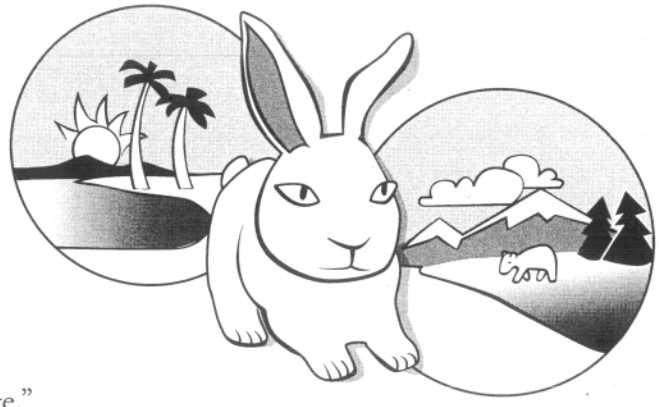
Adaptation



Three friends were arguing about what would happen if a population of rabbits from a warm, southern climate were moved to a cold, northern climate. This is what they said:

Bernie: "I think all of the rabbits will try to adapt to the change."

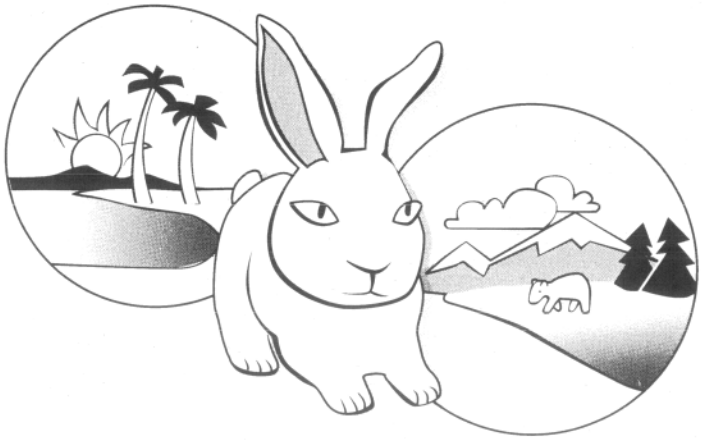
Leo: "I think most of the rabbits will try to adapt to the change."

Phoebe: "I think few or none of the rabbits will try to adapt to the change."

Which person do you most agree with and why? Explain your ideas about adaptation.

Adaptation

Teacher Notes



Purpose

The purpose of this assessment probe is to elicit students' ideas about biological adaptation. The probe is designed to find out if students think animals intentionally adapt to a change in their environment.

Related Concepts

adaptation, natural selection, variation

Explanation

The best answer is Phoebe's: "I think few or none of the rabbits will try to adapt to the change." The key word here is *try*. Biological adaptation involves genetic variation that allows some individuals to survive a particular change, such as a change in the environment, better than others. These individuals are then able to survive and reproduce, passing on their genes to successive generations of offspring that will be better adapted for the particular environment. This process is called natural selection, and it leads to adaptation. If the genetic variation that allows an individual to survive the change is not present, the individual cannot intentionally change its structure, physiology, or behavior in an attempt to "try" to adapt to the change and pass on its genes so that its offspring will be adapted. Either the genes are there that allow the rabbit to survive and pass on its traits that enhance survival to its offspring (natural selection) or they are not there. If they are not there, the rabbits can't intentionally adapt or change their genes by "trying." Adaptation is not intentional. The rabbits may try to survive by acclimating to the change, but trying to survive is different in a biological sense from trying to adapt. Another problem is the common use of the verb *adapt*,

which implies that an action is being taken by an individual.

Curricular and Instructional Considerations

Elementary Students

In the elementary grades, students build understandings of biological concepts through direct experience with living things and their habitats. They observe and learn about structures, functions, and behaviors that help organisms survive in their environments. They develop an understanding that some organisms are better suited than others to survive in certain environments. They develop beginning ideas about heredity—that is, that some characteristics are inherited and passed on to offspring. These basic ideas establish a foundation that will lead to a later understanding of natural selection.

