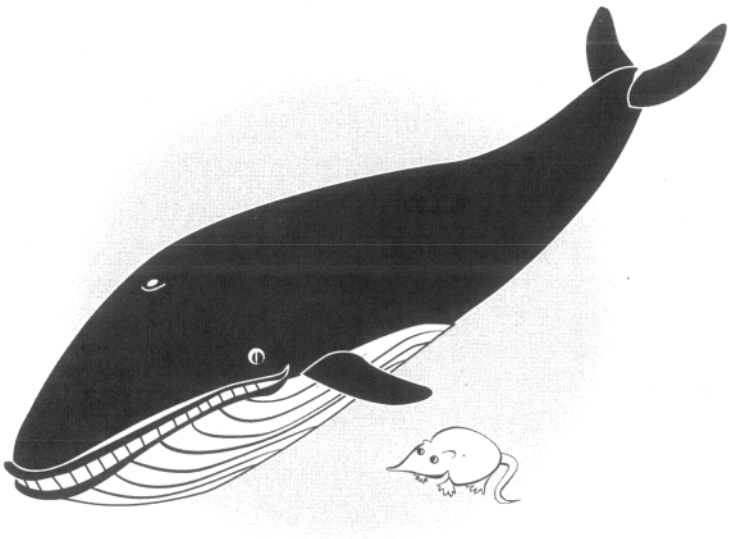
Whale and Shrew

The blue whale is the largest mammal in the world. The pygmy shrew is one of the smallest mammals in the world. How does the size of average cells compare between a blue whale and a pygmy shrew? Circle the answer that best matches your thinking.



A The average cell of a blue whale is smaller than the average cell of a pygmy shrew.

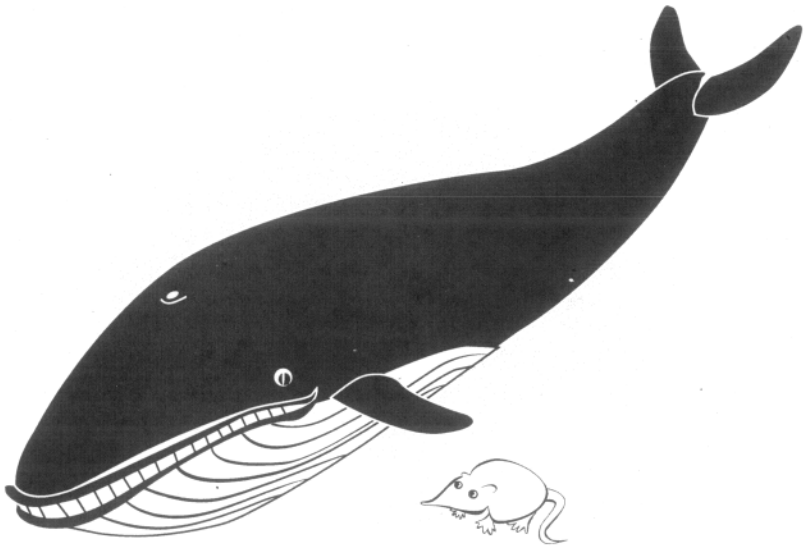
B The average cell of a blue whale is larger than the average cell of a pygmy shrew.

C The average cell of a blue whale is about the same size as the average cell of a pygmy shrew.

Explain your thinking. Describe the "rule" or reasoning you used to choose your answer.

Whale and Shrew

Teacher Notes



Purpose

The purpose of this assessment probe is to elicit students' ideas about cell size. The probe is designed to find out if students think that animal cell size is related to the overall size of an animal.

Related Concepts

cells, growth, cell division

Explanation

The best answer is C: The average cell of a blue whale is about the same size as the average cell of a pygmy shrew. The size of average mammal cells (this excludes cells that are unusually large, such as neurons) is similar in all mammal species. Even though some body cells (such as neurons) can be very large and cells vary, the average body cells of most mammals are about 10 micrometers in diameter. Interestingly, the earliest-stage embryos of the whale and shrew are also a similar size, even though a whale eventually reaches a mass of 150,000 kg whereas a mouse only reaches 15g—a 10-million-fold difference!

Cells are limited in how large they can be because the surface area-to-volume ratio does not stay the same as the size of a cell increases. Cells need to be able to move materials into

and out of a cell, and it is harder for a large cell to pass materials in and out of the membrane and to move materials through the cell. The reason blue whales are larger than pygmy shrews is because they have more cells, not because their cells are larger.

