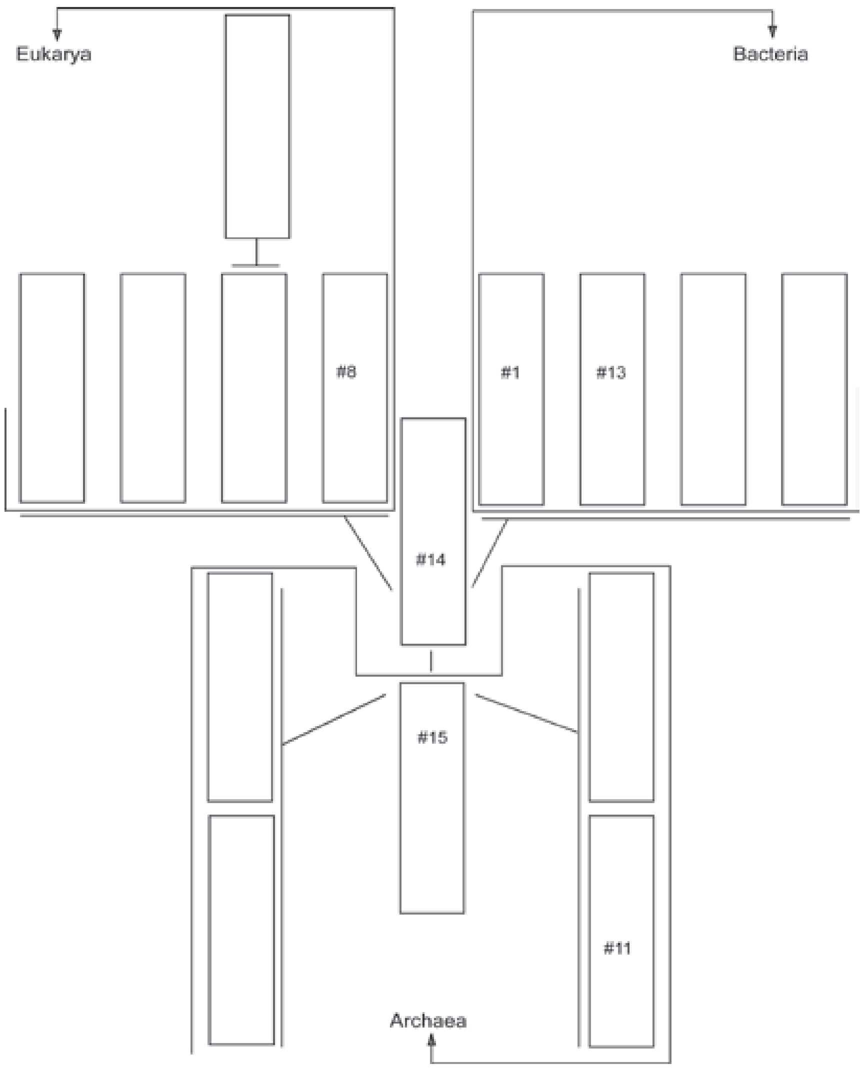


NSES
A-4
A-11
C-7
C-9
C-14

AAAS
5.A.2
5.B.3
5.B.4
5.F.2
5.F.4

activity 3 build a tree of life

2 Use the tree template to place the corresponding species on their assigned numbers in the phylogenetic tree. Look at the remaining 9 rDNA sequences, find the organisms that seem to be most closely related, group them together and place them on the tree where you think they best fit.



Notes: Each organism has at least one nucleotide different from every other organism. These differences arise from mutations. In this assignment, organisms next to each other may differ by one or more nucleotides. In reality, even closely related species can have thousands of nucleotides that differ from one another! The numbers next to the name of the organism were assigned randomly and have no relationship to their placement within the tree of life.

NSES
A-4
A-5
C-9
C-10
C-14

AAAS
5.A.2
5.B.4
5.F.2
5.F.1
5.F.5
5.F.8
5.F.9
12.D.7

3 When you think you have the correct tree call your teacher over to check it.

activity 3 build a tree of life

EVALUATE THE EVIDENCE

You have just discovered a new organism!

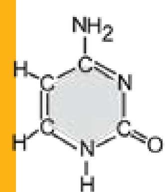
It was found in a water sample collected from a fissure deep below Earth's surface. The temperature of the water in the fissure is approximately 140°F (60°C), so you describe the organism as a thermophile—an organism that thrives in very hot environments—and give it the name *Calientus impervius*. You want to determine what its nearest relative is and whether it should be classified as bacteria, archaea or eukaryote. To do this you will examine its rDNA and try to match it up with other known organisms.

You have the rDNA sequences for 15 known organisms and for your specimen. You will need to assemble a tree of life for the 15 organisms and figure out where *Calientus impervius* belongs in the tree.

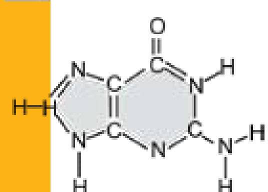
16) *Calientus impervius*

G	1
T	2
G	3
A	4
G	5
C	6
C	7
C	8
G	9
T	10
A	11
A	12
G	13
T	14
A	15
T	16
T	17
A	18

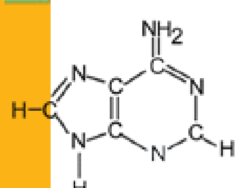
Cytosine



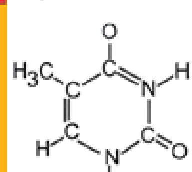
Guanine

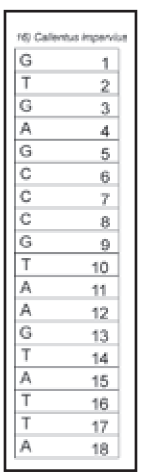


Adenine



Thymine





cut me out!

NSES
A-4
A-5
C-9
C-10
C-14

AAAS
5.A.2
5.B.4
5.F.2
5.F.4
5.F.1
5.F.5
5.F.8
5.F.9
12.D.7

activity 3 build a tree of life

CHALLENGE QUESTIONS AND ANSWER KEY

1 Determine where Calientus impervius belongs in the tree of life. Does it belong in the bacteria, archaea or eucarya domain? What organism is its closest relative?

ANSWER:	
Domain:	Bacteria
Nearest Relative:	#1

2 It turns out that one of the organisms in your tree of life does not belong in the bacteria, archaea, or eukaryote domains. This must be the last universal common ancestor (LUCA)—that is, the one organism that all the other organisms branched off from. Identify the LUCA. It should be more or less in the center of your tree of life.

[Note: in the real world, we have no idea what the LUCA is. There is currently much speculation about what the LUCA might have been like.]

ANSWER:
LUCA = #14

NSES
A-4
A-5

AAAS
12.D.7

activity 3 build a tree of life

CHALLENGE QUESTIONS AND ANSWER KEY

3 *Priggus parsimonius* and *Stinccus halitosus* are both halophilic, meaning that they both thrive in very salty environments. There are no other halophilic organisms in the tree of life. Identify the gene for halophilia.

Position #	Original Base	Mutated Base
1	G	C
2	T	A
3	G	C

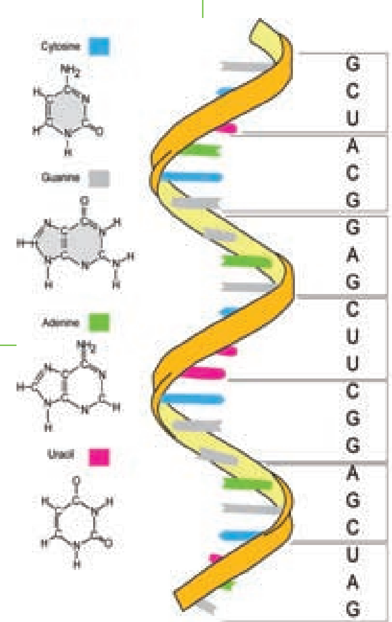
4 *Calientius impervious* is thermophilic—it thrives in very hot environments—but *Nomenclatura ridiculata* is not.

a) Identify the mutation that may have led to thermophilia.

Position #	Original Base	Mutated Base
16	C	T
17	G	T
18	T	A

b) Based on the above information what other organism is likely to be thermophilic?

ANSWER:
#11



mRNA
Ribonucleic acid

mRNA/DNA images adapted from: National Human Genome Research Institute. Talking Glossary of Genetic Terms. Available at: www.genome.gov/Pages/Hyperion//DIR/VIP/Glossary/Illustration/ma.shtml

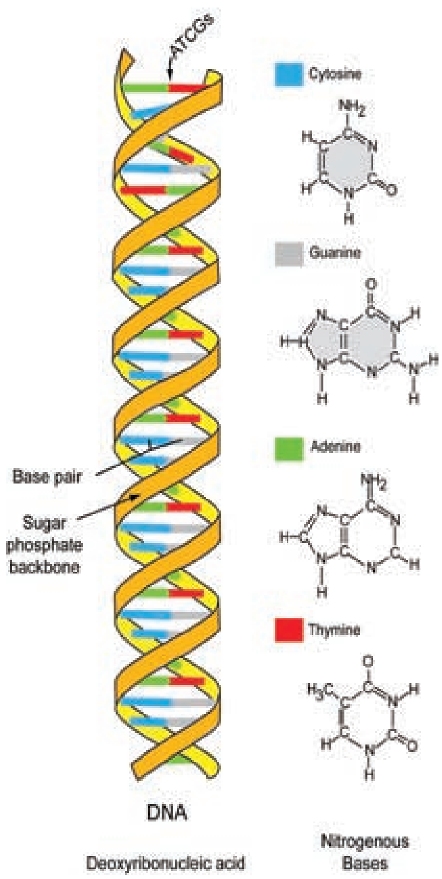
activity 3

vocabulary exercise - answer key

Wordbank

Acidophiles	Extremophile	Metabolism	Permafrost
Aerobic	Energy recruitment	Mitochondrion	Photosynthetic
Anaerobic	Eukaryote	Non-photosynthetic	Phychrophile
Chemoautotroph	Halophile	Nucleus	rDNA
Chemolithotroph	Hyperthermophile	Nucleotide	Thermophile

Use the wordbank to complete these sentences. You will not use all words, and some words may be used more than once.



1 **Psychrophiles** have been found in permafrost, sea ice, and other extremely cold environments.