Middle School Students

Understanding adaptation is still particularly troublesome at this level. Many students think *adaptation* means that individuals change in deliberate ways in response to changes in the environment (NRC 1996). At this level, it is important to develop the idea of variations in populations of organisms that may give some individuals an advantage in surviving, reproducing, and passing on those traits to their offspring. Teaching students about the selection of individuals is the first step in helping them understand natural selection as a mechanism for species' change.

High School Students

Biological evolution and its mechanism, natural selection, are major focuses of high school biology. At the high school level, students shift from a focus on selection of individuals with certain traits that help them survive to a focus on the changing proportion of such traits in a population of organisms. Their growing understanding of genetics builds on middle school ideas about variation. However, students at this level may still hold on to the misconception that adaptations can be controlled by an individual.

Administering the Probe

Make sure students understand the probe is a hypothetical situation and that there is a drastic change in the environment when the rabbits move from the southern climate to the northern climate. This change also involves more than just temperature. There may be changes in food, shelter, and predators as well. You might consider having students describe each of the environments first. Feel free to change the context of the probe to an animal and two different environments with which your students are most familiar.

Related Ideas in *National Science Education Standards* (NRC 1996)

K–4 The Characteristics of Organisms

- Organisms have basic needs. Organisms can survive only in environments in which their needs can be met.

- Each plant or animal has different structures that serve different functions in growth, survival, and reproduction.

K–4 Organisms and Their Environments

★ An organism's patterns of behavior are related to the nature of that organism's environment, including the kinds and numbers of other organisms present, the availability of food and resources, and the physical characteristics of the environment. When the environment changes, some plants and animals survive and reproduce, and others die or move to new locations.

5–8 Regulation and Behavior

- All organisms must be able to obtain and use resources, to grow, to reproduce, and to maintain stable internal conditions while living in a constantly changing environment.

5–8 Diversity and Adaptations of Organisms

★ Species acquire many of their unique characteristics through biological adaptation, which involves the selection of naturally occurring variations in populations. Biological adaptations include changes in structures, behaviors, or physiology that enhance survival and reproductive success in a particular environment.

9–12 Biological Evolution

- 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.

9–12 The Behavior of Organisms

★ 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.

Related Ideas in *Benchmarks for Science Literacy* (AAAS 1993 and 2008)

Note: Benchmarks revised in 2008 are indicated by (R). New benchmarks added in 2008 are indicated by (N).

K–2 Heredity

- There is variation among individuals of one kind within a population.

K–2 Evolution of Life

- Different plants and animals have external features that help them thrive in different kinds of places.

3–5 Interdependence of Life

- For any particular environment, some kinds of plants and animals thrive, some do not live as well, and some do not survive at all. (R)

★ Indicates a strong match between the ideas elicited by the probe and a national standard's learning goal.

3–5 Evolution of Life

★ Individuals of the same kind differ in their characteristics, and sometimes the differences give individuals an advantage in surviving and reproducing.

6–8 Evolution of Life

★ Individual organisms with certain traits are more likely than others to survive and have offspring.

★ Changes in environmental conditions can affect the survival of individual organisms and entire species.

9–12 Heredity

- Some new gene combinations make little difference, some can produce organisms with new and perhaps enhanced capabilities, and some can be harmful.

9–12 Evolution of Life

- 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. As a result, the proportion of individuals that have advantageous characteristics will increase. (R)
- Heritable characteristics can be observed at molecular and whole-organism levels—in structure, chemistry, or behavior.

Related Research

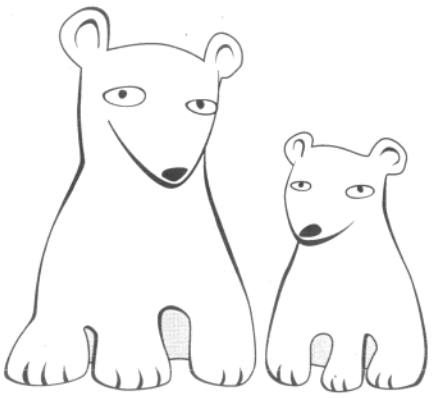
- Many students tend to see adaptation as an intention by the organism to satisfy a desire or need for survival (Driver et al. 1994).
- Middle and high school students may believe that organisms are able to intentionally change their bodily structure to be able to live in a particular habitat or that organisms respond to a changed environment by seeking a more favorable environment. It has been suggested that the language about adaptation used by teachers or textbooks may cause or reinforce these beliefs (AAAS 1993, p. 342).
- Many students ages 12–16 display Lamarckian beliefs about inheritance of acquired characteristics. This belief has been demonstrated both before and after instruction in genetics and evolution (Driver et al. 1994).

