THE WORLD OF BACTERIA

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INTRODUCTION

At this moment, you are surrounded by organisms you cannot see. Their ancestors were among the first organisms in the history of life on Earth—and their ability to adapt to new situations makes them well suited for life in the future. They are bacteria, tiny single-celled microbes that represent an enormous range of life styles.

All too often the study of biology focuses on larger, more familiar plants and animals and overlooks the amazingly versatile and widespread bacteria. Yet these microorganisms reproduce at fantastic rates, make use of a huge variety of living conditions, survive in extreme hardship, colonize our own bodies, and provide powerful tools for genetic engineering. Their relatively simple structure makes bacteria an excellent example for study.

Live-action video is an engaging way to present ideas—powerful images and a carefully-crafted narration can capture the imagination of students and bring the study of bacteria to life. ***The World of Bacteria*** poses a set of questions in everyday language as a way to draw attention to many of the most important concepts in biology. The program delivers many stunning microscopic sequences. Among the most powerful images is the visual record of bacterial reproduction—cells elongate and split in two, rapidly increasing from one or two cells to a huge population as you watch. Differences in cell shape are obvious in the beautiful scanning photomicrographs. The video shows the wide variety of habitats where bacteria are found and explains how they cause human disease. An interview with a research scientist helps to explain how mutation enables bacteria to develop resistance to antibiotics. The video also explains the ways that bacteria interact with other organisms and the impact of bacterial life on the physical environment. Just as bacteria use humans as a place to live, so the roles reverse: humans make use of bacteria in food industry, in toxic waste management and in genetic engineering.

LEARNING OBJECTIVES

After viewing the video ***The World of Bacteria***, participating in class discussions, and completing the activities and review questions in this Teacher's Resource Book, your students should:

- realize that bacteria are found almost everywhere on Earth.
- understand that some bacteria (pathogens) cause human disease, but other bacteria are beneficial.
- recognize the differences in prokaryotic bacterial cells and eukaryotic cells.
- become aware that bacteria are among the oldest species and exhibit huge diversity among modern species.
- appreciate the significance of rapid reproduction in bacterial populations.
- relate the role of mutation to natural selection in bacterial populations.
- recognize the interdependence of bacteria and other organisms.
- understand that scientific explanations are modified in response to new data.

The video ***The World of Bacteria*** brings to life the intriguing but sometimes overlooked story of microscopic organisms known as bacteria. Given that bacteria are among our most numerous neighbors, even living within our bodies, they are important to us in a variety of ways. Furthermore, the study of bacteria provides a dynamic example of the major principles of life, including reproduction, energy use, cell structure and function, genetic mutation, interactions with other organisms, and evolution.

The World of Bacteria organizes these ideas through a series of questions posed in familiar language:

- Where do bacteria live?
- How long have bacteria been around?
- What is the difference between bacteria and other organisms?
- How can you tell bacteria apart?
- How do bacteria reproduce?
- What do bacteria do to people?
- What do people do to bacteria?
- What do bacteria do to the environment?

For each question, the video combines rich images of these fascinating microorganisms and their habitats with instructive graphics and live laboratory scenes to explain the answers. The questions themselves offer a simple and engaging way to get students to think about the major biological concepts.

Where do bacteria live? The program opens with a trip to some of the strange places that bacteria are found: the blazing desert, frozen Antarctica, boiling hot springs, and even in the intestines of cows and humans. Students learn that bacteria are found in the dark depths of the ocean floor, near hot thermal vents. This unusual habitat supports a food web that does not have photosynthetic producers as the base. Instead, it depends on bacteria that gain energy from oxidizing hydrogen sulfide. This situation is in dramatic contrast to life in the upper, sunlit ocean waters, where huge quantities of photosynthetic bacteria called cyanobacteria are found.

How long have bacteria been around? For over three-and-a-half billion years, bacteria have lived on Earth—that is over three-quarters the age of the planet itself. It took another billion years for bacteria similar to the photosynthetic bacteria of the modern oceans to appear—and once they did, they began to supply oxygen and, indirectly, protective ozone to our atmosphere.

What is the difference between bacteria and other organisms? The video takes students into the microscopic world, first seeing the variety of tiny organisms in a droplet of pond water. Bacteria are there in the millions, but they are not the only single-celled organisms. The program uses vivid images through a microscope and clear diagrams to contrast prokaryotic bacterial cells with eukaryotic cells such as the amoeba and paramecium. This entertaining introduction to cell structure and function also demonstrates some of the basic characteristics on which taxonomic classification is based. For instance, students learn that eukaryotic cells, including human cells, have a nucleus and other membrane-contained organelles such as mitochondria. The nucleus houses the genetic material. The prokaryotic bacterial cell, in contrast, is generally smaller and simpler in structure, lacking a nucleus and organelles. Even the ribosomes are different in bacteria, so they are an important target for the action of antibiotics.

Evolutionary relationships form the basis of biological classification. Traditionally eukaryotes have been divided into four kingdoms: Plants, Animals, Fungi and Protists. Bacteria were grouped together as Monera. New genetic data suggest a higher level of organization, known as a domain. All eukaryotic kingdoms are in one domain, Eukarya. Prokaryotes form two domains, the Eubacteria (or simply Bacteria) and Archaea. These changes in nomenclature show that scientific explanations change and grow in response to new data.

How can you tell bacteria apart? Each bacterium is a single cell, yet there are many different species. Students generally do not have access to the genetic and biochemical technologies needed to do detailed classification of bacteria, but there are some simpler ways to tell bacteria apart. Excellent micrographs show the three main shapes of bacteria: spherical cocci, rod-shaped bacilli, and spiral spirilli. Differences in cell structure, such as cell wall differences, also can be used. A special staining process known as the Gram stain causes some species to appear violet-blue (Gram positive) while others appear reddish (Gram negative). The connection between structure and function is also apparent in bacteria that swim. They have one or more rotating structures called flagella that enable them to move toward or away from specific substances.

How do bacteria reproduce? This question is answered with time-lapse sequences of bacterial cells dividing—dramatically showing how bacteria achieve huge populations in a matter of hours. Without limitation, a bacterial population can double in as little as 20 to 30 minutes. Students learn that fortunately there are limitations to population size: lack of food, accumulation of toxins or predators can slow or stop growth. The video demonstrates the action of one natural enemy of bacteria, the bacteriophage virus. The DNA of the virus takes over the bacterial cell and turns it into a factory for more viruses.

Finally, students learn that when reproduction is hampered by very severe conditions, some bacteria go into a resting state to wait for better times. The cell DNA is packaged into a protective endospore, and the cell itself disintegrates.

What do bacteria do to people? Many bacteria are natural inhabitants of the surface or gut of humans, where they help maintain the local environment or compete against pathogenic microorganisms. *E. coli* found in the intestines are a good example. Other bacteria enter the body through cuts in skin, through food, through the respiratory tract or through sexual contact. These bacteria may be pathogenic. Some cause common conditions such as acne, body odor or dental cavities. Others may cause serious or fatal illnesses including tetanus, food poisoning, sore throat, pneumonia or sexually transmitted diseases including syphilis.