2 Under very high temperatures geologists might find **thermophiles** or even **hyperthermophiles**.

3 The portion of the DNA that codes for the production of ribosomes is called **rDNA**.

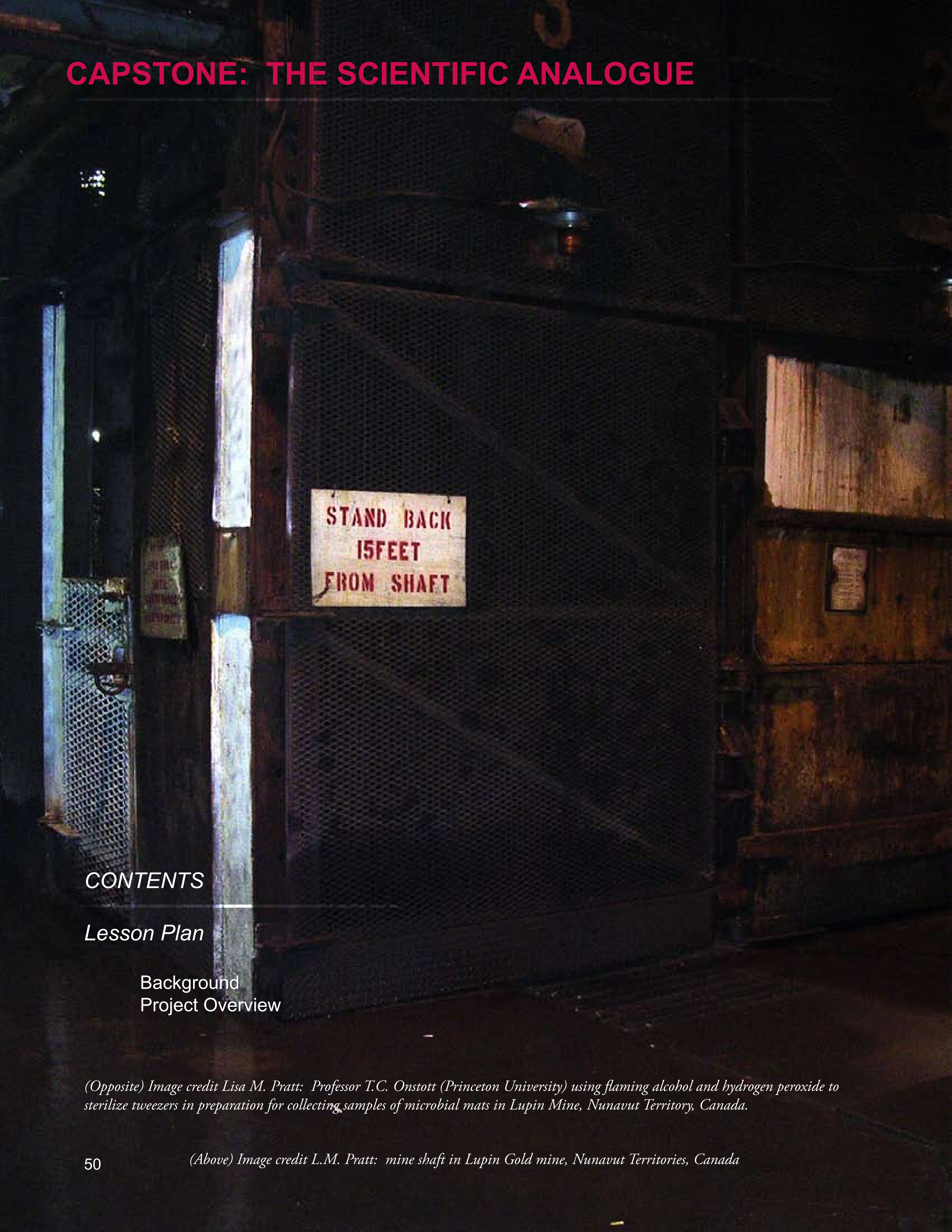
4 Organisms that live under extreme environmental conditions are classified as **extremophiles**.

5 **Acidophiles** thrive in highly acidic environments

6 In salt deposits and salt lakes, scientists are likely to find **halophilic** organisms.

7 Guanine, cytosine, adenine, and thymine are the four **nucleotides** used to construct DNA.

CAPSTONE: THE SCIENTIFIC ANALOGUE



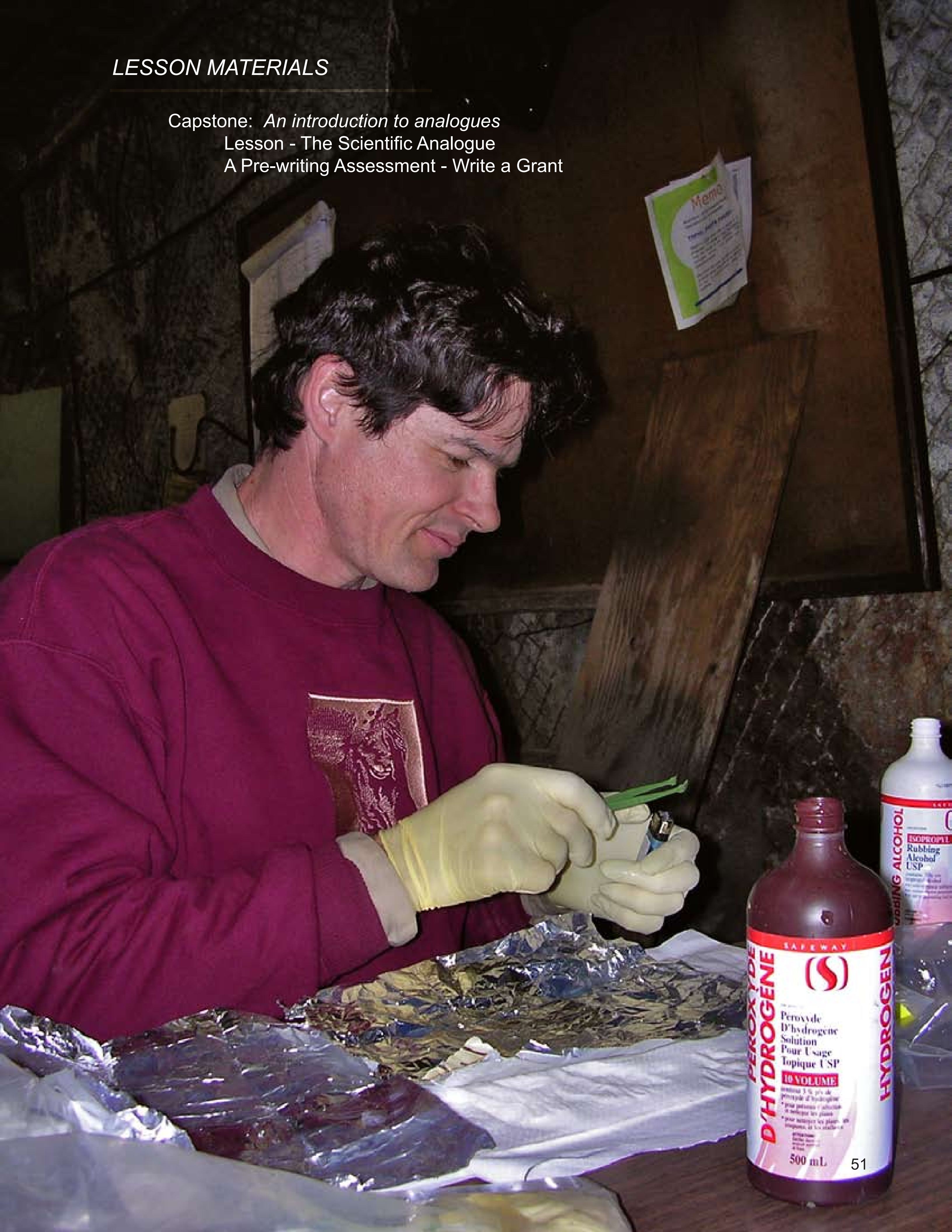
CONTENTS

(Opposite) Image credit Lisa M. Pratt: Professor T.C. Onstott (Princeton University) using flaming alcohol and hydrogen peroxide to sterilize tweezers in preparation for collecting samples of microbial mats in Lupin Mine, Nunavut Territory, Canada.

(Above) Image credit L.M. Pratt: mine shaft in Lupin Gold mine, Nunavut Territories, Canada

LESSON MATERIALS

Capstone: *An introduction to analogues*
Lesson - The Scientific Analogue
A Pre-writing Assessment - Write a Grant



Capstone

The Scientific Analogue

Image credit: Brandy Anglen, Fresno City College, Fresno California. Blood Falls, Antarctica.

SUMMARY:

Using prior assignments from this unit, students will write a scientific proposal to explore another planet or moon in our solar system for signs of life. The capstone is a writing assignment. As such, it is intended to be cross-curricular.

The numbers for the relevant National Standards and Benchmark Standards are noted in the margins.

Capstone Background

Astrobiology is a multidisciplinary science that requires synthesis of knowledge gained from chemistry, biology, geology, and astronomy in order to frame research questions and formulate hypotheses.

Astrobiologists often attempt to construct scenarios for life on Mars or elsewhere in our solar system. Since astrobiologists cannot visit these other worlds directly, they often look to places on Earth that are analogous to extraterrestrial environments in some way. Mars is cold and dry, so astrobiologists study the organisms found in lakes beneath ice in Antarctica. Another analog for Mars is the Atacama Desert of Chile because it is the driest place on Earth. Analogues allow scientists to infer conditions in places that have not been explored. These inferences allow scientists and engineers to design instruments and equipment suitable for exploration of other planetary bodies.

In order to explore the other planets and moons in our solar system, astrobiologists seek funding for orbiting and landed missions. An astrobiology mission proposal would predict the types of energy and nutrients available to sustain life. In addition, this proposal would describe equipment and instruments necessary for exploration and characterization of the target environment.

NSES
G-1
G-4
G-6
E-1
E-2
E-3
E-4

AAAS
1.B.1
1.B.2
1.B.7
1.C.4
3.A.1

Capstone notes for teachers

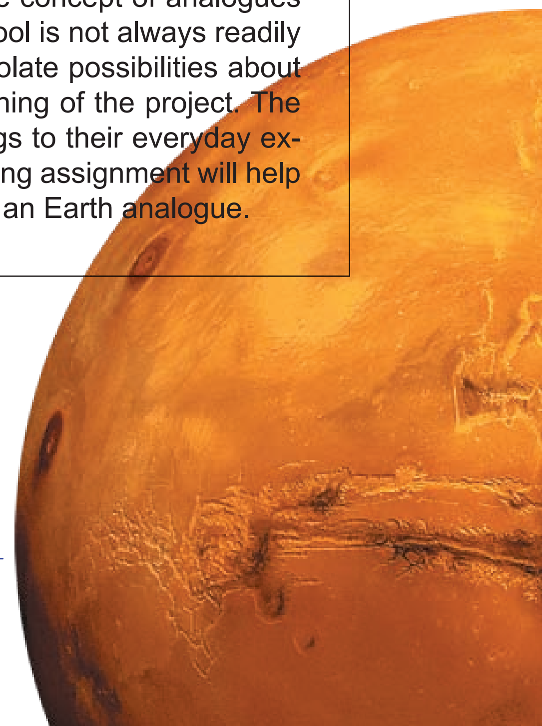
NOTES TO TEACHERS

The individual lessons in Exploring Deep-Subsurface Life were designed to be used either as a cohesive unit or implemented into the existing curriculum as stand alone lessons. The Capstone project, however, requires synthesis from all three lessons included in the Exploring Deep-Subsurface Life materials. We recommend that the Capstone be introduced only if at least two of the three lessons have been implemented in the classroom or if the students have been given adequate background in Astrobiology, microbiology, metabolism and genetics. The materials include a list of links to further information about existing or planned NASA missions with Astrobiology components. The background information provided in this lesson is intended for enrichment and review.