Suggestions for Instruction and Assessment

- Refrain from using the words *adapt* (particularly as an action verb that implies intentionality) or *adaptation* in elementary grades. Instead talk about characteristics and features that help organisms live in their environments. Teachers' early use of the words *adapt* or *adaptation*, before students understand the genetic basis for passing on traits that enable an organism to adapt, may imply that plants and animals intentionally adapt. This idea is particularly resistant to change at the middle level, perhaps because the idea of intentional adaptation was developed early on.

★ Indicates a strong match between the ideas elicited by the probe and a national standard's learning goal.

Is It "Fitter"?



Natural selection is sometimes described as "survival of the fittest." Four friends were arguing about what the phrase "survival of the fittest" means. This is what they said:

Dora: "I think 'fit' means bigger and stronger."

Lance: "I think 'fit' means more apt to reproduce."

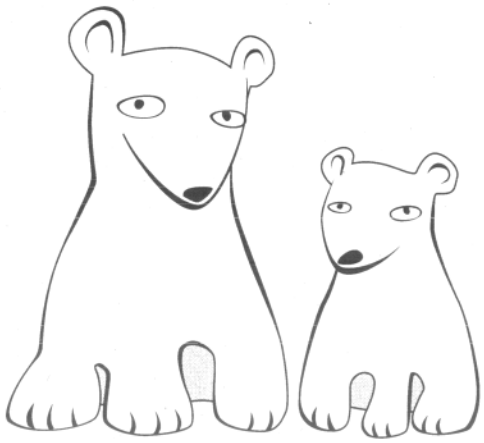
Felix: "I think 'fit' means able to run faster."

Hap: "I think 'fit' means more intelligent."

Which person do you most agree with? Explain what you think "survival of the fittest" means.

Is It "Fitter"?

Teacher Notes



Purpose

The purpose of this assessment probe is to elicit students' ideas about natural selection. The probe is designed to find out how students interpret the commonly used phrase "survival of the fittest."

Related Concepts

adaptation, natural selection, variation

Explanation

The best answer is Lance's: "I think 'fit' means more apt to reproduce." Size, swiftness, strength, and intelligence are key factors often related to survival, but they do not always determine whether an organism is most "fit" to reproduce and pass its genes on to offspring. The key idea portrayed in the phrase *survival of the fittest* is that *fittest* means best suited to survive and reproduce. In some instances, size is an advantage. For example, a large male sea lion is more apt to be the dominant male who breeds with a harem of female sea lions. Because of his impressive size, the females are more attracted to him and the other males are intimidated. Because the other males fear him, he has less competition for food as well. Therefore, he is more apt to survive and reproduce because he can outcompete the other males for food and mates. On the other hand, imagine breeding two dogs. One dog is a very large, muscular, big-boned, *fit* male. This male is bred to the same type of dog, a petite female. However, the puppies are too large and cannot be delivered without a caesarean section. In this case, the bigger male wasn't necessarily the *fittest*. If this had happened in nature, the female dog probably would have died in birth

and the male would have lost his chance to pass his genes on to offspring. Examples also exist in the plant world. Flower breeders have developed large dahlias that are prized for their huge flowers. However, these large dahlias must be supported with wires and stakes as they grow because they would fall to the ground and possibly die without support (BSCS 2005). Intelligence, swiftness in escaping danger, and strength are also factors that can contribute to survival, yet they do not always equate with reproductive success.