The video demonstrates that pathogenic bacteria cause damage to the human body in two ways: by direct invasion of tissues or by production of toxins that act at a distance. The body has a variety of natural defenses. The skin itself is a barrier, the lungs have ways to expel foreign material, and the body can make specific defense proteins known as antibodies. Immune cells also attack and ingest invading bacteria.

People do not always rely solely on the body's own defenses against bacterial infection. Antibiotics are chemicals used to target specific features of the prokaryotic bacterial cell that differ from the eukaryotic cells of the human host. Antibiotics have greatly reduced the threat of bacterial infections, but they are becoming less effective as bacteria mutate and become resistant. The video shows a laboratory culture plate used to test for antibiotic resistance. This topic serves as a tangible example to explain the role of mutation, reproduction and natural selection in evolution. The program describes the molecular basis of mutation, showing that errors can be introduced into the DNA code and passed on to offspring.

What do people do to bacteria? By overusing antibiotics, people unintentionally are directing the evolution of bacteria toward more antibiotic resistance. In other ways, people use bacteria for a variety of purposes, including food production and clean up of environmental hazards such as oil spills. One of the most widespread uses of bacteria by people is in genetic engineering. Bacteria are used in research and industry as the source of genes for cloning and as little factories for the production of cloned products. For example, genetically engineered bacteria are used to produce human insulin for the treatment of diabetes.

What do bacteria do to the environment? Ancient photosynthetic bacteria actually helped build our oxygen-rich atmosphere. Dead organisms are cleaned away and their molecules recycled by bacteria known as decomposers. Bacteria also are involved in the nitrogen cycle. A mutually helpful or symbiotic relationship between bacteria and plants is the first step for converting atmospheric nitrogen into forms that can be used by a variety of organisms. The nitrogen-fixing bacteria carry out this step. The nitrogen cycle includes denitrifying bacteria that break down nitrogen-containing compounds. The video closes with a brief review of these questions.

Use this video program and teaching guide to start students thinking about the big concepts in biology rather than memorizing facts. The dynamic format of the video medium and the active nature of this Teacher's Resource Book let students absorb and apply these ideas.

A good way to start is to do a quick preview of ideas to find out what students already think about the topics in the video and to help students focus on the ideas as they are presented. This process is a way of "testing the water" rather than a test *per se*. The following questions are offered as a sample. The important thing is to explore what students think rather than to push for correct answers or to penalize students for mistakes. Keep this preview short—just a teaser before you start the video.

Sample preview questions:

1. What do you think of when you hear the word "bacteria"?
2. Are all bacteria dangerous?
3. How are bacteria different from humans?
4. How do bacteria interact with the world around them?
5. Look at this [*insert a substance such as soil, pond water, or object that has been left outdoors*]. Do you think it contains bacteria? How could you tell?

After students have a few minutes to express their existing ideas about bacteria, view the video. Then reinforce the concepts by using the *Discussion Guide* on pages 9-12, and by letting students try the *Student Activity Sheets* on pages 13-28 in this Teacher's Resource Book. In addition, you may want to use the *Video Review Questions* on pages 13-16 to reinforce their recall of basic information.

Keep in mind that the *Video Review Questions* focus on basic information. For deeper understanding, use the *Discussion Guide* questions on pages 9-12 and the *Student Activity Sheets* which begin on page 13. They provide a way for students to apply and reinforce their new knowledge. The organizing questions in the video also can be used to guide a discussion or a review. They are related to major concepts in the National Science Education Standards.

Making the most of the student activities:

The student activities in this Teacher's Resource Book require the use of worksheets, interpretation of diagrams and data or access to outside resources. These activities may work best as a homework assignments. When appropriate, an answer sheet is offered.

- **COLOR ENHANCEMENT**: Please note that micrographs have been color enhanced for clarity. You may want to explain to students that bacteria are not in reality the bright colors depicted in some of the images.

- **BIOLOGICAL CLASSIFICATION**: New data from genome studies is rapidly expanding our understanding of bacterial species. As this happens, taxonomic classifications change to reflect the new data. As the video explains, organisms traditionally were divided into five kingdoms, with all prokaryotes being grouped together as Monera. More modern approaches recognize distinct divisions among prokaryotes, most often grouped as the domains Eubacteria (or simply called Bacteria) and Archaea. In the strictest sense, the term "bacteria" excludes the Archaea. For simplicity in this program, we have used the term "bacteria" more loosely, in the traditional sense, to refer to prokaryotes. Detailed differences between the prokaryotic domains are not covered. For example, Archaea lack the peptidoglycan characteristic of the bacterial cell wall. Taxonomy is a topic of intense research. Over the next several years, the details of classification in this area will no doubt be further modified. Help your students appreciate that change shows the strength of scientific knowledge, which is shaped and improved as new evidence comes to light.

- **CELL SIZE**: Not all bacterial cells are smaller than eukaryotic cells, though the larger ones are rare. An extreme example is a huge bacterium discovered in 1993 by Ester Angert and Norman Pace. The huge bacterium was found in the digestive system of surgeonfish. It is about the size of a typewritten period. Clearly bacteria show enormous diversity.

- **CYTOSKELETON**: Another distinction traditionally listed between prokaryotes and eukaryotes was the presence of a protein cytoskeleton in cells of eukaryotes. In a few instances, however, a fairly simple cytoskeleton framework has been observed in prokaryotes, too. The first observation was in *Bacillus subtilis* by an Oxford University team. See Science News, Vol. 159, March 31, 2001, page 198 for a summary. The research report was published in the technical journal Cell on March 23, 2001.

- **PLASMIDS**: The program refers to genetic engineering but does not attempt in the short time available to describe the technology. You may want to explain to students that bacteria are useful for a variety of reasons. For one thing, they are the source of cloning vehicles known as plasmids. A plasmid is a small loop of DNA found outside the DNA chromosome (the major genetic material). Bacteria may contain more than one plasmid. Plasmids have been altered for use in laboratory research. They often have a selectable factor such as antibiotic resistance and convenient sites that can be cut open for insertion of a gene to be cloned. Replication of the plasmid within a bacterial population provides multiple copies of the cloned gene.

NATIONAL SCIENCE EDUCATION STANDARDS: KEY CONCEPTS

The World of Bacteria video program and this Teacher's Resource Book can be used to teach many key concepts based on the National Science Education Standards (NSES) content standards for life science and scientific inquiry, grades 9 through 12. In particular, they are:

The cell
The video makes a comparison between bacterial (prokaryotic) and eukaryotic cell structures and shows the main parts of the cell and how structure relates to function. For example, the cell wall protects the bacterial cell from stress. Flagella provide motility. Cell membranes help regulate flow of molecules in and out of cells. The nucleus of eukaryotic cells houses and protects the genetic material.

Molecular basis for heredity
The program describes the role of DNA as the storage molecule for genetic information. It shows how molecular alterations in DNA result in heritable changes (mutations).