Figure 4.1: Looking down on bubbles of methane gas escaping from a borehole (about 8 mm in diameter) 1130 meters underground in the Lupin gold mine, Nunavut Territories, Canada

This project can be given as an individual assignment, but will work best with some group collaboration. The proposal brings together many of the ideas presented in this unit. Students discuss the assignment in small groups in much the same manner that scientists share information and collaborate on major exploration projects. In the group setting, students will exchange ideas and compare their research to help formulate individual proposals to seek evidence of life in the solar system. In order to create a logical argument for their proposals, they will need to identify an Earth analogue. By working together as a team and comparing data, students have the opportunity to explore community-based interdisciplinary science.

The pre-writing assignment is designed to make the concept of analogues accessible to students. How scientists use this simple tool is not always readily apparent. Being able to make comparisons and extrapolate possibilities about the unknown can seem nearly impossible at the beginning of the project. The brief writing assignment will help students relate analogs to their everyday experiences. If used at the start of the project, the pre-writing assignment will help students become more comfortable with the concept of an Earth analogue.



Valles Marineris on the Planet Mars
Image credit: NASA Mars Global Surveyor JPL

Capstone

introduction to analogues

BACKGROUND

Over the past few weeks, you have learned about extremophile organisms and the harsh environments they inhabit. Next, you will apply what you have learned about astrobiology by assembling a grant proposal. Research of any kind is usually very expensive and almost all science is funded by grants from governmental agencies (such as NASA) or by private organizations. To receive grant money, researchers must submit a proposal that outlines what research they want to do, what purpose it will serve and how much it will cost. As a group, think about what would need to be included in a grant proposal for an astrobiology mission to explore a planet or moon in our solar system for evidence of life. Discussion should include what habitable conditions might exist for extremophiles on other planetary bodies. Think about what evidence of life can be collected given the limitations on current space travel and decide where you think life might be found and how its presence could be verified. Consider as well the cost of your research and any experts you may have to hire. By the end of this exercise, you should have put together a formal plan requesting funds for your scientific research.

ANALOGUES?

Scientists often use analogues to draw inferences about unknown situations by comparing them point by point with something similar and known. For example, you notice a friend has recently had his or her car painted a new color. You have never painted a car, but by using your prior knowledge and experiences you can begin to picture how the car may have been painted. Scientists work in a similar way.

Astrobiologists examine where we find life on Earth today, and compare these habitable environments to locations on other planets that might be similar in some way. Habitable extreme environments on Earth are analogues for extraterrestrial environments with the potential to sustain life.

NSES
A-1
A-2
A-6
E-3
G-4
G-5

AAAS
1.A.1
1.C.8

Capstone introduction to analogues

PRE-WRITING EXERCISE #1

Using prior knowledge and experiences write an analogue for something you have not experienced.

A) So how do you create an analogue? You examine something you know and compare and contrast it with something you know less about. You extrapolate; that is, you make predictions about what a new situation might be like based on your prior experiences in similar situations.

For example: you've never been on a skateboard, but you are an expert on roller blades.
You know that skateboards and roller blades both have wheels.
You would then create an explanation of how you would balance and turn a skateboard compared to roller blades.

B) In the space below start by making a list of your knowledge of an activity with which you have had some experience. Then make a list of similar things about a new experience. Additionally, try to anticipate what would be different.

Aspect of previous experience	Similarities/Differences with new experience

C) Finally, write a paragraph-long comparison of the new experience and its analogue.

NSES
A-1
A-2
A-6
E-3
G-4
G-5

AAAS
1.A.1
1.C.8

Capstone write a grant proposal

A PRE-WRITING EXERCISE

Before you begin to write your grant proposal, read and think about the following questions. On a separate piece of paper, write down some responses in short-answer format. These questions have been grouped into categories in order to help you organize and write your final proposal. Remember: You are trying to convince people to fund your work

- What planet or moon seems most interesting to you as a place where life could be sustained? What region or geographic feature on your target planet or moon is the most interesting habitable environment? Would you explore near the poles or the equator, on the surface or deep below the surface? Is there an unusual geographic feature like a valley, a volcano, a crater, or a fracture network that seems more habitable than the general landscape? Justify your choice of location based on an Earth analogue.
- What signs of life do you think you can find? What lines of evidence would be the most convincing for living organisms? What tests will you conduct?
- Why should the federal government pay for this research? What are the risks? If successful, what impact will your research have on the scientific community and on the public in general?
- What equipment and instruments will you need? Describe the function and purpose of each piece of equipment you plan to send.
- How much will this astrobiology mission cost? Include an itemized budget.

log onto http://science.hq.nasa.gov/ for upcoming missions

Figure 4.2: This image was taken by the Mars Exploration Rover Spirit's panoramic camera during the rover's grinding of the rock dubbed "Mazatzal" with its rock abrasion tool. The picture shows the rock after the rover drilled 3.8 millimeters (.15 inches) into the target dubbed "New York" on Sol 82. The dark grey coating seen after brushing remains on the right side of the hole, while the left side is the underlying basaltic rock. This approximate true-color image was created using the panoramic camera's red, green and blue filters. Image credit: NASA/JPL/Cornell

NSES
A-1
A-2
A-6
E-3
G-4
G-5

AAAS
1.A.1
1.C.8
3.C.1
12.D.6

Capstone

write a grant proposal

THE FINAL PROJECT:

Write a two page proposal (double-spaced) to explore for life on another planet. If possible, you should also put together a brief presentation about your proposal to share with your classmates. Want to piggyback your project on a NASA mission? Go to http://science.hq.nasa.gov/ and take a look at some of the current and upcoming missions.

You will need all of your past assignments and notes to help you do this. Your proposal must include:

1 An introduction/explanation of why this research is important.

2 At least a paragraph explaining what is currently known about your target planet or moon.

3 Describe the specific location to be sampled and the expected environmental conditions at the sample site.

4 What prior studies have been conducted on Earth analogue sites for your mission target? How is your target similar or different from the Earth analogues? What forms of life are found in the Earth analogues?

5 Describe how you will collect and handle samples. Discuss the tests you will conduct and the equipment you will need. Discuss any new technologies you will need to develop in order to conduct these tests.

6 A Budget. (Think big.) This can be on a separate spreadsheet. Include the cost of equipment development and manufacture, operating expenses and salaries for all people associated with the mission over its lifetime. Hint: If you can keep the total cost to under 200 million dollars, your chances of receiving funding are much greater.

7 A conclusion that explains the importance (merit) of this research and the potential contributions to science and society.

You should discuss ideas and possibilities within your group, but you will make all the final decisions about the exploration mission that you propose, and you will need to turn in your own proposal. Share ideas, but do not duplicate someone else's work. Be creative, but stay realistic.

NSES
A-1
A-2
A-6
E-3
G-4
G-5

AAAS
1.A.1
1.C.8
3.C.1

Capstone grading rubric

Capstone Grading Rubric	Poor 0 pts	Fair 5 pts	Good 10 pts
Spelling/Grammar	Many errors	Fewer than 5 errors	Fewer than 2 errors
Introduction Content	Doesn't address importance of research at all	Weakly addresses importance of research in astrobiology	Clearly addresses importance of research in astrobiology
Background	Provides no background on their chosen study site and project	Provides minimal background on their chosen study site and project	Provides clear and concise information on their chosen study site and project
Link to Earth Analogues	Provides no information on how their study site links to current Earth habitats and life forms	Provides minimal but some information on how their study site links to current Earth habitats and life forms	Provides thorough, clear information on how their study site applies to current Earth habitats and life forms
Procedure	Provides no information on how students will conduct testing for life on other planets	Provides minimal information on how students will conduct testing for life on other planets	Provides clear ideas on how students will test for life on other planets
Budget	Did not provide a budget	Provided a budget but did not list all necessary materials and supplies	Provides a thorough budget for all materials and/or personnel needed to complete the research
Conclusion	Provides no wrap-up paragraph regarding impacts on society	Provides some idea on how their research may impact society	Provides many ideas on how their research may impact society and has clearly explained the potential it has within the scientific community.

Standards

National Science Education Standards (National Research Council, 1996)

SCIENCE AS INQUIRY - CONTENT STANDARD A

ABILITIES NECESSARY TO DO SCIENTIFIC INQUIRY

A-1 IDENTIFY QUESTIONS AND CONCEPTS THAT GUIDE SCIENTIFIC INVESTIGATIONS. Students should formulate a testable hypothesis and demonstrate the logical connections between the scientific concepts guiding a hypothesis and the design of an experiment. They should demonstrate appropriate procedures, a knowledge base, and conceptual understanding of scientific investigations.

A-2 DESIGN AND CONDUCT SCIENTIFIC INVESTIGATIONS. Designing and conducting a scientific investigation requires introduction to the major concepts in the area being investigated, proper equipment, safety precautions, assistance with methodological problems, recommendations for use of technologies, clarification of ideas that guide the inquiry, and scientific knowledge obtained from sources other than the actual investigation. The investigation may also require student clarification of the question, method, controls, and variables; student organization and display of data; student revision of methods and explanations; and a public presentation of the results with a critical response from peers. Regardless of the scientific investigation performed, students must use evidence, apply logic, and construct an argument for their proposed explanations.

A-3 USE TECHNOLOGY AND MATHEMATICS TO IMPROVE INVESTIGATIONS AND COMMUNICATIONS. A variety of technologies, such as hand tools, measuring instruments, and calculators, should be an integral component of scientific investigations. The use of computers for the collection, analysis, and display of data is also a part of this standard. Mathematics plays an essential role in all aspects of an inquiry. For example, measurement is used for posing questions, formulas are used for developing explanations, and charts and graphs are used for communicating results.

A-4 FORMULATE AND REVISE SCIENTIFIC EXPLANATIONS AND MODELS USING LOGIC AND EVIDENCE. Student inquiries should culminate in formulating an explanation or model. Models should be physical, conceptual, and mathematical. In the process of answering the questions, the students should engage in discussions and arguments that result in the revision of their explanations. These discussions should be based on scientific knowledge, the use of logic, and evidence from their investigation.

A-5 RECOGNIZE AND ANALYZE ALTERNATIVE EXPLANATIONS AND MODELS. This aspect of the standard emphasizes the critical abilities of analyzing an argument by reviewing current scientific understanding, weighing the evidence, and examining the logic so as to decide which explanations and models are best. In other words, although there may be several plausible explanations, they do not all have equal weight. Students should be able to use scientific criteria to find the preferred explanations.

A-6 COMMUNICATE AND DEFEND A SCIENTIFIC ARGUMENT. Students in school science programs should develop the abilities associated with accurate and effective communication. These include writing and following procedures, expressing concepts, reviewing information, summarizing data, using language appropriately, developing diagrams and charts, explaining statistical analysis, speaking clearly and logically, constructing a reasoned argument, and responding appropriately to critical comments. [See Teaching Standard B in Chapter 3].