Curricular and Instructional Considerations

Elementary Students

In the elementary grades, students build understandings of biological concepts through direct experience with living things and their habitats. They observe and learn about structures, functions, and behaviors that help organisms survive in their environments. They develop an understanding that some organisms are better suited than others to survive in certain environments. They develop precursor ideas to the concept of natural selection, such as the idea that some characteristics are inherited and passed on to offspring. They may have heard the phrase *survival of the fittest* and equate *fit* with strength and size.

Middle School Students

Students at the middle level formally develop an understanding of the concept of natural selection. Often the phrase *survival of the fittest* is used without defining what is meant by *fit*, thus leading to students' erroneous misinterpretation of the intent of this phrase. At this level, it is important to develop the idea of variations in populations of organisms that may give some individuals an advantage in surviving, reproducing, and passing on those traits to their offspring. Teaching students about the selection of individuals is the first step in helping them understand natural selection as a mechanism for species' change.

High School Students

Biological evolution and its mechanism, natural selection, are major focuses of high school biology. At the high school level, students shift from a focus on selection of individuals with certain traits that help them survive to a focus on the changing proportion of such traits in a population of organisms. Their growing understanding of genetics builds on middle school ideas about variation. However, students at this level may still hold on to a misconception that "survival of the fittest" means that "physically fit" species are more *fit* than smaller ones.

Administering the Probe

This probe is best used at the middle or high school level. Make sure students have encountered the concept of natural selection before using this probe as is. If they have not encountered this term, consider removing the first sentence from the prompt. This probe is best used to engage students in argumentation about the phrase *survival of the fittest* and what it means.

Related Ideas in *National Science Education Standards* (NRC 1996)

K–4 The Characteristics of Organisms

- Each plant or animal has different structures that serve different functions in growth, survival, and reproduction.

5–8 Regulation and Behavior

★ All organisms must be able to obtain and use resources, to grow, to reproduce, and to maintain stable internal conditions while living in a constantly changing environment.

5–8 Diversity and Adaptations of Organisms

★ Species acquire many of their unique characteristics through biological adaptation, which involves the selection of naturally occurring variations in populations. Biological adaptations include changes in structures, behaviors, or physiology that enhance survival and reproductive success in a particular environment.

9–12 Biological Evolution

- 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.

Related Ideas in *Benchmarks for Science Literacy* (AAAS 1993 and 2008)

Note: Benchmarks revised in 2008 are indicated by (R). New benchmarks added in 2008 are indicated by (N).

K–2 Heredity

- There is variation among individuals of one kind within a population.

3–5 Evolution of Life

★ Individuals of the same kind differ in their characteristics, and sometimes the differences give individuals an advantage in surviving and reproducing.

6–8 Evolution of Life

★ Individual organisms with certain traits are more likely than others to survive and have offspring.

9–12 Heredity

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

9–12 Evolution of Life

★ 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

★ Indicates a strong match between the ideas elicited by the probe and a national standard's learning goal.

likely than others to survive and reproduce. As a result, the proportion of individuals that have advantageous characteristics will increase. (R)

Related Research

- Field-test results of this probe showed that many middle school students are more apt to think of "fit" as big and strong. They relate "fittest" to physical fitness, rather than a species' ability to survive and reproduce.
- Many people mistakenly think that the biggest individual is the fittest (BSCS 2005).

Suggestions for Instruction and Assessment

- Have students generate examples of when "bigger is better" in relation to an organism's ability to survive and reproduce. Then generate examples in which it may be a detriment. Try this with other characteristics to show that there is not one characteristic that always determines *fitness for survival.*
- Compare and contrast with students the common use of the word *fit* (as in physical fitness) with the scientific meaning of the word in relation to natural selection. Add this to students' growing number of examples of the way we use words in our society that are not always the same as the way they are used in science.

Related NSTA Science Store Publications, NSTA Journal Articles, NSTA SciGuides, NSTA SciPacks, and NSTA Science Objects

American Association for the Advancement of Science (AAAS). 2001. *Atlas of science literacy.* Vol. 1. (See "Natural Selection" map, pp. 82–83.) Washington, DC: AAAS.

Benz, R. 2000. *Ecology and evolution: Islands of change.* Arlington, VA: NSTA Press.

Biological Sciences Curriculum Study (BSCS). 2005. *The nature of science and the study of biological evolution.* Colorado Springs, CO: BSCS.