Biological evolution
The video describes the long history of bacteria over three-and-a-half billion years. Current classification systems that reflect the newest data about evolutionary relationships are presented. The program uses the example of antibiotic resistance to show how natural selection can alter a population of bacteria.

Interdependence of organisms
The video outlines the flow of energy from bacterial producers (photosynthetic bacteria in ocean waters and the chemosynthetic thermophiles at deep sea vents) to other organisms known as consumers. The program explains that bacterial reproduction is rapid but limited by factors such as lack of food, toxins or predators. Bacterial cooperation with other organisms including humans is described. The video uses the example of natural bacterial populations in the human body to show competition between beneficial bacteria and pathogens.

Matter, energy and organization in living systems
Photosynthetic bacteria are shown to be one of the major sources of energy flow from nonliving systems into living systems. The role of bacteria as decomposers and as part of the nitrogen cycle shows how chemical elements are organized in different ways as they cycle through living and nonliving systems.

Scientific explanations are modified in response to new evidence
Introduction of a new level of classification, the three domain system, shows students how scientific explanations change as new data, such as genome sequences, are discovered.

The video's organizing questions (listed in the *Program Summary* on pages 3-5) can be used after viewing the video to help students recall what they have seen. This *Discussion Guide* below go into more depth than the review questions. These questions are useful to foster discussion and encourage students to apply and expand what they have learned. It is not necessary to use all the questions listed below—we provide a variety of discussion areas. Select the points you want to emphasize.

1. **Some bacteria produce endospores when conditions are hazardous.**

    a) **What are endospores and what advantage do they provide?**
    Endospores are dormant forms of bacteria. An endospore is a protective capsule that encloses the cell's genetic material. The advantage of endospores is that they let the cell remain inactive when conditions do not favor growth. If conditions improve, the endospore becomes active and normal reproduction resumes.

    b) **Are endospores a form of reproduction? Explain.**
    Endospores are not a form of reproduction because each one is produced from one bacterial cell. They do not involve replication of DNA to make a second copy as is true in the production of offspring.

2. **Antibiotics are chemicals used to kill bacteria without killing the human host.**

    a) **Many antibiotics, including erythromycin and streptomycin, target the ribosomes of bacteria but not those of eukaryotes. Why is that useful?**
    Ribosomes carry out protein synthesis, an essential function for life. Bacterial ribosomes are different than those of eukaryotic cells such as human cells, so these antibiotics do not disrupt protein synthesis in human cells. In this way the bacterial infection can be stopped without harming the person.

    b) **Penicillin is an antibiotic that binds to a particular component of prokaryotic cell walls during cell division. What does that tell you about its impact on a population of bacteria?**
    Unless the bacteria are resistant, the penicillin will kill cells as they divide. If a population of bacteria is not actively reproducing, however, the penicillin will not have much effect.

    c) **Recall from the video what you learned about mycoplasmas. Which antibiotic would you expect to be more useful in treating a tuberculosis infection caused by *Mycoplasma tuberculosis*, penicillin or streptomycin? Explain your reasoning.**
    Streptomycin would be more useful, because it targets protein synthesis. Mycoplasmas do not have cell walls, so penicillin is not effective.

d) **Viruses can cause human disease. Explain why bacterial antibiotics are not useful against viral infections.**
The virus is a parasite that enters the human host cell and relies on its protein machinery and DNA replication enzymes to reproduce. Antibiotics that target bacterial cells will not kill the human cell and hence won't harm the virus inside. There are some relatively modern drugs that can target viral replication and are effective. They are separate from bacterial antibiotics.

e) **An exciting report about a new approach to antibiotics appeared in Science News Vol. 160 on 28 July 2001. It describes nanobiotics. These molecules form extraordinarily tiny, hollow tubes when they encounter the negatively charged membranes of bacteria. Nanobiotics do not form these tubes in the neutral membranes of mammals. Speculate about why nanobiotics may be useful.**
They target an aspect of bacterial structure that is different from human cells. The hollow tubes would disrupt membrane and cell function, killing the bacteria. Because nanobiotics aim for a broader target than many antibiotics, bacteria may be slower to develop resistance to them.

3. **Some organisms are producers that make organic compounds (food) from inorganic compounds. They also bring energy into living systems. Some organisms are consumers that eat material from other organisms. One group of consumers are known as decomposers because they feed on dead organisms.**

a) **Describe how these different roles form a food web.**
Producers such as photosynthetic organisms form a bridge between the inorganic and organic systems. Producers serve directly as a source of chemical energy and building materials for consumers that eat them. When organisms die, their material may be recycled into the inorganic world by decomposers.

b) **Which of these roles do bacteria play? Explain.**
Bacteria can play all three roles. For example, cyanobacteria are photosynthetic producers found in the upper waters of the ocean. Bacteria that invade a human body are consumers. Bacteria that decompose dead animals or plants are playing the role of decomposers.

c) **Name two sources of energy for different producers.**
Photosynthetic producers use light energy from sunlight. Chemosynthetic producers use energy from oxidizing chemical compounds such as oxidization of sulfur compounds.

4. **How do bacteria move? Can all bacteria do it? How might motility (the ability to move) be an advantage for bacteria?**

   Not all bacteria are motile. Most species that are motile move by means of one or more long, rotating structures known as flagella. Motility enables bacteria to move toward food or away from danger.

5. **Some bacteria are pathogens that can cause human disease.**

   a) **What are the entry points for bacterial infection?**
   Entry points include a break in the skin, through the mouth or nose while breathing, through food, and through sexual contact.

   b) **What natural defenses does the body have?**
   Natural defenses include immune cells (white blood cells) that attack invaders; proteins known as antibodies made specifically to attach to chemical components of a particular invader; unbroken skin serves as a barrier to invasion; cilia in airways to push out foreign material; and our conscious choice for low-risk behaviors.

   c) **Why might these defenses sometimes be unable to protect a person?**
   Illness can lower immune defenses; the invading organisms could be present in such high numbers that they overwhelm defenses; invading organisms could actually attack the immune system.

   d) **What behaviors can you personally choose to reduce your risk of infection?**
   You could have good personal hygiene, such as washing hands often; you could avoid engaging in unprotected sexual activity; you could avoid people with contagious infections; keep the body strong by good nutrition, sleep and exercise; be sure not to leave food unrefrigerated; cook meat well; wash fruit and vegetables before eating them.

   e) **What public policies exist to reduce the threat of bacterial infection?**
   Examples include: public water supplies are monitored for contamination; most places of business provide sick leave—if sick people stay at home they will not infect coworkers; food quality and handling is regulated; antibiotic use is regulated.

6. **Sometimes bacteria that are normal inhabitants of the human body can cause disease, if given the chance. One example is *Staphylococcus epidermidis*. These bacteria normally live on the skin. They grow in colonies that are clusters of cells held together with a protein-sugar substance made by the bacteria themselves. However, these bacteria may cause serious damage by infection if they enter the body during surgery or via a wound.**

   a) **What might be the advantage of the protein-sugar substance holding the cells together in a cluster?**
   The substance provides some protection from predators (white blood cells) or from antibiotic action, and it offers some protection against environmental changes (flow of body fluids). To some extent the bacteria are making their own environment or habitat that is favorable to them.

   b) **Why do you think *Staphylococcus epidermidis* does not normally cause disease?**
   The skin acts as a barrier to keep them out of internal body systems. Surgery can provide an opening for their entry.