UNDERSTANDINGS ABOUT SCIENTIFIC INQUIRY

A-7 Scientists usually inquire about how physical, living, or designed systems function. Conceptual principles and knowledge guide scientific inquiries. Historical and current scientific knowledge influence the design and interpretation of investigations and the evaluation of proposed explanations made by other scientists. [See Unifying Concepts and Processes]

A-8 Scientists conduct investigations for a wide variety of reasons. For example, they may wish to discover new aspects of the natural world, explain recently observed phenomena, or test the conclusions of prior investigations or the predictions of current theories.

A-9 Scientists rely on technology to enhance the gathering and manipulation of data. New techniques and tools provide new evidence to guide inquiry and new methods to gather data, thereby contributing to the advance of science. The accuracy and precision of the data, and therefore the quality of the exploration, depends on the technology used. [Content Standard E (grades 9-12)]

Standards

UNDERSTANDINGS ABOUT SCIENCE AND TECHNOLOGY

A-10 Mathematics is essential in scientific inquiry. Mathematical tools and models guide and improve the posing of questions, gathering data, constructing explanations and communicating results. [See Program Standard C]

A-11 Scientific explanations must adhere to criteria such as: a proposed explanation must be logically consistent; it must abide by the rules of evidence; it must be open to questions and possible modification; and it must be based on historical and current scientific knowledge.

A-12 Results of scientific inquiry--new knowledge and methods--emerge from different types of investigations and public communication among scientists. In communicating and defending the results of scientific inquiry, arguments must be logical and demonstrate connections between natural phenomena, investigations, and the historical body of scientific knowledge. In addition, the methods and procedures that scientists used to obtain evidence must be clearly reported to enhance opportunities for further investigation.

PHYSICAL SCIENCE - CONTENT STANDARD B

STRUCTURE OF ATOMS

B-1 Matter is made of minute particles called atoms, and atoms are composed of even smaller components. These components have measurable properties, such as mass and electrical charge. Each atom has a positively charged nucleus surrounded by negatively charged electrons. The electric force between the nucleus and electrons holds the atom together.

B-2 The atom's nucleus is composed of protons and neutrons, which are much more massive than electrons. When an element has atoms that differ in the number of neutrons, these atoms are called different isotopes of the element.

B-3 The nuclear forces that hold the nucleus of an atom together, at nuclear distances, are usually stronger than the electric forces that would make it fly apart. Nuclear reactions convert a fraction of the mass of interacting particles into energy, and they can release much greater amounts of energy than atomic interactions. Fission is the splitting of a large nucleus into smaller pieces. Fusion is the joining of two nuclei at extremely high temperature and pressure, and is the process responsible for the energy of the sun and other stars.

B-4 Radioactive isotopes are unstable and undergo spontaneous nuclear reactions, emitting particles and/or wavelike radiation. The decay of any one nucleus cannot be predicted, but a large group of identical nuclei decay at a predictable rate. This predictability can be used to estimate the age of materials that contain radioactive isotopes.

STRUCTURE AND PROPERTIES OF MATTER

B-5 Atoms interact with one another by transferring or sharing electrons that are furthest from the nucleus. These outer electrons govern the chemical properties of the element.

B-6 An element is composed of a single type of atom. When elements are listed in order according to the number of protons (called the atomic number), repeating patterns of physical and chemical properties identify families of elements with similar properties. This "Periodic Table" is a consequence of the repeating pattern of outermost electrons and their permitted energies.

B-7 Bonds between atoms are created when electrons are paired up by being transferred or shared. A substance composed of a single kind of atom is called an element. The atoms may be bonded together into molecules or crystalline solids. A compound is formed when two or more kinds of atoms bind together chemically.

B-8 The physical properties of compounds reflect the nature of the interactions among its molecules. These interactions are determined by the structure of the molecule, including the constituent atoms and the distances and angles between them.

B-9 Solids, liquids, and gases differ in the distances and angles between molecules or atoms and therefore the energy that binds them together. In solids the structure is nearly rigid; in liquids molecules or atoms move around each other but do not move apart; and in gases molecules or atoms move almost independently of each other and are mostly far apart.

Standards

STRUCTURE AND PROPERTIES OF MATTER

B-10 Carbon atoms can bond to one another in chains, rings, and branching networks to form a variety of structures, including synthetic polymers, oils, and the large molecules essential to life.

CHEMICAL REACTIONS

B-11 Chemical reactions occur all around us, for example in health care, cooking, cosmetics, and automobiles. Complex chemical reactions involving carbon-based molecules take place constantly in every cell in our bodies. [See Content Standard C (grades 9-12)]

B-12 Chemical reactions may release or consume energy. Some reactions such as the burning of fossil fuels release large amounts of energy by losing heat and by emitting light. Light can initiate many chemical reactions such as photosynthesis and the evolution of urban smog.

B-13 A large number of important reactions involve the transfer of either electrons (oxidation/reduction reactions) or hydrogen ions (acid/base reactions) between reacting ions, molecules, or atoms. In other reactions, chemical bonds are broken by heat or light to form very reactive radicals with electrons ready to form new bonds. Radical reactions control many processes such as the presence of ozone and greenhouse gases in the atmosphere, burning and processing of fossil fuels, the formation of polymers, and explosions.

B-14 Chemical reactions can take place in time periods ranging from the few femtoseconds (10-15 seconds) required for an atom to move a fraction of a chemical bond distance to geologic time scales of billions of years. Reaction rates depend on how often the reacting atoms and molecules encounter one another, on the temperature, and on the properties--including shape--of the reacting species.

B-15 Catalysts, such as metal surfaces, accelerate chemical reactions. Chemical reactions in living systems are catalyzed by protein molecules called enzymes.

THE CELL

LIFE SCIENCE - CONTENT STANDARD C

C-1 Cells have particular structures that underlie their functions. Every cell is surrounded by a membrane that separates it from the outside world. Inside the cell is a concentrated mixture of thousands of different molecules which form a variety of specialized structures that carry out such cell functions as energy production, transport of molecules, waste disposal, synthesis of new molecules, and the storage of genetic material. [See Unifying Concepts and Processes]

C-2 Most cell functions involve chemical reactions. Food molecules taken into cells react to provide the chemical constituents needed to synthesize other molecules. Both breakdown and synthesis are made possible by a large set of protein catalysts, called enzymes. The breakdown of some of the food molecules enables the cell to store energy in specific chemicals that are used to carry out the many functions of the cell.

C-3 Cells store and use information to guide their functions. The genetic information stored in DNA is used to direct the synthesis of the thousands of proteins that each cell requires.

C-4 Cell functions are regulated. Regulation occurs both through changes in the activity of the functions performed by proteins and through the selective expression of individual genes. This regulation allows cells to respond to their environment and to control and coordinate cell growth and division.

C-5 Plant cells contain chloroplasts, the site of photosynthesis. Plants and many microorganisms use solar energy to combine molecules of carbon dioxide and water into complex, energy rich organic compounds and release oxygen to the environment. This process of photosynthesis provides a vital connection between the sun and the energy needs of living systems.

C-6 Cells can differentiate, and complex multicellular organisms are formed as a highly organized arrangement of differentiated cells. In the development of these multicellular organisms, the progeny from a single cell form an embryo in which the cells multiply and differentiate to form the many specialized cells, tissues and organs that comprise the final organism. This differentiation is regulated through the expression of different genes.

Standards

THE MOLECULAR BASIS OF HEREDITY

C-7 In all organisms, the instructions for specifying the characteristics of the organism are carried in DNA, a large polymer formed from subunits of four kinds (A, G, C, and T). The chemical and structural properties of DNA explain how the genetic information that underlies heredity is both encoded in genes (as a string of molecular "letters") and replicated (by a templating mechanism). Each DNA molecule in a cell forms a single chromosome. [See Content Standard B (grades 9-12)]

C-8 Most of the cells in a human contain two copies of each of 22 different chromosomes. In addition, there is a pair of chromosomes that determines sex: a female contains two X chromosomes and a male contains one X and one Y chromosome. Transmission of genetic information to offspring occurs through egg and sperm cells that contain only one representative from each chromosome pair. An egg and a sperm unite to form a new individual. The fact that the human body is formed from cells that contain two copies of each chromosome--and therefore two copies of each gene--explains many features of human heredity, such as how variations that are hidden in one generation can be expressed in the next.

C-9 Changes in DNA (mutations) occur spontaneously at low rates. Some of these changes make no difference to the organism, whereas others can change cells and organisms. Only mutations in germ cells can create the variation that changes an organism's offspring.

BIOLOGICAL EVOLUTION

C-10 Species evolve over time. Evolution is the consequence of the interactions of (1) the potential for a species to increase its numbers, (2) the genetic variability of offspring due to mutation and recombination of genes, (3) a finite supply of the resources required for life, and (4) the ensuing selection by the environment of those offspring better able to survive and leave offspring. [See Unifying Concepts and Processes]

C-11 The great diversity of organisms is the result of more than 3.5 billion years of evolution that has filled every available niche with life forms.

C-12 Natural selection and its evolutionary consequences provide a scientific explanation for the fossil record of ancient life forms, as well as for the striking molecular similarities observed among the diverse species of living organisms.

C-13 The millions of different species of plants, animals, and microorganisms that live on earth today are related by descent from common ancestors.

C-14 Biological classifications are based on how organisms are related. Organisms are classified into a hierarchy of groups and subgroups based on similarities which reflect their evolutionary relationships. Species is the most fundamental unit of classification.

INTERDEPENDENCE OF ORGANISMS

C-15 The atoms and molecules on the earth cycle among the living and nonliving components of the biosphere.

C-16 Energy flows through ecosystems in one direction, from photosynthetic organisms to herbivores to carnivores and decomposers.

C-17 Organisms both cooperate and compete in ecosystems. The interrelationships and interdependencies of these organisms may generate ecosystems that are stable for hundreds or thousands of years.

C-18 Living organisms have the capacity to produce populations of infinite size, but environments and resources are finite. This fundamental tension has profound effects on the interactions between organisms.

C-19 Human beings live within the world's ecosystems. Increasingly, humans modify ecosystems as a result of population growth, technology, and consumption. Human destruction of habitats through direct harvesting, pollution, atmospheric changes, and other factors is threatening current global stability, and if not addressed, ecosystems will be irreversibly affected.

MATTER, ENERGY, AND ORGANIZATION IN LIVING SYSTEMS

C-20 All matter tends toward more disorganized states. Living systems require a continuous input of energy to maintain their chemical and physical organizations. With death, and the cessation of energy input, living systems rapidly disintegrate. [See Unifying Concepts and Processes]

C-21 The energy for life primarily derives from the sun. Plants capture energy by absorbing light and using it to form strong (covalent) chemical bonds between the atoms of carbon-containing (organic) molecules. These molecules can be used to assemble larger molecules with biological activity (including proteins, DNA, sugars, and fats). In addition, the energy stored in bonds between the atoms (chemical energy) can be used as sources of energy for life processes.