Diamond, J., C. Zimmer, E. M. Evans, L. Allison, and S. Disbrow, eds. 2006. *Virus and the whale: Exploring evolution in creatures large and small.* Arlington, VA: NSTA Press.

Kampourakis, K. 2006. The finches' beaks: Introducing evolutionary concepts. *Science Scope* (Mar.): 14–17.

Scotchmoor, J., and A. Janulaw. 2005. Understanding evolution. *The Science Teacher* (Dec.): 28–29.

Related Curriculum Topic Study Guide

(Keeley 2005)

"Natural and Artificial Selection"

References

American Association for the Advancement of Science (AAAS). 1993. *Benchmarks for science literacy.* New York: Oxford University Press.

American Association for the Advancement of Sci-

Cells and Size

Teacher Notes

Purpose

The purpose of this assessment probe is to elicit students' ideas about the size of cells. The probe can be used to determine whether students recognize how small a cell is relative to other things.

Related Concepts

cell size, micrometer (or micron)

Explanation

Although some of the choices depend on the size of a small object, the best choices are: thickness of a leaf, grain of salt, eye of an ant, width of a hair, piece of sawdust, tiny seed, bread crumb, larva of a tiny fruit fly, speck of pepper, period at end of a sentence, dust mite, frog embryo, point of a pin, and flea egg. Several of the items in this list are living things or parts of plants and animals and thus are made up of a collection of cells (the cell layers that make up the width of a leaf, sawdust, eye of an ant, tiny seed, larva of a tiny fruit fly, speck of pepper, dust mite, and microscopic frog embryo), which generally makes them larger than a single "typical" animal or plant cell. Chromosomes are organelles found within plant and animal cells, which make them smaller than a cell. Likewise, proteins, DNA, and water are molecules found within a cell and within cell structures, which reasons that they are also smaller than a cell. Bacteria are much smaller than animal and plant cells and viruses are much smaller than bacteria. The atom is the smallest particle of matter on the list. Trying to figure out the number of atoms in a cell is almost like trying to figure out the number of stars in the sky.

Generally, any very small object or particle of matter that can be seen with a handheld magnifying lens or the human eye (which can detect sizes up to about 0.1 mm) is larger than a cell. However, an object or organism does not have to be visible by the unaided eye to be larger than a cell. To get a quantitative sense of scale, cells are typically measured in micrometers (μm; also called *microns*). There are 1,000 μm in 1 mm. Most types of plant and animal cells generally range between 10 and 100 μm (some cells, like eggs, nerve cells, and muscle cells, are much larger than "average" cells). The point of a pin is about 1,500 μm. A grain of table salt is about 300 μm. The width of a human hair is about 200 μm and a flea's egg is about 500 μm. Dust mites, bizarre looking multicellular animals, are still larger than typical cells even though they are typically photographed using electron microscopes. Several of these dust mites live at the base of your eyelashes and feed on secretions and dead skin cell debris! Dust mites range in size from 250 to 400 μm.

Typically, a microscope with magnification greater than 10× is needed to see most cells. Magnifications of 100× and more are needed to see things smaller than typical cells. While cells of different tissues vary in size, they are still much smaller than many of the things on the list. For example, a typical animal cheek cell is 60 μm, a red blood cell is about 8 μm, and a small leaf's cell is about 30 μm. Bacteria are single-celled organisms that are much smaller than a plant or animal cell. E. coli, a common bacterium, measures 2 μm. The typical common cold virus measures 20 nm (nanometer). There are 1,000 nm in 1 μm. Even smaller is a water molecule. It measures about 0.2 nm!

Curricular and Instructional Considerations

Elementary Students

Students in the early elementary school grades use magnifying lenses to observe parts of living things that are too small to see clearly with their naked eye. Upper elementary students are just beginning to learn about cells and use simple microscopes to observe them. However, students' conceptions of a cell's very small size are limited by their ability to grasp very small magnitudes of scale.