7. ***Prochlorococcus* is the smallest known photosynthetic organism. It is an example of cyanobacteria found in the ocean water. Some reports suggest that *Prochlorococcus* is the single most abundant photosynthetic species in the world.**

   a) **In what part of the ocean would you expect to find *Prochlorococcus*?**
   In the upper few meters in which sunlight filters through the water.

   b) **How could the presence of *Prochlorococcus* in ocean water affect animals living in the ocean?**
   As one of the major sources of photosynthesis, these bacteria are an entry point for energy and carbon into the food web of the ocean. Some animals consume organic material from Prochlorococcus *and, in turn, become a meal to larger animals. Material from bacteria in the upper layers of the ocean filter down into lower waters.*

STUDENT ACTIVITIES

Name: ____________________________

ACTIVITY 1-A

VIDEO REVIEW QUESTIONS

After you have viewed the video ***The World of Bacteria***, answer the following questions on the back of this page, or on a separate sheet of paper.

1. Are all bacteria dangerous to people? Explain.
2. Why don't antibiotics kill people as well as bacteria?
3. What is antibiotic resistance, and what can make it increase?
4. Describe two ways in which pathogenic bacteria harm people.
5. Organisms are classified as prokaryotes or eukaryotes. Describe the difference in prokaryotic cells and eukaryotic cells.
6. In which group are bacteria classified?
7. Give at least four examples of eukaryotes.
8. Are any eukaryotes single-celled? Explain.
9. Explain how organisms are classified into three domains, Eubacteria (Bacteria), Archaea, and Eukarya.
10. Bacterial reproduction can be very rapid. How do bacteria reproduce?
11. What happens to the DNA of a cell when it is going to reproduce?
12. What happens to the DNA of a cell when a mutation occurs?
13. What is the importance of a rapid reproduction rate in terms of evolution?
14. What is meant by the term "doubling time?"
15. How can the overuse of antibiotics increase resistance in bacterial populations?
16. What roles do bacteria play in the nitrogen cycle?
17. Why are photosynthetic cyanobacteria found in the upper few meters of the ocean instead of deeper?
18. Bacterial populations are found everywhere on Earth, and they show great ability to adapt to new conditions. How long have bacteria lived on Earth?
19. What effect did early photosynthetic bacteria have on the atmosphere?
20. A simple way to tell bacteria apart is by their shape. What are the three main shapes of bacteria?
21. What group is an exception to these three shapes and why?
22. What is a Gram stain?

Name: ___________________________

ACTIVITY 1-B

ANSWER KEY

1. Are all bacteria dangerous to people? Explain.
No, some are pathogenic but many are beneficial. They are normal inhabitants of the human body that compete with pathogens or maintain body conditions. Bacteria also are used in food processing, waste management and genetic engineering.

2. Why don't antibiotics kill people as well as bacteria?
Bacterial antibiotics target characteristics of prokaryotic cells that are different than eukaryotic cells.

3. What is antibiotic resistance, and what can make it increase?
Antibiotic resistance is the ability of bacteria to survive treatment with an antibiotic. It results from an altered gene (mutation) that can be passed from one bacterium to another or inherited by offspring in a population. Continued exposure to the antibiotic provides a selective pressure that favors survival of the resistant bacteria.

4. Describe two ways in which pathogenic bacteria harm people.
Bacteria cause harm by directly invading and damaging tissue or by producing toxins that attack the body often away from the site of infection.

5. Organisms are classified as prokaryotes or eukaryotes. Describe the difference in prokaryotic cells and eukaryotic cells.
Prokaryotes have simpler cells that lack a nucleus or organelles. Almost all prokaryotes have special cell walls. The ribosomes of prokaryotes differ from those of eukaryotes. Prokaryotes generally are smaller.

6. In which group are bacteria classified?
Bacteria are prokaryotes.

7. Give at least four examples of eukaryotes.
Eukaryotic organisms are found in four kingdoms: Animals, Protists, Fungi or Plants. Humans are eukaryotes.

8. Are any eukaryotes single-celled? Explain.
Not all single-celled microorganisms are prokaryotes. For example, the amoeba and the paramecium are single-celled eukaryotes.

9. Explain how organisms are classified into three domains, Eubacteria (Bacteria), Archaea, and Eukarya.
Organisms are classified according to their evolutionary relationships. Genetic data and biochemical data are particularly helpful in analyzing these relationships. Prokaryotes fall into two of the domains (Bacteria and Archaea) and all eukaryotes are in the third domain (Eukarya).

10. Bacterial reproduction can be very rapid. How do bacteria reproduce?
They reproduce by cell division (binary fission).

11. What happens to the DNA of a cell when it is going to reproduce?
The DNA is replicated to produce a new copy so that both offspring cells will have a copy.

12. What happens to the DNA of a cell when a mutation occurs?
A physical alteration in DNA changes the encoded genetic information. This change can then be passed along to offspring.

13. What is the importance of a rapid reproduction rate in terms of evolution?
Rapid reproduction means that many generations and large populations are produced in a relatively short time. This increases the chance of a useful mutant showing up when conditions are difficult. In that situation, offspring of the mutant organism may come to dominate a population.

14. What is meant by the term "doubling time?"
It refers to the time needed for the size of a population to double, in other words, to produce a new generation in the case of bacteria.

15. How can the overuse of antibiotics increase resistance in bacterial populations?
It provides a selective pressure that favors bacteria carrying the resistance genes.

16. What roles do bacteria play in the nitrogen cycle?
Nitrogen-fixing bacteria bring nitrogen from the atmosphere into living systems. Other bacteria produce various nitrogen compounds. Denitrifying bacteria break down nitrogen compounds and return nitrogen to the atmosphere.

17. Why are photosynthetic cyanobacteria found in the upper few meters of the ocean instead of deeper?
Sunlight, the energy for photosynthesis, only filters through the upper waters.

18. Bacterial populations are found everywhere on Earth, and they show great ability to adapt to new conditions. How long have bacteria lived on Earth?
For about three-and-a-half billion years, about three-quarters of the age of the planet.

19. What effect did early photosynthetic bacteria have on the atmosphere?
They contributed oxygen and, indirectly, ozone to the atmosphere.

20. A simple way to tell bacteria apart is by their shape. What are the three main shapes of bacteria?
The three shapes are spheres (cocci), rods (bacilli), and spirals (spirilli).

21. What group is an exception to these three shapes and why?
Mycoplasmas lack a cell wall to give rigidity to the cell, so they form twisted and irregular shapes.