C-22 The chemical bonds of food molecules contain energy. Energy is released when the bonds of food molecules are broken and new compounds with lower energy bonds are formed. Cells usually store this energy temporarily in phosphate bonds of a small high-energy compound called ATP.

C-23 The complexity and organization of organisms accommodates the need for obtaining, transforming, transporting, releasing, and eliminating the matter and energy used to sustain the organism.

C-24 The distribution and abundance of organisms and populations in ecosystems are limited by the availability of matter and energy and the ability of the ecosystem to recycle materials.

C-25 As matter and energy flows through different levels of organization of living systems--cells, organs, organisms, communities--and between living systems and the physical environment, chemical elements are recombined in different ways. Each recombination results in storage and dissipation of energy into the environment as heat. Matter and energy are conserved in each change.

THE BEHAVIOR OF ORGANISMS

C-26 Multicellular animals have nervous systems that generate behavior. Nervous systems are formed from specialized cells that conduct signals rapidly through the long cell extensions that make up nerves. The nerve cells communicate with each other by secreting specific excitatory and inhibitory molecules. In sense organs, specialized cells detect light, sound, and specific chemicals and enable animals to monitor what is going on in the world around them.

C-27 Organisms have behavioral responses to internal changes and to external stimuli. Responses to external stimuli can result from interactions with the organism's own species and others, as well as environmental changes; these responses either can be innate or learned. The broad patterns of behavior exhibited by animals have evolved to ensure reproductive success. Animals often live in unpredictable environments, and so their behavior must be flexible enough to deal with uncertainty and change. Plants also respond to stimuli.

C-28 Like other aspects of an organism's biology, behaviors have evolved through natural selection. Behaviors often have an adaptive logic when viewed in terms of evolutionary principles.

C-29 Behavioral biology has implications for humans, as it provides links to psychology, sociology, and anthropology.

EARTH AND SPACE SCIENCE - CONTENT STANDARD D

ENERGY IN THE EARTH SYSTEM

D-1 Earth systems have internal and external sources of energy, both of which create heat. The sun is the major external source of energy. Two primary sources of internal energy are the decay of radioactive isotopes and the gravitational energy from the earth's original formation.

D-2 The outward transfer of earth's internal heat drives convection circulation in the mantle that propels the plates comprising earth's surface across the face of the globe. [See content Standard B (grades 9-12)]

D-3 Heating of earth's surface and atmosphere by the sun drives convection within the atmosphere and oceans, producing winds and ocean currents.

D-4 Global climate is determined by energy transfer from the sun at and near the earth's surface. This energy transfer is influenced by dynamic processes such as cloud cover and the earth's rotation, and static conditions such as the position of mountain ranges and oceans.

GEOCHEMICAL CYCLES

D-5 The earth is a system containing essentially a fixed amount of each stable chemical atom or element. Each element can exist in several different chemical reservoirs. Each element on earth moves among reservoirs in the solid earth, oceans, atmosphere, and organisms as part of geochemical cycles.

D-6 Movement of matter between reservoirs is driven by the earth's internal and external sources of energy. These movements are often accompanied by a change in the physical and chemical properties of the matter. Carbon, for example, occurs in carbonate rocks such as limestone, in the atmosphere as carbon dioxide gas, in water as dissolved carbon dioxide, and in all organisms as complex molecules that control the chemistry of life.

SCIENCE AND TECHNOLOGY - CONTENT STANDARD E

UNDERSTANDINGS ABOUT SCIENCE AND TECHNOLOGY

E-1 Scientists in different disciplines ask different questions, use different methods of investigation, and accept different types of evidence to support their explanations. Many scientific investigations require the contributions of individuals from different disciplines, including engineering. New disciplines of science, such as geophysics and biochemistry often emerge at the interface of two older disciplines.

E-2 Science often advances with the introduction of new technologies. Solving technological problems often results in new scientific knowledge. New technologies often extend the current levels of scientific understanding and introduce new areas of research.

E-3 Creativity, imagination, and a good knowledge base are all required in the work of science and engineering.

E-4 Science and technology are pursued for different purposes. Scientific inquiry is driven by the desire to understand the natural world, and technological design is driven by the need to meet human needs and solve human problems. Technology, by its nature, has a more direct effect on society than science because its purpose is to solve human problems, help humans adapt, and fulfill human aspirations. Technological solutions may create new problems. Science, by its nature, answers questions that may or may not directly influence humans. Sometimes scientific advances challenge people's beliefs and practical explanations concerning various aspects of the world.

E-5 Technological knowledge is often not made public because of patents and the financial potential of the idea or invention. Scientific knowledge is made public through presentations at professional meetings and publications in scientific journals.

HISTORY AND NATURE OF SCIENCE - CONTENT STANDARD G

SCIENCE AS A HUMAN ENDEAVOR

G-1 Individuals and teams have contributed and will continue to contribute to the scientific enterprise. Doing science or engineering can be as simple as an individual conducting field studies or as complex as hundreds of people working on a major scientific question or technological problem. Pursuing science as a career or as a hobby can be both fascinating and intellectually rewarding.

G-2 Scientists have ethical traditions. Scientists value peer review, truthful reporting about the methods and outcomes of investigations, and making public the results of work. Violations of such norms do occur, but scientists responsible for such violations are censured by their peers.

G-3 Scientists are influenced by societal, cultural, and personal beliefs and ways of viewing the world. Science is not separate from society but rather science is a part of society.

G-4 Science distinguishes itself from other ways of knowing and from other bodies of knowledge through the use of empirical standards, logical arguments, and skepticism, as scientists strive for the best possible explanations about the natural world.

Standards

NATURE OF SCIENTIFIC KNOWLEDGE

G-5 Scientific explanations must meet certain criteria. First and foremost, they must be consistent with experimental and observational evidence about nature, and must make accurate predictions, when appropriate, about systems being studied. They should also be logical, respect the rules of evidence, be open to criticism, report methods and procedures, and make knowledge public. Explanations on how the natural world changes based on myths, personal beliefs, religious values, mystical inspiration, superstition, or authority may be personally useful and socially relevant, but they are not scientific.

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Benchmarks for Science Literacy
(Project 2061: American Association for the Advancement of Science, AAAS 1993)

CHAPTER 1 THE NATURE OF SCIENCE

A. THE SCIENTIFIC WORLD VIEW

1.A.1 Scientists assume that the universe is a vast single system in which the basic rules are the same everywhere. The rules may range from very simple to extremely complex, but scientists operate on the belief that the rules can be discovered by careful, systematic study.

1.A.2 From time to time, major shifts occur in the scientific view of how the world works. More often, however, the changes that take place in the body of scientific knowledge are small modifications of prior knowledge. Change and continuity are persistent features of science.

1.A.3 No matter how well one theory fits observations, a new theory might fit them just as well or better, or might fit a wider range of observations. In science, the testing, revising, and occasional discarding of theories, new and old, never ends. This ongoing process leads to an increasingly better understanding of how things work in the world but not to absolute truth. Evidence for the value of this approach is given by the improving ability of scientists to offer reliable explanations and make accurate predictions.

B. SCIENTIFIC INQUIRY

1.B.1 Investigations are conducted for different reasons, including to explore new phenomena, to check on previous results, to test how well a theory predicts, and to compare different theories.

1.B.2 Hypotheses are widely used in science for choosing what data to pay attention to and what additional data to seek, and for guiding the interpretation of the data (both new and previously available).

1.B.3 Sometimes, scientists can control conditions in order to obtain evidence. When that is not possible for practical or ethical reasons, they try to observe as wide a range of natural occurrences as possible to be able to discern patterns.

1.B.4 There are different traditions in science about what is investigated and how, but they all have in common certain basic beliefs about the value of evidence, logic, and good arguments. And there is agreement that progress in all fields of science depends on intelligence, hard work, imagination, and even chance.

1.B.5 Scientists in any one research group tend to see things alike, so even groups of scientists may have trouble being entirely objective about their methods and findings. For that reason, scientific teams are expected to seek out the possible sources of bias in the design of their investigations and in their data analysis. Checking each other's results and explanations helps, but that is no guarantee against bias.

B. SCIENTIFIC INQUIRY

1.B.6 In the short run, new ideas that do not mesh well with mainstream ideas in science often encounter vigorous criticism. In the long run, theories are judged by how they fit with other theories, the range of observations they explain, how well they explain observations, and how effective they are in predicting new findings.

1.B.7 New ideas in science are limited by the context in which they are conceived; are often rejected by the scientific establishment; sometimes spring from unexpected findings; and usually grow slowly, through contributions from many investigators.

C. THE SCIENTIFIC ENTERPRISE

1.C.1 The early Egyptian, Greek, Chinese, Hindu, and Arabic cultures are responsible for many scientific and mathematical ideas and technological inventions.

1.C.2 Modern science is based on traditions of thought that came together in Europe about 500 years ago. People from all cultures now contribute to that tradition.

1.C.3 Progress in science and invention depends heavily on what else is happening in society, and history often depends on scientific and technological developments.

1.C.4 Science disciplines differ from one another in what is studied, techniques used, and outcomes sought, but they share a common purpose and philosophy, and all are part of the same scientific enterprise. Although each discipline provides a conceptual structure for organizing and pursuing knowledge, many problems are studied by scientists using information and skills from many disciplines. Disciplines do not have fixed boundaries, and it happens that new scientific disciplines are being formed where existing ones meet and that some subdisciplines spin off to become new disciplines in their own right.

1.C.5 Current ethics in science hold that research involving human subjects may be conducted only with the informed consent of the subjects, even if this constraint limits some kinds of potentially important research or influences the results. When it comes to participation in research that could pose risks to society, most scientists believe that a decision to participate or not is a matter of personal ethics rather than professional ethics.

1.C.6 Scientists can bring information, insights, and analytical skills to bear on matters of public concern. Acting in their areas of expertise, scientists can help people understand the likely causes of events and estimate their possible effects. Outside their areas of expertise, however, scientists should enjoy no special credibility. And where their own personal, institutional, or community interests are at stake, scientists as a group can be expected to be no less biased than other groups are about their perceived interests.

1.C.7 The strongly held traditions of science, including its commitment to peer review and publication, serve to keep the vast majority of scientists well within the bounds of ethical professional behavior. Deliberate deceit is rare and likely to be exposed sooner or later by the scientific enterprise itself. When violations of these scientific ethical traditions are discovered, they are strongly condemned by the scientific community, and the violators then have difficulty regaining the respect of other scientists.

1.C.8 Funding influences the direction of science by virtue of the decisions that are made on which research to support. Research funding comes from various federal government agencies, industry, and private foundations.

CHAPTER 2 THE NATURE OF MATHEMATICS

A. PATTERNS AND RELATIONSHIPS

2.A.1 Mathematics is the study of any patterns or relationships, whereas natural science is concerned only with those patterns that are relevant to the observable world. Although mathematics began long ago in practical problems, it soon focused on abstractions from the material world, and then on even more abstract relationships among those abstractions.