Middle School Students

Students' fine motor skills help them become more adept in using compound microscopes at the middle school level to view a variety of cells and small parts of organisms and objects. They can interpret what they see under a microscope, can determine the magnification of their view, and begin to connect the size of cells to numbers that are much smaller than a millimeter. However, small scales are still difficult for them to comprehend.

High School Students

At the high school level, students transition from the whole cell to looking at structures within the cell. They learn about the molecules that make up a cell. Their understandings en-

compass smaller scales, including a growing awareness of nanoscale and nanoscience. They use more sophisticated microscopes and microscopic techniques that allow them to see bacterial cells.

Administering the Probe

This probe can be used once students understand that all organisms are made up of cells. Remove items on the list that may be unfamiliar to students.

Related Ideas in *National Science Education Standards* (NRC 1996)

K–4 Abilities Necessary to Do Scientific Inquiry

- Employ simple equipment and tools (magnifiers and simple microscopes) to gather data and extend the senses.

5–8 Abilities Necessary to Do Scientific Inquiry

- Use appropriate tools (microscopes) and techniques to gather, analyze, and interpret data.

5–8 Structure and Function in Living Systems

- All organisms are composed of cells, the fundamental unit of life.
- Groups of specialized cells cooperate to form a tissue, such as a muscle. Different tissues are grouped together to form larger functional units, called *organs*.

9–12 The Cell

- Cells have particular structures that underlie their functions. Inside the cell is a concentrated mixture of thousands of different molecules that form a variety of specialized structures.
- Most of the cells in a human contain two copies of each of 22 different chromosomes.
- Each DNA molecule in a cell forms a single chromosome.

Related Ideas in Benchmarks for Science Literacy (AAAS 1993)

K–2 The Cell

- Magnifiers help people see things that they would otherwise not be able to see.

K–2 Scale

- Things in nature and things people make have very different sizes, weights, ages, and speeds.

3–5 The Cell

★ Microscopes make it possible to see that living things are made mostly of cells. Some organisms are made of a collection of similar cells that benefit from cooperating.

- Some living things consist of a single cell.

6–8 Cells

★ All living things are composed of cells, from just one to many millions, whose details usually are visible only through a microscope. Different body tissues and

★ Indicates a strong match between the ideas elicited by the probe and a national standard's learning goal.

organs are made up of different kinds of cells.

9–12 Cells

- Within every cell are specialized parts.
- The work of the cell is carried out by the many different types of molecules it assembles, mostly proteins.

Related Research

- Studies have shown that students have difficulties with orders of magnitude. In a study of 16-year-old Israeli students (Dreyfus and Jungwirth 1988, 1989), students thought that molecules of protein were bigger than the size of a cell. Over a third of students' responses showed "inadequate" ideas about cells (Driver et al. 1994).
- Research conducted by Arnold (1983) indicated that students have difficulty differentiating between the concepts of cell and molecule. Students identified any materials encountered in biology class (carbohydrates, proteins, and water) as being made up of smaller units called *cells*. Arnold coined the term *molecell* to describe the notion of organic molecules being considered as cells.
- The range of numbers people can grasp increases with age (AAAS 1993, p. 276).

Suggestions for Instruction and Assessment

- Be aware that describing cells as being "very small" is a relative term to students. Small compared to what? When teaching the concept of smallness of cells, make comparisons to things that are smaller and larger than a cell.
- Provide students with opportunities to examine and compare very small things that their unaided eyes can detect, such as a grain of salt or width of a hair, to things their unaided eyes cannot detect, such as individual cells on a prepared microscope slide. Using a microscope, have students compare the two differently sized things, noting the difference in relative size under the same magnification.
- Begin by having students in the early elementary grades use 3×–10× magnification hand lenses to magnify things. Encourage them to wonder what they might see with more powerful lenses (AAAS 1993).
- By the upper elementary school grades, the magnification that students use should increase to 30×–100× magnification, using more powerful handheld viewers, dissection scopes, or simple microscopes. Students' observations should include microscopic one-celled organisms, plant and animal cells, and small animals, such as brine shrimp. As they observe different types of cells, they should be encouraged to think about whether those cells could be seen without a microscope.
- By middle school, students should have developed "magnification sense" and can extend their observations of cells using a microscope to photographs of cells, including bacteria, taken under much greater magnifications than their school microscopes can provide.