Name: ___________________________

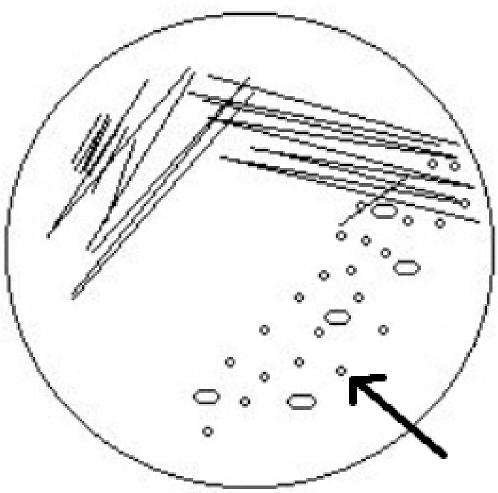
22. What is a Gram stain?
It is a differential staining technique used to tell different bacteria apart. The first dye or stain turns cells a deep blue-violet color. After decolorizing and exposure to a second dye, some cells retain the original color (Gram positive) while others lose the first stain and pick up the second, turning a reddish color (Gram negative). This process lets the laboratory worker quickly distinguish bacteria in these groups. The difference in staining is based on differences in the cell wall composition.

Name: ___________________________

Look at the following diagram of bacterial culture plates. The bacteria are grown on a support substance known as agar that contains nutrients needed for growth. The arrow below marks the specific colony on Plate A used to inoculate Plate B.

Plate A

Plate B



On a separate sheet of paper, answer the following questions.

1. A sample from a patient's throat was streaked across plate A. What does each dot on plate A represent?

2. Plate B was prepared by touching a sterile inoculation loop to one dot on plate A and streaking the loop across plate B. What might be the advantage of this technique?

3. In the video, a plate with antibiotic discs was used to test for antibiotic resistance. How was resistance observed?

Name: ______________________

ACTIVITY 2-B

ANSWER KEY

1. A sample from a patient's throat was streaked across plate A. What does each dot on plate A represent?
Each dot on plate A is a colony which contains millions of bacteria. The bacteria in each colony are a population grown from a single cell, so most of the bacteria in a colony are identical (except rare mutants). Because the source was a throat culture, however, the different dots likely contain different species or strains of bacteria. Some are normal inhabitants and some may be pathogenic.

2. Plate B was prepared by touching a sterile inoculation loop to one dot on plate A and streaking the loop across plate B. What might be the advantage of this technique?
By streaking from one dot or colony on plate A, the technician can produce a culture of just that one bacterial population (plate B) for further study. This population is called an isolate. Note that the colonies on plate B all look essentially the same.

3. In the video, a plate with antibiotic discs was used to test for antibiotic resistance. How was resistance observed?
The resistance test uses a plate with a lawn of bacteria covering the surface. Each disc contains one antibiotic to be tested. If a clear area appears around the disc, the antibiotic is preventing growth of bacteria that come in contact. If the opaque lawn of bacteria grows right up to the disc, however, the bacteria must be resistant to the antibiotic in that particular disc and can thrive even when in contact with it.

Name: ___________________________

POPULATION GROWTH DATA

Reproduction in a bacterial population can be measured in the laboratory. A flask of sterile, liquid medium containing nutrients for growth is inoculated with a small quantity of bacteria. The flask is incubated at the appropriate temperature, usually on a shaker to keep the liquid aerated. As the bacteria reproduce, the liquid becomes cloudy. The degree of cloudiness or turbidity can be measured by shining light through the culture and finding out how opaque it becomes as the population grows. The instrument used for this measurement is a spectrometer. The reading is called absorbance. Absorbance is measured at a specific wavelength of light (usually 600nm). The greater the light absorbance value, the larger the population of bacteria. When the absorbance reading doubles, the number of cells in the solution has doubled.

1. On a separate sheet of paper, plot the growth data for an *E. coli* culture given in Table 1. Each measurement shows how opaque the culture is at particular time intervals. Plot time on the X-axis and amount of cells shown by absorbance on the Y-axis. (Hint: You can use either regular graph paper or logarithmic paper to make this plot.)

TABLE 1:

Time (hr)	Absorbance (600 nm)
0	0.05
0.5	0.05
1	0.05
1.5	0.08
2	0.09
2.5	0.12
3	0.14
3.5	0.21
4	0.25
4.5	0.35
5	0.50
5.5	0.64
6	0.78
6.5	0.91
7	1.01
7.5	1.02
8	1.03
8.5	1.02
9	1.01
9.5	1.04
10	1.02

This activity is continued on the next page.

2. What is the shape of the resulting curve?

3. Does the curve level off at advanced times? What do you think is happening?

4. Estimate the doubling time by determining how long it takes the culture to grow from an absorbance of 0.2 to 0.4. and then from 0.4 to 0.8. What time do you calculate?

5. Based on the information in the video, *E. coli* can produce a new generation in as little as 20-30 minutes. Do you think the population of *E. coli* measured in this experiment is growing at its maximum rate? Explain.

Name: ___________________________

ACTIVITY 3-C

ANSWER KEY

1. On a separate sheet of paper, plot the growth data for an *E. coli* culture given in Table 1. Each measurement shows how opaque the culture is at particular time intervals. Plot time on the X-axis and amount of cells shown by absorbance on the Y-axis. (Hint: You can use either regular graph paper or logarithmic paper to make this plot.)
Student graphs will vary, but the curve should be S-shaped or similar.

2. What is the shape of the resulting curve?
Plotted on regular graph paper, the curve will be S-shaped, with a slow start or "lag phase" during which time all the cells are getting ready to divide and then rapid increase during reproduction, followed by leveling off. If plotted on logarithmic paper, the area of maximum growth rate or exponential growth will form a straight line.

3. Does the curve level off at advanced times? What do you think is happening?
Yes, it reaches a maximum value. Bacterial reproduction is being limited. Barriers could include crowding, lack of food, presence of toxins from wastes or dying cells.

4. Estimate the doubling time by determining how long it takes the culture to grow from an absorbance of 0.2 to 0.4. and then from 0.4 to 0.8. What time do you calculate?
This culture undergoes a generation (doubling) in about one hour.

5. Based on the information in the video, *E. coli* can produce a new generation in as little as 20-30 minutes. Do you think the population of *E. coli* measured in this experiment is growing at its maximum rate? Explain.
This population is not growing at the faster rate observed for E. coli. These cells may not be in the best growth conditions (nutrients, pH, temperature) or they may be a strain that grows more slowly normally.

Name: ______________________________

cows
soybeans
giant tubeworms at deep sea vents

All of these organisms have mutually beneficial (symbiotic) relationships with bacteria. For this activity, students should work in teams of three.

Each team member must choose one organism from the list above and research its relationship with bacteria. Use information from the video, from your textbook or seek additional information from the library and on the Internet. As a team, combine your information to prepare a short presentation.

Your presentation should describe the relationship of each of these organisms with bacteria. You should also be able to develop some general conclusions about how bacteria interact with other organisms and with the environment.

Name: ___________________________

ACTIVITY 4-B

ANSWER KEY

Cows

The foregut (rumen) of cows contains bacteria that digest cellulose, allowing the cows to live on food such as grass. The gut is a protected environment of controlled conditions including low oxygen that favor growth of the bacteria living there. The cow provides the cellulose in its diet, and in turn it gets protein by digesting some of the bacteria.