2.A.2 As in other sciences, simplicity is one of the highest values in mathematics. Some mathematicians try to identify the smallest set of rules from which many other propositions can be logically derived.

Standards

A. PATTERNS AND RELATIONSHIPS

2.A.3 Theories and applications in mathematical work influence each other. Sometimes a practical problem leads to the development of new mathematical theories; often mathematics developed for its own sake turns out to have practical applications.

2.A.4 New mathematics continues to be invented, and connections between different parts of mathematics continue to be found.

B. MATHEMATICS, SCIENCE, AND TECHNOLOGY

2.B.1 Mathematical modeling aids in technological design by simulating how a proposed system would theoretically behave.

2.B.2 Mathematics and science as enterprises share many values and features: belief in order, ideals of honesty and openness, the importance of criticism by colleagues, and the essential role played by imagination.

2.B.3 Mathematics provides a precise language for science and technology-to describe objects and events, to characterize relationships between variables, and to argue logically.

2.B.4 Developments in science or technology often stimulate innovations in mathematics by presenting new kinds of problems to be solved. In particular, the development of computer technology (which itself relies on mathematics) has generated new kinds of problems and methods of work in mathematics.

2.B.5 Developments in mathematics often stimulate innovations in science and technology.

C. MATHEMATICAL INQUIRY

2.C.1 Some work in mathematics is much like a game-mathematicians choose an interesting set of rules and then play according to those rules to see what can happen. The more interesting the results, the better. The only limit on the set of rules is that they should not contradict one another.

2.C.2 Much of the work of mathematicians involves a modeling cycle, which consists of three steps: (1) using abstractions to represent things or ideas, (2) manipulating the abstractions according to some logical rules, and (3) checking how well the results match the original things or ideas. If the match is not considered good enough, a new round of abstraction and manipulation may begin. The actual thinking need not go through these processes in logical order but may shift from one to another in any order.

CHAPTER 3 THE NATURE OF TECHNOLOGY

A. TECHNOLOGY AND SCIENCE

3.A.1 Technological problems often create a demand for new scientific knowledge, and new technologies make it possible for scientists to extend their research in new ways or to undertake entirely new lines of research. The very availability of new technology itself often sparks scientific advances.

3.A.2 Mathematics, creativity, logic and originality are all needed to improve technology.

3.A.3 Technology usually affects society more directly than science because it solves practical problems and serves human needs (and may create new problems and needs). In contrast, science affects society mainly by stimulating and satisfying people's curiosity and occasionally by enlarging or challenging their views of what the world is like.

B. DESIGN AND SYSTEMS

3.B.1 In designing a device or process, thought should be given to how it will be manufactured, operated, maintained, replaced, and disposed of and who will sell, operate, and take care of it. The costs associated with these functions may introduce yet more constraints on the design.

3.B.2 The value of any given technology may be different for different groups of people and at different points in time.

3.B.3 Complex systems have layers of controls. Some controls operate particular parts of the system and some control other controls. Even fully automatic systems require human control at some point.

B. DESIGN AND SYSTEMS

3.B.4 Risk analysis is used to minimize the likelihood of unwanted side effects of a new technology. The public perception of risk may depend, however, on psychological factors as well as scientific ones.

3.B.5 The more parts and connections a system has, the more ways it can go wrong. Complex systems usually have components to detect, back up, bypass, or compensate for minor failures.

3.B.6 To reduce the chance of system failure, performance testing is often conducted using small-scale models, computer simulations, analogous systems, or just the parts of the system thought to be least reliable.

C. ISSUES IN TECHNOLOGY

3.C.1 Social and economic forces strongly influence which technologies will be developed and used. Which will prevail is affected by many factors, such as personal values, consumer acceptance, patent laws, the availability of risk capital, the federal budget, local and national regulations, media attention, economic competition, and tax incentives.

3.C.2 Technological knowledge is not always as freely shared as scientific knowledge unrelated to technology. Some scientists and engineers are comfortable working in situations in which some secrecy is required, but others prefer not to do so. It is generally regarded as a matter of individual choice and ethics, not one of professional ethics.

3.C.3 In deciding on proposals to introduce new technologies or to curtail existing ones, some key questions arise concerning alternatives, risks, costs, and benefits. What alternative ways are there to achieve the same ends, and how do the alternatives compare to the plan being put forward? Who benefits and who suffers? What are the financial and social costs, do they change over time, and who bears them? What are the risks associated with using (or not using) the new technology, how serious are they, and who is in jeopardy? What human, material, and energy resources will be needed to build, install, operate, maintain, and replace the new technology, and where will they come from? How will the new technology and its waste products be disposed of and at what costs?

3.C.4 The human species has a major impact on other species in many ways: reducing the amount of the earth's surface available to those other species, interfering with their food sources, changing the temperature and chemical composition of their habitats, introducing foreign species into their ecosystems, and altering organisms directly through selective breeding and genetic engineering.

3.C.5 Human inventiveness has brought new risks as well as improvements to human existence.

CHAPTER 4 THE PHYSICAL SETTING

A. THE UNIVERSE

4.A.1 The stars differ from each other in size, temperature, and age, but they appear to be made up of the same elements that are found on the earth and to behave according to the same physical principles. Unlike the sun, most stars are in systems of two or more stars orbiting around one another.

4.A.2 On the basis of scientific evidence, the universe is estimated to be over ten billion years old. The current theory is that its entire contents expanded explosively from a hot, dense, chaotic mass. Stars condensed by gravity out of clouds of molecules of the lightest elements until nuclear fusion of the light elements into heavier ones began to occur. Fusion released great amounts of energy over millions of years. Eventually, some stars exploded, producing clouds of heavy elements from which other stars and planets could later condense. The process of star formation and destruction continues.

4.A.3 Increasingly sophisticated technology is used to learn about the universe. Visual, radio, and x-ray telescopes collect information from across the entire spectrum of electromagnetic waves; computers handle an avalanche of data and increasingly complicated computations to interpret them; space probes send back data and materials from the remote parts of the solar system; and accelerators give subatomic particles energies that simulate conditions in the stars and in the early history of the universe before stars formed.

4.A.4 Mathematical models and computer simulations are used in studying evidence from many sources in order to form a scientific account of the universe.

Standards

B. THE EARTH

4.B.1 Life is adapted to conditions on the earth, including the force of gravity that enables the planet to retain an adequate atmosphere, and an intensity of radiation from the sun that allows water to cycle between liquid and vapor.

4.B.2 Weather (in the short run) and climate (in the long run) involve the transfer of energy in and out of the atmosphere. Solar radiation heats the land masses, oceans, and air. Transfer of heat energy at the boundaries between the atmosphere, the land masses, and the oceans results in layers of different temperatures and densities in both the ocean and atmosphere. The action of gravitational force on regions of different densities causes them to rise or fall-and such circulation, influenced by the rotation of the earth, produces winds and ocean currents.

C. PROCESSES THAT SHAPE THE EARTH

4.C.1 Plants alter the earth's atmosphere by removing carbon dioxide from it, using the carbon to make sugars and releasing oxygen. This process is responsible for the oxygen content of the air.

4.C.2 The formation, weathering, sedimentation, and reformation of rock constitute a continuing "rock cycle" in which the total amount of material stays the same as its forms change.

4.C.3 The slow movement of material within the earth results from heat flowing out from the deep interior and the action of gravitational forces on regions of different density.

4.C.4 The solid crust of the earth-including both the continents and the ocean basins-consists of separate plates that ride on a denser, hot, gradually deformable layer of the earth. The crust sections move very slowly, pressing against one another in some places, pulling apart in other places. Ocean-floor plates may slide under continental plates, sinking deep into the earth. The surface layers of these plates may fold, forming mountain ranges.

4.C.5 Earthquakes often occur along the boundaries between colliding plates, and molten rock from below creates pressure that is released by volcanic eruptions, helping to build up mountains. Under the ocean basins, molten rock may well up between separating plates to create new ocean floor. Volcanic activity along the ocean floor may form undersea mountains, which can thrust above the ocean's surface to become islands.

D. THE STRUCTURE OF MATTER

4.D.1 Atoms are made of a positive nucleus surrounded by negative electrons. An atom's electron configuration, particularly the outermost electrons, determines how the atom can interact with other atoms. Atoms form bonds to other atoms by transferring or sharing electrons.

4.D.2 The nucleus, a tiny fraction of the volume of an atom, is composed of protons and neutrons, each almost two thousand times heavier than an electron. The number of positive protons in the nucleus determines what an atom's electron configuration can be and so defines the element. In a neutral atom, the number of electrons equals the number of protons. But an atom may acquire an unbalanced charge by gaining or losing electrons.

4.D.3 Neutrons have a mass that is nearly identical to that of protons, but neutrons have no electric charge. Although neutrons have little effect on how an atom interacts with others, they do affect the mass and stability of the nucleus. Isotopes of the same element have the same number of protons (and therefore of electrons) but differ in the number of neutrons.

4.D.4 The nucleus of radioactive isotopes is unstable and spontaneously decays, emitting particles and/or wavelike radiation. It cannot be predicted exactly when, if ever, an unstable nucleus will decay, but a large group of identical nuclei decay at a predictable rate. This predictability of decay rate allows radioactivity to be used for estimating the age of materials that contain radioactive substances.

4.D.5 Scientists continue to investigate atoms and have discovered even smaller constituents of which neutrons and protons are made.

4.D.6 When elements are listed in order by the masses of their atoms, the same sequence of properties appears over and over again in the list.

Standards

D. THE STRUCTURE OF MATTER

4.D.7 Atoms often join with one another in various combinations in distinct molecules or in repeating three-dimensional crystal patterns. An enormous variety of biological, chemical, and physical phenomena can be explained by changes in the arrangement and motion of atoms and molecules.

4.D.8 The configuration of atoms in a molecule determines the molecule's properties. Shapes are particularly important in how large molecules interact with others.

4.D.9 The rate of reactions among atoms and molecules depends on how often they encounter one another, which is affected by the concentration, pressure, and temperature of the reacting materials. Some atoms and molecules are highly effective in encouraging the interaction of others.

E. ENERGY TRANSFORMATIONS

4.E.1 Whenever the amount of energy in one place or form diminishes, the amount in other places or forms increases by the same amount.

4.E.2 Heat energy in a material consists of the disordered motions of its atoms or molecules. In any interactions of atoms or molecules, the statistical odds are that they will end up with less order than they began-that is, with the heat energy spread out more evenly. With huge numbers of atoms and molecules, the greater disorder is almost certain.

4.E.3 Transformations of energy usually produce some energy in the form of heat, which spreads around by radiation or conduction into cooler places. Although just as much total energy remains, its being spread out more evenly means less can be done with it.

4.E.4 Different energy levels are associated with different configurations of atoms and molecules. Some changes of configuration require an input of energy whereas others release energy.