- Middle school students are learning about the fundamental unit of matter (the atom) and molecules made up of atoms as well as the basic unit of life (the cell). When taught separately, there is the potential for misconceptions to develop related to the sizes of atoms, molecules, and cells. Explicitly address the size of a cell in comparison to atoms and molecules because some students think they are similar in size and fail to recognize that cells are made up of atoms and molecules. The Powers of Ten website, at *www.powersof10.com,* provides a source of representations to help students distinguish between the magnitudes of scale in observing cells versus atoms and molecules.
- At the high school level, help students make explicit comparisons of the size of protein and DNA molecules to the size of a cell, recognizing that these molecules fit within cells. Combining this probe with "Is It Made of Cells?" and "Is It Made of Molecules?" from Volume 1 of this series (Keeley, Eberle, and Farrin 2005) may help reveal whether high school students hold the concept of molecell, as is indicated by research studies.

Related NSTA Science Store Publications and Journal Articles

American Association for the Advancement of Science (AAAS). 1993. *Benchmarks for science literacy.* New York: Oxford University Press.

Driver, R., A. Squires, P. Rushworth, and V. Wood-Robinson. 1994. *Making sense of secondary science: Research into children's ideas.* London and New York: RoutledgeFalmer.

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Related Curriculum Topic Study Guide

(Keeley 2005)
"Cells"

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Dreyfus, A., and E. Jungwirth. 1989. The pupil and the living cell: A taxonomy of dysfunctional ideas about an abstract idea. *Journal of Biological Education* 23 (1): 49–53.

Driver, R., A. Squires, P. Rushworth, and V. Wood-Robinson. 1994. *Making sense of secondary sci-*

Biological Evolution

Four friends were discussing the meaning of the term *biological evolution*. This is what they said:

Mario: "I think it is another term for natural selection."

Sally: "I think it mainly explains how life started."

Cameron: "I think it mainly explains how life changed after it started."

Paz: "I think it includes both how life started and how it changed after it started."

Who do you most agree with? Explain what you think biological evolution is.

Biological Evolution

Teacher Notes

Purpose

The purpose of this assessment probe is to elicit students' ideas about biological evolution. The probe is designed to find out if students distinguish the theory of biological evolution from ideas about the origin of life and the mechanism for biological evolution.

Related Concepts

biological evolution, natural selection, origin of life

Explanation

The best answer is Cameron's: "I think it mainly explains how life changed after it started." It explains that living things share common ancestors. Scientists seek to understand how life started, but this aspect of biology is not the central focus of the theory of biological evolution. The origin of life is associated with chemical evolution. The study of chemical evolution yields insight into the processes that lead to the generation of the chemical materials essential for the development of life. Regardless of how scientists think life on Earth started, we do know that after life originated it branched and diversified. Natural selection is part of the theory of biological evolution. It is a mechanism that drives evolutionary change in organisms. The theory of biological evolution focuses on explaining life's diversity, and scientists continue to study the relatedness among organisms and how life diversified.

Curricular and Instructional Considerations

Elementary Students

In the elementary grades, the focus is on building a knowledge base about biological diversity to build a foundation for later understanding of the concept of biological evolution. Students learn about life-forms that no longer exist and compare their similarities to present-day organisms. They also examine features of organisms that help the organisms survive in their environments. They examine visible anatomical similarities that help them begin to build evidence for similarities within the diversity of life.

Middle School Students

In middle school, students expand the idea of similarity among seemingly diverse organisms by examining similarities in cells, tissues, and organs as well as similarities in patterns of development and chemical processes such as photosynthesis. This contributes further to building an evidence base for relatedness within the vast diversity of organisms on Earth.

Furthermore, students build a deeper understanding of fossil evidence and Earth's geologic history, solidifying the notion of evolutionary change. They develop an understanding of how successful traits allow individuals to survive and reproduce as well as the effect of environmental changes on organisms and species. Understanding these ideas lays a foundation for understanding the formal concepts of adaptation and natural selection. The formal terminology, *biological evolution* and *natural selection*, is introduced in middle school after students have developed a beginning conceptual understanding of these concepts.