Soybeans

Soybeans are legumes which have nodules on their roots. The nodules offer protection for the nitrogen fixing bacteria that live inside them. The plant also provides some nutrients. The bacteria bring nitrogen from the atmosphere into nitrogen containing compounds that act directly or indirectly as fertilizer for the plants. Other bacteria, called nitrifying bacteria, produce nitrates from the initial nitrogen fixation product, ammonia. Nitrates are a better source of nitrogen for the plants.

Giant tubeworms at deep sea vents

Giant tubeworms (scientific name Riftia pachyptila*) harbor colonies of chemosynthetic bacteria. The bacteria are protected by the tubeworms and in turn provide nutrients to the tubeworms.*

Name: ___________________________

GENOME DATA

Genome research includes reading the entire sequence of the DNA genome of different bacterial species. The table below describes five bacterial species whose genomes have been sequenced. Use this information to answer the following questions on a separate sheet of paper. (Follow your teacher's instructions to work in a team.)

1. Briefly summarize what is interesting or significant about each species.

2. Based on information presented in the video, think about how the genome data from these organisms can be used. Describe at least two applications of new genome data such as these.

TABLE 2
Based on information from genome projects at U.S. Department of Energy Microbial Genome Program and the TIGR Institute for Genome Research. For details search for their websites. (Current addresses are listed at the end of this Teacher's Resource Guide.)

Name	Domain	Description
Methanosarcina barkeri fusaro	Archaea	Live in cattle rumen where there is little oxygen; digest cellulose and produce methane.
Deinococcus radiodurans	Bacteria	Have DNA repair enzymes that may help these bacteria survive exposure to high levels of radiation.
Helicobacter pylori	Bacteria	Gram negative spirilli with flagella; this pathogen has enzymes that let it live in very acidic conditions of the human gut; it is associated with diseases that include peptic ulcer.
Mycoplasma genitalium	Bacteria	Have smallest genome of any organism; sequenced in 1995; unusually low G-C content in DNA; live as parasites in cells of animals (including humans) and plants.
Methanococcus jannaschii	Archaea	First Archaea species and first autotrophic species for which genome was determined; live at deep sea vents above 85º C under extreme pressure; produce methane.

1. Briefly summarize what is interesting or significant about each species.
See chart below. Students should easily be able to find interesting or unusual characteristics for each species listed. For example, Mycoplasma genitalium *G-37 has the smallest genome of any known species, while* Methanococcus jannaschii *lives in extremely hot conditions under high pressure and has an interesting metabolism that chemosynthetically produces methane.*

Name	Domain	Description
Methanosarcina barkeri fusaro	Archaea	Live in cattle rumen where there is little oxygen; digest cellulose and produce methane.
Deinococcus radiodurans	Bacteria	Have DNA repair enzymes that may help these bacteria survive exposure to high levels of radiation.
Helicobacter pylori	Bacteria	Gram negative spirilli with flagella; this pathogen has enzymes that let it live in very acidic conditions of the human gut; it is associated with diseases that include peptic ulcer.
Mycoplasma genitalium	Bacteria	Have smallest genome of any organism; sequenced in 1995; unusually low G-C content in DNA; live as parasites in cells of animals (including humans) and plants.
Methanococcus jannaschii	Archaea	First Archaea species and first autotrophic species for which genome was determined; live at deep sea vents above 85º C under extreme pressure; produce methane.

2. Based on information presented in the video, think about how the genome data from these organisms can be used. Describe at least two applications of new genome data such as these.
Generally speaking, the genetic data can be used to find useful genes, such as enzymes that work at high temperatures, in very salty conditions or exposed to radiation. Studies of Helicobacter pylori may help provide targets to reduce the pathogenicity of the bacteria that cause ulcers. Studying mycoplasma species can teach scientists what are the absolutely essential genes or functions, because the genome is so small. A second general application for genome studies is to refine biological classification and to better understand the evolution of these microorganisms by comparing the genomes of different species.

Name: ____________________________

ACTIVITY 6-A

LIFE IN HARSH CONDITIONS

Could bacteria live on Mars? First, consider some of the extreme places that scientists are searching for bacteria on Earth. Some people are searching for bacteria within the deep ocean crust (Scientific American June 2000, page 94.) Bacteria that can consume ancient carbon in rock known as shale adds to the idea that bacteria may live in the crust of the Earth (Science News, Vol. 159, page 198.)

1. Recall what you learned in the video about where and how bacterial populations grow. What observations from the video suggest that bacteria might be able to live deep in the Earth's crust?

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2. What about the question of life on Mars? NASA scientists published a collection of indirect evidence about life on Mars in the Aug. 16, 1996 issue of the journal Science, but it is not conclusive. Much more evidence and discussion will be needed to decide whether or not Mars has ever had life. Find current reports of studies to look for bacteria-like life on Mars. For example, you might start with an article titled "Why Go to Mars?" in the March 2000 issue of Scientific American or look at current NASA web pages for updates. What observations from Earth predict whether bacteria could or could not currently live on Mars? What about in the past on Mars?

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Name: ___________________________

ACTIVITY 6-B

ANSWER KEY

1. Recall what you learned in the video about where and how bacterial populations grow. What observations from the video suggest that bacteria might be able to live deep in the Earth's crust?
   Responses will vary but may include the observation that bacteria show a wide variety of metabolic styles and that extremophiles (thermophiles) live in unusual and harsh environments, showing the versatility of bacterial species.

2. What about the question of life on Mars? NASA scientists published a collection of indirect evidence about life on Mars in the Aug. 16, 1996 issue of the journal Science, but it is not conclusive. Much more evidence and discussion will be needed to decide whether or not Mars has ever had life. Find current reports of studies to look for bacteria-like life on Mars. For example, you might start with an article titled "Why Go to Mars?" in the March 2000 issue of Scientific American or look at current NASA web pages for updates. What observations from Earth predict whether bacteria could or could not currently live on Mars? What about in the past on Mars?
   Responses may be similar to part 1. In addition, students may point out that bacteria can withstand high temperatures, and can remain dormant (endospores) in some cases. The possible lack of liquid water on Mars might argue against life, including bacteria. Evidence of bacterial fossils or organic molecules could suggest life at an earlier date on Mars, when there could have been more water. The point of this activity is not to guess wildly or produce a specific "right" answer, but to stimulate students to think and to look for current evidence pro or con. The nature of this topic suggests that students likely will find evidence published after this guide is brought to press.

Name: ___________________________

ANTIBIOTIC RESISTANCE

In the video, you saw an interview with Dr. Stuart Levy. He talked about how naturally occurring bacteria on or in our bodies compete with pathogens. He also talked about antibiotic resistance. He provides more details about these ideas in an article in the March 1998 issue of Scientific American. In the article, Dr. Levy points out that antibiotic resistance to the pathogen *Staphylococcus aureus* first appeared in hospitals in the 1950s. Now more than 60 percent of strains of the pathogen *Staphylococcus aureus* are resistant. Similarly, resistance to antibiotics first was observed in *Mycobacterium tuberculosis,* the pathogen that causes tuberculosis, in the 1970s and now some strains are untreatable and fatal. Another pathogen, *Enterococcus faecalis,* causes blood poisoning and other infections. Resistance was first observed in the 1980s, and some strains are now resistant to so many antibiotics that infections are untreatable.