4.E.5 When energy of an isolated atom or molecule changes, it does so in a definite jump from one value to another, with no possible values in between. The change in energy occurs when radiation is absorbed or emitted, so the radiation also has distinct energy values. As a result, the light emitted or absorbed by separate atoms or molecules (as in a gas) can be used to identify what the substance is.

4.E.6 Energy is released whenever the nuclei of very heavy atoms, such as uranium or plutonium, split into middleweight ones, or when very light nuclei, such as those of hydrogen and helium, combine into heavier ones. The energy released in each nuclear reaction is very much greater than the energy given off in each chemical reaction.

F. MOTION

4.F.1 The change in motion of an object is proportional to the applied force and inversely proportional to the mass.

4.F.2 All motion is relative to whatever frame of reference is chosen, for there is no motionless frame from which to judge all motion.

4.F.3 Accelerating electric charges produce electromagnetic waves around them. A great variety of radiations are electromagnetic waves: radio waves, microwaves, radiant heat, visible light, ultraviolet radiation, x rays, and gamma rays. These wavelengths vary from radio waves, the longest, to gamma rays, the shortest. In empty space, all electromagnetic waves move at the same speed-the "speed of light."

4.F.4 Whenever one thing exerts a force on another, an equal amount of force is exerted back on it.

4.F.5 The observed wavelength of a wave depends upon the relative motion of the source and the observer. If either is moving toward the other, the observed wavelength is shorter; if either is moving away, the wavelength is longer. Because the light seen from almost all distant galaxies has longer wavelengths than comparable light here on earth, astronomers believe that the whole universe is expanding.

4.F.6 Waves can superpose on one another, bend around corners, reflect off surfaces, be absorbed by materials they enter, and change direction when entering a new material. All these effects vary with wavelength. The energy of waves (like any form of energy) can be changed into other forms of energy.

G. FORCES OF NATURE

4.G.1 Gravitational force is an attraction between masses. The strength of the force is proportional to the masses and weakens rapidly with increasing distance between them.

4.G.2 Electromagnetic forces acting within and between atoms are vastly stronger than the gravitational forces acting between the atoms. At the atomic level, electric forces between oppositely charged electrons and protons hold atoms and molecules together and thus are involved in all chemical reactions. On a larger scale, these forces hold solid and liquid materials together and act between objects when they are in contact-as in sticking or sliding friction.

4.G.3 There are two kinds of charges-positive and negative. Like charges repel one another, opposite charges attract. In materials, there are almost exactly equal proportions of positive and negative charges, making the materials as a whole electrically neutral. Negative charges, being associated with electrons, are far more mobile in materials than positive charges are. A very small excess or deficit of negative charges in a material produces noticeable electric forces.

4.G.4 Different kinds of materials respond differently to electric forces. In conducting materials such as metals, electric charges flow easily, whereas in insulating materials such as glass, they can move hardly at all. At very low temperatures, some materials become superconductors and offer no resistance to the flow of current. In between these extremes, semiconducting materials differ greatly in how well they conduct, depending on their exact composition.

4.G.5 Magnetic forces are very closely related to electric forces and can be thought of as different aspects of a single electromagnetic force. Moving electric charges produce magnetic forces and moving magnets produce electric forces. The interplay of electric and magnetic forces is the basis for electric motors, generators, and many other modern technologies, including the production of electromagnetic waves.

4.G.6 The forces that hold the nucleus of an atom together are much stronger than the electromagnetic force. That is why such great amounts of energy are released from the nuclear reactions in the sun and other stars.

CHAPTER 5 THE LIVING ENVIRONMENT

A. DIVERSITY OF LIFE

5.A.1 The variation of organisms within a species increases the likelihood that at least some members of the species will survive under changed environmental conditions, and a great diversity of species increases the chance that at least some living things will survive in the face of large changes in the environment.

5.A.2 The degree of kinship between organisms or species can be estimated from the similarity of their DNA sequences, which often closely matches their classification based on anatomical similarities.

B. HEREDITY

5.B.1 Some new gene combinations make little difference, some can produce organisms with new and perhaps enhanced capabilities, and some can be deleterious.

5.B.3 The information passed from parents to offspring is coded in DNA molecules.

5.B.4 Genes are segments of DNA molecules. Inserting, deleting, or substituting DNA segments can alter genes. An altered gene may be passed on to every cell that develops from it. The resulting features may help, harm, or have little or no effect on the offspring's success in its environment.

5.B.5 Gene mutations can be caused by such things as radiation and chemicals. When they occur in sex cells, the mutations can be passed on to offspring; if they occur in other cells, they can be passed on to descendant cells only. The experiences an organism has during its lifetime can affect its offspring only if the genes in its own sex cells are changed by the experience.

5.B.6 The many body cells in an individual can be very different from one another, even though they are all descended from a single cell and thus have essentially identical genetic instructions. Different parts of the instructions are used in different types of cells, influenced by the cell's environment and past history.

Standards

C. CELLS

5.C.1 Every cell is covered by a membrane that controls what can enter and leave the cell. In all but quite primitive cells, a complex network of proteins provides organization and shape and, for animal cells, movement.

5.C.2 Within every cell are specialized parts for the transport of materials, energy transfer, protein building, waste disposal, information feedback, and even movement. In addition, most cells in multicellular organisms perform some special functions that others do not.

5.C.3 The work of the cell is carried out by the many different types of molecules it assembles, mostly proteins. Protein molecules are long, usually folded chains made from 20 different kinds of amino-acid molecules. The function of each protein molecule depends on its specific sequence of amino acids and the shape the chain takes is a consequence of attractions between the chain's parts.

5.C.4 The genetic information encoded in DNA molecules provides instructions for assembling protein molecules. The code used is virtually the same for all life forms. Before a cell divides, the instructions are duplicated so that each of the two new cells gets all the necessary information for carrying on.

5.C.5 Complex interactions among the different kinds of molecules in the cell cause distinct cycles of activities, such as growth and division. Cell behavior can also be affected by molecules from other parts of the organism or even other organisms.

5.C.6 Gene mutation in a cell can result in uncontrolled cell division, called cancer. Exposure of cells to certain chemicals and radiation increases mutations and thus increases the chance of cancer.

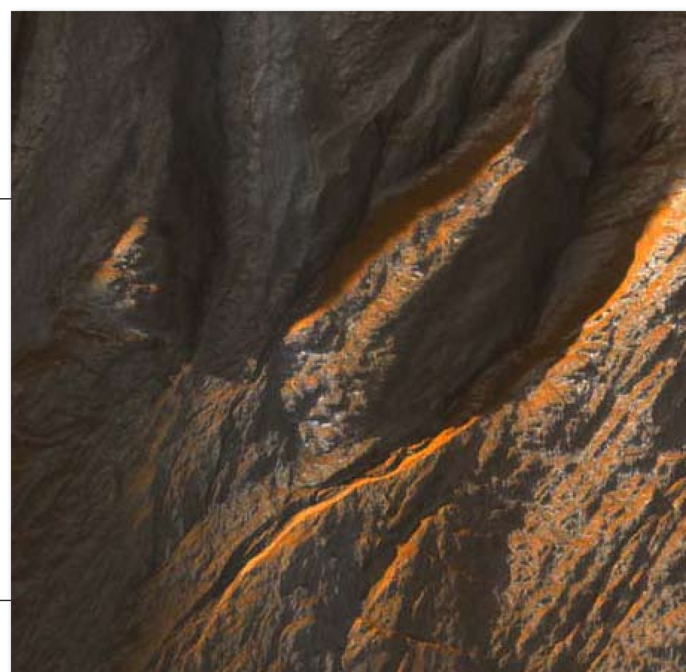
5.C.7 Most cells function best within a narrow range of temperature and acidity. At very low temperatures, reaction rates are too slow. High temperatures and/or extremes of acidity can irreversibly change the structure of most protein molecules. Even small changes in acidity can alter the molecules and how they interact. Both single cells and multicellular organisms have molecules that help to keep the cell's acidity within a narrow range.

5.C.8 A living cell is composed of a small number of chemical elements mainly carbon, hydrogen, nitrogen, oxygen, phosphorous, and sulfur. Carbon atoms can easily bond to several other carbon atoms in chains and rings to form large and complex molecules.

This enhanced-color view shows gullies in an unnamed crater in the Terra Sirenum region of Mars. It is a sub-image from a larger view imaged by the High Resolution Imaging Science Experiment (HiRISE) camera on NASA's Mars Reconnaissance Orbiter on Oct. 3, 2006. This scene is about 254 meters (about 830 feet) wide. The upper and left regions of this scene are in shadow, yet color variations are still apparent. The high signal to noise ratio of the HiRISE camera allows for colors to be distinguished in shadows. This allows dark features to be identified as true albedo features versus topographical features.

Image credit: NASA/JPL/Univ. of Arizona

http://www.nasa.gov/mission_pages/MRO/multimedia/pia01923.html



Standards

D. INTERDEPENDENCE OF LIFE

5.D.1 Ecosystems can be reasonably stable over hundreds or thousands of years. As any population of organisms grows, it is held in check by one or more environmental factors: depletion of food or nesting sites, increased loss to increased numbers of predators, or parasites. If a disaster such as flood or fire occurs, the damaged ecosystem is likely to recover in stages that eventually result in a system similar to the original one.

5.D.2 Like many complex systems, ecosystems tend to have cyclic fluctuations around a state of rough equilibrium. In the long run, however, ecosystems always change when climate changes or when one or more new species appear as a result of migration or local evolution.

5.D.3 Human beings are part of the earth's ecosystems. Human activities can, deliberately or inadvertently, alter the equilibrium in ecosystems.

E. FLOW OF MATTER AND ENERGY

5.E.1 At times, environmental conditions are such that plants and marine organisms grow faster than decomposers can recycle them back to the environment. Layers of energy-rich organic material have been gradually turned into great coal beds and oil pools by the pressure of the overlying earth. By burning these fossil fuels, people are passing most of the stored energy back into the environment as heat and releasing large amounts of carbon dioxide.

5.E.2 The amount of life any environment can support is limited by the available energy, water, oxygen, and minerals, and by the ability of ecosystems to recycle the residue of dead organic materials. Human activities and technology can change the flow and reduce the fertility of the land.

5.E.3 The chemical elements that make up the molecules of living things pass through food webs and are combined and recombined in different ways. At each link in a food web, some energy is stored in newly made structures but much is dissipated into the environment as heat. Continual input of energy from sunlight keeps the process going.

Evidence of a Water-Soaked Past

This navigation camera image taken by the Mars Exploration Rover Opportunity on the 36th martian day, or sol, of its mission (March 1, 2004) shows the layered rocks of the "El Capitan" area near the rover's landing site at Meridiani Planum, Mars. Visible on two of the rocks are the holes drilled by the rover, which provided scientists with a window to this part of the red planet's water-soaked past.