High School Students

Biological evolution is the central theme of modern biology. The foundational ideas and evidence base developed in K–8 can now converge into developing a formal understanding of biological evolution and its mechanism, natural selection. Because of students' readiness to examine molecular evidence and other complexities, combined with their increased skills in examining arguments, high school is the time to develop a clear understanding of biological evolution. In middle school, the emphasis was on selection of individuals with advantageous traits. In high school, the emphasis shifts to include the changing proportions of traits that can result in species changes. Historical perspectives, including Charles Darwin's contribution, provide an opportunity to understand how careful observations lead to solving some of the great puzzles of science.

Administering the Probe

This probe is most appropriate for use at the high school level, although it can be used at the middle school level to ascertain students' preexisting ideas about biological evolution that they may have encountered through the media or other means. Make sure students understand that the probe is focused on biological evolution, not evolution in general.

Related Ideas in *National Science Education Standards* (NRC 1996)

K–4 The Characteristics of Organisms

- Organisms can survive only in environments in which their needs can be met.
- Each plant or animal has different structures that serve different functions in growth, survival, and reproduction.

K–4 Organisms and Their Environments

- When the environment changes, some plants and animals survive and reproduce, and others die or move to new locations.

K–4 Properties of Earth Materials

- Fossils provide evidence about the plants and animals that lived long ago and the nature of the environment at that time.

5–8 Diversity and Adaptations of Organisms

★ Biological evolution accounts for the diversity of species developed through gradual processes over many generations. Species acquire many of their unique characteristics through biological adaptation, which involves the selection of naturally occurring variations in populations.

- Millions of species of animals, plants, and microorganisms are alive today. Although different species might look dissimilar, the unity among organisms becomes apparent from an analysis of internal structures, the similarity of their chemical processes, and the evidence of common ancestry.

9–12 Biological Evolution

★ 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.

★ 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.

Related Ideas in *Benchmarks for Science Literacy* (AAAS 1993 and 2008)

Note: Benchmarks revised in 2008 are indicated by (R). New benchmarks added in 2008 are indicated by (N).

K–2 Evolution of Life

- Some kinds of organisms that once lived on Earth have completely disappeared, although they were something like other organisms that are alive today.

3–5 Evolution of Life

- Individuals of the same kind differ in their characteristics, and sometimes the differences give individuals an advantage in surviving and reproducing.

★ Indicates a strong match between the ideas elicited by the probe and a national standard's learning goal.

- Fossils can be compared with one another and with living organisms according to their similarities and differences. Some organisms that lived long ago are similar to existing organisms, but some are quite different.

6–8 Evolution of Life

- Small differences between parents and offspring can accumulate (through selective breeding) in successive generations so that descendants are very different from their ancestors.
- Individual organisms with certain traits are more likely than others to survive and have offspring.
- Changes in environmental conditions can affect the survival of individual organisms and entire species.

9–12 Evolution of Life

★ The basic idea of biological evolution is that the Earth's present-day species are descended from earlier, distinctly different species. (R)

- 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. As a result, the proportion of individuals that have advantageous characteristics will increase. (R)
- Life on Earth is thought to have begun as simple, one-celled organisms about four billion years ago. Once cells with nuclei developed about one billion years ago, increasingly complex multicellular organisms evolved.

★ Modern ideas about evolution and heredity provide 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.

Related Research

- Many people believe that evolution is a theory about the origin of life (University of California Museum of Paleontology 2006).
- Research suggests that students' understanding of evolution is related to their understanding of the nature of science and their general reasoning abilities (AAAS 1993).

Suggestions for Instruction and Assessment

- The word *evolution* is used in many ways in science, including in the terms *biological evolution, chemical evolution, stellar evolution, evolution of the Earth system,* and *evolution of the universe.* Explicitly develop the precise meaning of *biological evolution* so that students distinguish it from other types of change.
- Be aware that some students confuse natural selection with biological evolution. Explicitly develop the notion that natural selection is the mechanism for biological evolution.

★ Indicates a strong match between the ideas elicited by the probe and a national standard's learning goal.