Based on these observation and information from the video, answer these questions:

1. What can you conclude about biological change (evolution) of these pathogens?

2. What is significant or surprising about the dates when resistance first appeared? (Hint: it may help you to know that general antibiotic use was introduced in the 1940s and became widespread in the 1950s. It has increased ever since.)

3. What steps might people take to avoid this problem with other pathogenic bacteria in the future?

4. What is the molecular mechanism that lets antibiotic resistance appear in a population? (You will need a copy of the March 1998 Scientific American article along with information from the video to answer this question.)

Name: ___________________________

ACTIVITY 7-B

ANSWER KEY

1. What can you conclude about biological change (evolution) of these pathogens?
Mutant forms of the bacteria are more adapted to survive exposure to antibiotics. In the presence of widespread antibiotic use, these altered bacteria have come to dominate many populations. This evolution represents a serious health risk to humans.

2. What is significant or surprising about the dates when resistance first appeared? (Hint: it may help you to know that general antibiotic use was introduced in the 1940s and became widespread in the 1950s. It has increased ever since.)
Evolution is biological change over time, and usually it occurs very slowly. This slow pace reflects how rare mutations are and how long it usually takes to undergo enough generations to significantly alter the make-up of a population. Changes in antibiotic resistance have become widespread during a very short period of time, just a few decades. This speed reflects the fact that bacteria reproduce quickly. Thus a mutant form can become widespread in a relatively short number of years, particularly if the selective pressure is constant. In this case, the selective pressure is exposure to antibiotics.

3. What steps might people take to avoid this problem with other pathogenic bacteria in the future?
Doctors can be more selective about when to prescribe bacterial antibiotics, using them only for potentially serious bacterial infections. To avoid the need for antibiotics, people can reduce the chance of infection. To do this, they can develop habits of better cleanliness, including washing fruit and vegetables, washing hands, avoiding unprotected sexual contact with many partners, staying home when they have infectious respiratory infections.

4. What is the molecular mechanism that lets antibiotic resistance appear in a population? (You will need a copy of the March 1998 Scientific American article along with information from the video to answer this question.)
Changes in DNA code result in new characteristics that may confer resistance. These changes can be mutations in the bacterial chromosome or on plasmids, which are small rings of DNA that replicate separately. Resistance genes need not arise independently: they can be transferred to other bacteria. Plasmids may be transferred directly. Viruses can carry in genes from other bacteria. Bits of DNA may be picked up from dead cells and incorporated. Each time the plasmid or chromosome replicates, the resistance gene is maintained and can be passed to offspring.

Name: ___________________________

FACT SHEET 1-A

GLOSSARY

Absorbance: A laboratory measurement used to determine the turbidity (cloudiness) of a solution, such as a sample of a bacterial culture. The absorbance is the logarithm of the ratio of light entering a sample to the light leaving the sample.

Amoeba (plural is **Amoebas** or **Amoebae**): A single-celled, microscopic eukaryote with an unusual and irregular cell shape. Amoebas move by extending lobe-shaped extensions into which cell contents flow. Amoebas are protists.

Animals: One of four kingdoms of eukaryotes in the domain Eukarya. Most are multicellular. Humans are animals, for instance.

Antibodies: Part of the human body's natural defense system. Antibodies are Y-shaped proteins produced to recognize chemical components of specific foreign invaders and bind to and immobilize them.

Antibiotics: Chemicals used to kill specific classes of pathogenic microorganisms without harming the human host.

Archaea: A large taxonomic group known as a domain. The Archaea form one of two domains that comprise prokaryotes (previously all prokaryotes were grouped together in the kingdom Monera). Archaea include prokaryotes that live in extreme environments such as thermophiles (heat-loving organisms) and halophiles (salt-loving organisms).

Bacillus (plural is **Bacilli):** Refers to the rod-shaped bacteria.

Bacteria (singular is **Bacterium):** Microscopic, single-celled organisms that are prokaryotes. Strictly speaking the term refers to "true" bacteria of the domain Eubacteria, but more loosely it refers to all prokaryotes, which includes the domain Archaea. An older classification put all bacteria into the kingdom Monera.

Bacteriophage: A virus that attacks bacteria.

Cell Membrane: A highly organized, flexible layer that surrounds a cell. It consists mainly of lipids and proteins, and surrounds a cell. Membranes contain pores that regulate the flow of molecules into and out of the cell.

Cell Wall: A rigid protective layer that surrounds and protects a cell. Bacterial cell walls have a different composition than plant cell walls. Eubacteria cell walls contain peptidoglycan, but those of Archaea cells do not. Animal and fungal cells and a few bacteria (the mycoplasmas) lack cell walls.

Name: ___________________________

GLOSSARY

Chemosynthesis: Chemical process that uses energy from inorganic compounds, such as oxidation of sulfur compounds, to fuel the process of making organic molecules (food). Bacteria that do chemosynthesis are producers, also called chemotrophs (chemosynthetic autotrophs).

Coccus (plural is **Cocci):** Refers to the sphere-shaped bacteria.

Consumers: Organisms that eat material from other organisms. Also known as heterotrophs.

Cyanobacteria: A group of photosynthetic bacteria that are sometimes known as blue-green bacteria. Some live singly and others in colonies or chains. Cyanobacteria are major photosynthetic producers in ocean ecosystems.

Cytoskeleton: An elaborate array of long filaments consisting mostly of protein molecules that help provide structure for a cell and can be involved in movement of molecules or arrangement of organelles within cells. Traditionally, the cytoskeleton was thought to be found only in eukaryotic cells, but more recently evidence of a simple cytoskeleton in some prokaryotic cells has come to light.

Decomposers: A special group of consumers that break down the material of dead organisms. Decomposers recycle the material, returning elements back to nonliving systems.

Denitrification: Process through which nitrogen is released from nitrogen-containing compounds or ions and returned as nitrogen gas to the environment. Bacteria carry out this step in the nitrogen cycle. See also "Nitrogen Fixation."

DNA: Deoxyribonucleic acid. This molecule serves as the main genetic storage material of cells including bacteria.

Endospore: Resting state capsule that protects DNA and key cell structures of a bacterium until conditions favor active growth. An endospore is *not* a reproductive structure (like the spores of ferns). It is made by a one-to-one process, formed from a single bacterial cell, without duplication of the genetic material.

Eubacteria (Bacteria): One of three domains of living things, Eubacteria are sometimes simply called Bacteria. Eubacteria form one of two prokaryotic domains; the other prokaryotic domain is Archaea. The eukaryotes form the domain Eukarya.