Scientists used the rover's microscopic imager and two spectrometers to look at the details of the freshly exposed, clean surfaces created by the rover's rock abrasion tool. Seeing beyond the veil of dust and coatings on the surface of the rock, scientists obtained the best views of the chemical composition of the areas. These data indicated that the rocks are made up of types of sulfate that could have only been created by interaction between water and martian rock.

The chemical make-up of the two holes is slightly different, giving scientists an inkling into the geologic history of this area. This history may help to explain the origin of the granular hematite found around the small crater cradling Opportunity and the "El Capitan" rock region.

The sulfates and the other chemicals found in the rocks at this location on Mars also occur on Earth, but only rarely. In places like Rio Tinto, Spain, similar minerals are forming today, and microorganisms live and thrive there. Analyzing these two clean surfaces created by the rock abrasion tool proves that Mars had interactions between water and rock over extended amounts of time. Life on Earth is sustained by extended interaction between water and the environment. The fact that scientists have now found evidence of a similar relationship between water and rock on Mars does not necessarily mean that life did develop on Mars, but it does bring the possibility one step closer to reality.

Opportunity's wheel tracks can be seen at the bottom left and right sides of this image. The tracks extend to the center of the image, indicating where Opportunity sat when it analyzed the rocks with the instruments on its robotic arm. Image Credit: NASA/JPL

http://marsrover.nasa.gov/gallery/press/opportunity/20040303a.html

Standards

F. EVOLUTION OF LIFE

5.F.1 The basic idea of biological evolution is that the earth's present-day species developed from earlier, distinctly different species.

5.F.2 Molecular evidence substantiates the anatomical evidence for evolution and provides additional detail about the sequence in which various lines of descent branched off from one another.

5.F.3 Natural selection provides the following mechanism for evolution: Some variation in heritable characteristics exists within every species, some of these characteristics give individuals an advantage over others in surviving and reproducing, and the advantaged offspring, in turn, are more likely than others to survive and reproduce. The proportion of individuals that have advantageous characteristics will increase.

5.F.4 Heritable characteristics can be observed at molecular and whole-organism levels-in structure, chemistry, or behavior. These characteristics strongly influence what capabilities an organism will have and how it will react, and therefore influence how likely it is to survive and reproduce.

5.F.5 New heritable characteristics can result from new combinations of existing genes or from mutations of genes in reproductive cells. Changes in other cells of an organism cannot be passed on to the next generation.

5.F.6 Natural selection leads to organisms that are well suited for survival in particular environments. Chance alone can result in the persistence of some heritable characteristics having no survival or reproductive advantage or disadvantage for the organism. When an environment changes, the survival value of some inherited characteristics may change.

5.F.7 The theory of natural selection provides a scientific explanation for the history of life on earth as depicted in the fossil record and in the similarities evident within the diversity of existing organisms.

5.F.8 Life on earth is thought to have begun as simple, one-celled organisms about 4 billion years ago. During the first 2 billion years, only single-cell microorganisms existed, but once cells with nuclei developed about a billion years ago, increasingly complex multicellular organisms evolved.

5.F.9 Evolution builds on what already exists, so the more variety there is, the more there can be in the future. But evolution does not necessitate long-term progress in some set direction. Evolutionary changes appear to be like the growth of a bush: Some branches survive from the beginning with little or no change, many die out altogether, and others branch repeatedly, sometimes giving rise to more complex organisms.

CHAPTER 12 HABITS OF MIND

A. VALUES AND ATTITUDES

12.A.1 Know why curiosity, honesty, openness, and skepticism are so highly regarded in science and how they are incorporated into the way science is carried out; exhibit those traits in their own lives and value them in others.

12.A.2 View science and technology thoughtfully, being neither categorically antagonistic nor uncritically positive.

B. COMPUTATION AND ESTIMATION

12.B.1 Use ratios and proportions, including constant rates, in appropriate problems.

12.B.2 Find answers to problems by substituting numerical values in simple algebraic formulas and judge whether the answer is reasonable by reviewing the process and checking against typical values.

12.B.3 Make up and write out simple algorithms for solving problems that take several steps.

12.B.4 Use computer spreadsheet, graphing, and database programs to assist in quantitative analysis.

12.B.5 Compare data for two groups by representing their averages and spreads graphically.

12.B.6 Express and compare very small and very large numbers using powers-of-ten notation.

Standards

B. COMPUTATION AND ESTIMATION

12.B.7 Trace the source of any large disparity between an estimate and the calculated answer.

12.B.8 Recall immediately the relations among 10, 100, 1000, 1 million, and 1 billion (knowing, for example, that 1 million is a thousand thousands).

12.B.9 Consider the possible effects of measurement errors on calculations.

C. MANIPULATION AND OBSERVATION

12.C.1 Learn quickly the proper use of new instruments by following instructions in manuals or by taking instructions from an experienced user.

12.C.2 Use computers for producing tables and graphs and for making spreadsheet calculations.

12.C.3 Troubleshoot common mechanical and electrical systems, checking for possible causes of malfunction, and decide on that basis whether to make a change or get advice from an expert before proceeding.

12.C.4 Use power tools safely to shape, smooth, and join wood, plastic, and soft metal.

D. COMMUNICATION SKILLS

12.D.1 Make and interpret scale drawings.

12.D.2 Write clear, step-by-step instructions for conducting investigations, operating something, or following a procedure.

12.D.3 Choose appropriate summary statistics to describe group differences, always indicating the spread of the data as well as the data's central tendencies.

12.D.4 Describe spatial relationships in geometric terms such as perpendicular, parallel, tangent, similar, congruent, and symmetrical.

12.D.5 Use and correctly interpret relational terms such as if . . . then . . . , and, or, sufficient, necessary, some, every, not, correlates with, and causes.

12.D.6 Participate in group discussions on scientific topics by restating or summarizing accurately what others have said, asking for clarification or elaboration, and expressing alternative positions.

12.D.7 Use tables, charts, and graphs in making arguments and claims in oral and written presentations.

Evidence of A Wet Martian Past

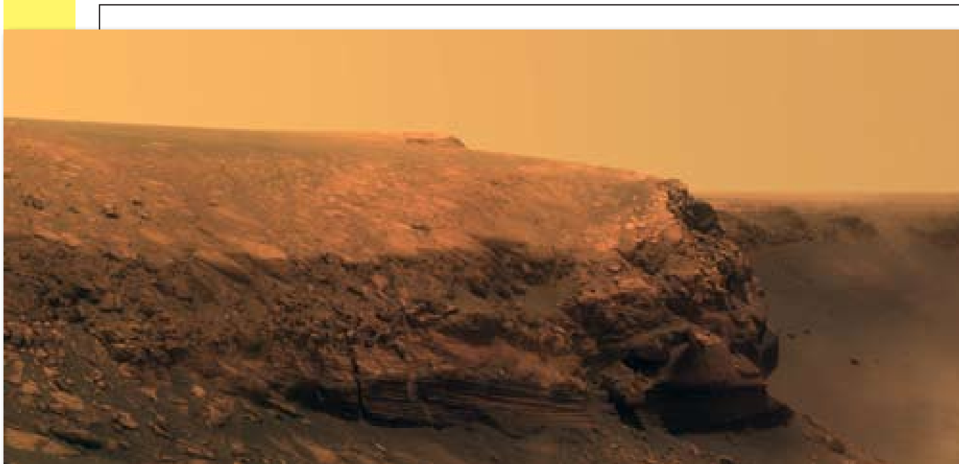
A shallow trench made by Spirit's dragging right front wheel uncovered some of the best evidence Spirit has found for ancient water-rich environments in Gusev Crater -- bright patches of almost pure, fine-grained silica (SiO2). On ancient Earth, warm, evaporating coastal waters deposited fine silica in shallow sediments. In Yellowstone National Park, hot, mineral-laden waters deposit fine-grained silica around geysers and hot springs. The discovery of silica-rich deposits on Mars adds compelling new evidence of ancient environments that might have been favorable for life.

Spirit acquired this false-color view of the remarkable, light-colored soil patch with the panoramic camera on the rover's 1,198th sol, or Martian day of exploration (May 17, 2007), more than three years after landing on Mars.

Image credit: NASA/JPL-Caltech/Cornell

http://marsrover.nasa.gov/gallery/press/spirit/20070628a.html

Standards



A promontory nicknamed "Cape Verde" can be seen jutting out from the walls of Victoria Crater in this approximate true-color picture taken by the panoramic camera on NASA's Mars Exploration Rover Opportunity. The rover took this picture on martian day, or sol, 1329 (Oct. 20, 2007), more than a month after it began descending down the crater walls – and just 9 sols shy of its second Martian birthday on sol 1338 (Oct. 29, 2007). Opportunity landed on the Red Planet on Jan. 25, 2004. That's nearly four years ago on Earth, but only two on Mars because Mars takes longer to travel around the sun than Earth. One Martian year equals 687 Earth days.

The overall soft quality of the image, and the "haze" seen in the lower right portion, are the result of scattered light from dust on the front sapphire window of the rover's camera.

This view was taken using three panoramic-camera filters, admitting light with wavelengths centered at 750 nanometers (near infrared), 530 nanometers (green) and 430 nanometers (violet).

Image Credit: NASA/JPL-Caltech/Cornell http://www.nasa.gov/mission_pages/mer/images/sol-1329atc.html

E. CRITICAL-RESPONSE SKILLS

12.E.1 Notice and criticize arguments based on the faulty, incomplete, or misleading use of numbers, such as in instances when (1) average results are reported, but not the amount of variation around the average, (2) a percentage or fraction is given, but not the total sample size (as in "9 out of 10 dentists recommend..."), (3) absolute and proportional quantities are mixed (as in "3,400 more robberies in our city last year, whereas other cities had an increase of less than 1%), or (4) results are reported with overstated precision (as in representing 13 out of 19 students as 68.42%).

12.E.2 Check graphs to see that they do not misrepresent results by using inappropriate scales or by failing to specify the axes clearly.

12.E.3 Wonder how likely it is that some event of interest might have occurred just by chance.

12.E.4 Insist that the critical assumptions behind any line of reasoning be made explicit so that the validity of the position being taken-whether one's own or that of others-can be judged.

12.E.5 Be aware, when considering claims, that when people try to prove a point, they may select only the data that support it and ignore any that would contradict it.

12.E.6 Suggest alternative ways of explaining data and criticize arguments in which data, explanations, or conclusions are represented as the only ones worth consideration, with no mention of other possibilities. Similarly, suggest alternative trade-offs in decisions and designs and criticize those in which major trade-offs are not acknowledged.

CONTENTS

DVD with introduction and lessons

CD containing all activities in Microsoft Word and Adobe Acrobat formats for classroom duplication only and a poster to print and display.

Image credit Peter Suchecki: Timo Ruskeeniemi (Geological Survey of Finland) taking water chemistry measurements from High Lake mine, Nunavut Territories, Canada.

Image credit Peter Suchecki: Adam Johnson (Indiana University) collecting soil samples at High Lake mine, Nunavut Territory, Canada

Back cover image credit Lisa M. Pratt: Snowy night at Lupin Mine, Nunavut Territories, Canada.

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