Name: ___________________________

FACT SHEET 1-C

GLOSSARY

Eukaryote: Refers to organisms belonging to the domain Eukarya, comprised of four kingdoms, Protists, Fungi, Plants, Animals. Eukaryotes have cells in which the genetic material is protected in a membrane-enclosed nucleus. Subcellular organelles include mitochondria, which are involved in oxidative energy metabolism, and chloroplasts, which are found in photosynthetic (green) plant cells.

Fission: Refers to the process of cell division through which bacteria reproduce. First, the DNA is replicated. Next the cell elongates and finally divides into two offspring cells.

Fungi: One of four kingdoms of eukaryotes in the domain Eukarya. Some are multicellular; some are single-celled. Familiar examples of fungi include mushrooms and yeast.

Genetic Material: Molecules that store or serve as copies of genetic information, the information that directs protein and RNA synthesis. Genetic material is the basis for heredity. The major long term storage material for cellular genetic information is DNA.

Gram Stain: A differential staining process to help identify different bacteria. The process involves exposing cells to a stain called crystal violet and fixing that stain with iodine. Then a decolorizing agent, acetone-alcohol, is used and followed by a second stain, safranin. Cells that retain the first stain look violet-blue and are said to be Gram positive. Cells that lose the first stain are able to pick up the second stain and have a reddish appearance. They are said to be Gram negative.

Legume: Plant involved in nitrogen fixation. The legume plant produces knobs or nodules on the roots that are infected with nitrogen-fixing bacteria. Soybeans, alfalfa, beans and peas are legumes.

Macrophages: White blood cells that are part of the immune system. Macrophages fight infection by attacking and engulfing invaders.

Mitochondria: Membrane-bound organelles found in eukaryotic cells that carry out important oxidative reactions involved in supplying energy for the cell.

Mutation: Error introduced into the DNA of a cell and passed on to offspring. A mutation can result in a difference in protein function that is helpful or harmful. If a mutation makes a bacterium more likely to survive in specific conditions, its offspring may come to dominate a population and become the "norm."

Mycoplasmas: Bacteria that lack a cell wall and consequently have irregular shape.

Name: ___________________________

FACT SHEET 1-D

GLOSSARY

Nitrogen Fixation: A step in the nitrogen cycle in which bacteria use atmospheric nitrogen gas to produce nitrogen-containing compounds such as ammonia, that can be used by plants and some other bacteria. Nitrogen fixing bacteria live in nodules on the roots of plants called legumes. Nitrifying bacteria convert ammonia into nitrates.

Nucleus: Membrane-bound compartment found in eukaryotic cells that houses the genetic material (chromosomes).

Organelle: Subcellular structure with a specific function, such as mitochondria and chloroplasts that are found in eukaryotic cells.

Paramecium (plural **Paramecia**): The genus or an individual from the genus called *Paramecium* that are single-celled microscopic eukaryotes in the kingdom Protists.

Pathogen: Organism that infects a host and causes disease.

Photosynthesis: Chemical process that uses energy from sunlight and carbon dioxide as an carbon source to produce organic molecules (food). Photosynthesis is the basis of most food webs on Earth. Photosynthetic producers also are known as phototrophs (photosynthetic autotrophs).

Plants: One of four kingdoms of eukaryotes in the domain Eukarya. Green plants are photosynthetic.

Plasmid: Small loop of DNA found in bacteria in addition to the chromosomal DNA. There can be more than one plasmid per cell, and they can be transferred from cell to cell. Antibiotic resistance genes often are carried on plasmids. Plasmids provide a powerful tool in cloning procedures used in genetic engineering.

Producers: Organisms that bring energy into living systems by making their own food from inorganic sources. Another name for producers is autotrophs. Producers include photosynthetic bacteria that use sunlight for energy and chemosynthetic bacteria that get energy from oxidation of inorganic compounds.

Prokaryote: Refers to a taxonomic classification in which the cells are simple in structure and do not contain a nucleus. Bacteria are prokaryotes. Compare to eukaryote.

Protein Synthesis: The process of making protein molecules according to the instructions copied from DNA in a messenger RNA molecule. Proteins are composed of specific sequences of twenty amino acids subunits. Protein synthesis takes place on ribosomes.

Name: ___________________________

FACT SHEET 1-E

GLOSSARY

Protists: One of four kingdoms of eukaryotes in the domain Eukarya. Protists are single-celled and live in aquatic environments. Examples include the amoeba and paramecium.

Replication: Refers to the process through which genetic material, DNA, is duplicated. A new copy of DNA is needed prior to cell division so that each resulting cell has a copy.

Reproduction: The process of producing offspring for perpetuation of a species. In bacteria, reproduction occurs by a process called binary fission. First, the DNA is replicated. Next the cell elongates and finally divides into two cells. Bacterial reproduction is quite rapid under favorable conditions, with a new generation appearing in as little as 20-30 minutes in some species.

Resistance (antibiotic): Refers to the ability of some mutant bacteria to survive exposure to antibiotics. Bacterial antibiotic resistance is rapidly increasing due in part to overuse of antibiotics. Resistance is an example of natural selective pressure in the evolution of bacterial populations.

Ribosome: Subcellular structure on which protein synthesis is carried out. Ribosomes are composed mainly of ribosomal RNA with specific protein factors. Ribosomes of bacteria (prokaryotes) have a different structure than those of eukaryotes.

Ruminants: A group of mammals that include cattle, sheep and deer that can digest cellulose. This process requires the help of bacterial populations living in a part of the animals' gut known as a rumen.

Spirillus (plural is **Spirilli):** Refers to the spiral-shaped bacteria.

Stromatolite: Formation of sedimentary rocks made of fossil remains of ancient bacteria.

Thermophile: Means "heat loving" and refers to any organism that lives above 50°C; extreme thermophiles live above 80°C. Extreme thermophiles are found in the domain Archaea. Examples include bacteria found at hot ocean vents and in hot springs such as those in Yellowstone National Park.

Name: ___________________________

INTERNET RESOURCES

Web addresses do not stay constant. For that reason we do not list a large selection of addresses, as they may change after publication. Instead, we recommend that students expand their understanding by choosing appropriate keywords for a search. For example, information about the use of bacteria in waste clean-up can be found using the words "bacteria" and "bioremediation." A list of suggested keywords follows below.

We will suggest two genomes sites as they are particularly useful. Genome information is available at websites for the U.S. Department of Energy Microbial Genome Program and the TIGR Institute for Genome Research. Their current addresses are:

http://www.ornl.gov/microbialgenomes/organisms.html
http://www.tigr.org/tdb/

For more information on research concerning life on Mars, you might try:

http://spaceflight.nasa.gov/mars/science/ancient/

For an exploration of the biological classification, a useful site is the Tree of Life site maintained by the University of Arizona. The address is:

http://phylogeny.arizona.edu/tree/phylogeny.html

Similar information may be found at a University of California, Berkeley site at:

http://www.ucmp.berkeley.edu/alllife/threedomains.html

Useful keywords for searches include:

Bacteria
Archaea
Bioremediation
Cyanobacteria
Antibiotic resistance
Food production bacteria
Nitrogen fixation legumes

Name: ___________________________

FACT SHEET 3

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for grades 9 - 12

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