Curricular and Instructional Considerations

Elementary Students

In the upper elementary grades students are just beginning to learn about cells as the fundamental unit of all living organisms. They observe a variety of cells of single-celled and multicelled organisms in pictures and with simple microscopes. At this level, students are not ready to compare cell sizes, but they do observe that larger animals have larger body parts such as legs and teeth as well as larger organs such as heart, lungs, and stomach. This can lead to a preconception that their cells are also larger. Students learn about growth in the context of life cycles but do not yet equate growth with an increase in the number of cells. However, this probe is useful in determining if the idea of cell size increasing with overall animal size and size of body parts is a conception that develops early on.

Middle School Students

Middle school students extend their observations of cells to making comparisons of similar cell types across animal species. Students develop the idea of similarities among species by examining internal structures as well as cells. They can also begin to recognize the very small size of most cells and that most cells repeatedly divide to make more cells. Organisms and the organs they contain generally grow in size from birth until they reach adulthood. Yet, students may believe that the cells that make up organs are proportional to the size of the organ and thus the size of the animal, not recognizing that it is the process of cell division that contributes to growth, not the individual cells getting larger.

High School Students

High school students have a deeper understanding of the cell, including cell division and what controls it. Mathematically they develop an understanding of the relationship between volume and surface area and how the total surface area decreases with an increase in volume. Through lab experiences with model cells made of gels, they observe how the surface area-to-volume ratio affects the passage of materials into, around, and out of a cell, thus limiting the size of a cell. This probe is useful in eliciting students' ideas before designing experiences that help students understand that cell size is limited by the surface area-to-volume ratio and thus is relatively similar for most mammals' cells.

Administering the Probe

Show a picture of a whale and a shrew to contrast size. Make sure middle and high school students focus on the concept of "average-

sized" cells. You might explain that some cells, such as neurons, vary considerably in size. If necessary, choose a particular cell, such as a red blood cell or a cell from the liver. Alert students to the fact that the picture on the probe handout is not drawn to scale. In a scale drawing, the shrew would be several times smaller than the size of the whale's eye and would be a mere dot next to the whale.

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

5–8 Structure and Function in Living Systems

- All organisms are composed of cells—the fundamental unit of life.
- ★ Cells carry on the many functions needed to sustain life. They grow and divide, thereby producing more cells.

5–8 Diversity and Adaptations of Organisms

- ★ 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 evidence of common ancestry.

9–12 The Cell

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

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

3–5 Cells

- 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.

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 organs are made up of different kinds of cells. The cells in similar tissues and organs in other animals are similar to those in human beings but differ somewhat from cells found in plants.
- ★ Cells continually divide to make more cells for growth and repair.

Related Research

- Stavy and Tirosh (2000) asked students in grades 7–12 a question similar to the one in this probe, comparing muscle cells of a mouse to muscle cells of an elephant. The majority of students, especially in grades 7

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

and 8, thought that larger animals have larger cells. The common justification was that "according to the dimensions of the elephants and those of the mice, it is obvious that the muscle cells of the mice are smaller than those of the elephants" (p. 30). This is an example of the intuitive rule "more A, more B." Most of the younger students who answered correctly explained the equality in terms of the cells having the same function and therefore being the same size. Most of the high school students who responded correctly used formal biological knowledge of cells and also described the elephant as having more cells.

- Available research on cells is limited. However, in piloting this probe with more than 100 middle and high school students, many students chose answer B (the blue whale has larger cells than a shrew). Their reasoning matched Stavy and Tirosh's results and was based on the idea that whales are much larger and therefore need larger cells.

Suggestions for Instruction and Assessment

- When students are examining the same cell types of different organisms, encourage them to look not only at the similarity in the shape of the cells but also the size. For example, when comparing the muscle cells of frogs to the blood cells of humans, notice the similar size.
- Develop the idea that cell size is limited by the ability of molecules to pass in, around, and out of cells. Older students can test this idea by making model cells out of blocks of agar of different volume to surface area-to-volume ratios and measuring the rate and depth of penetration of a dye into the model cell. Calculate the volume to surface area ratios of the different cell sizes and compare the results of the diffusion based on the ratios.
- Have students investigate the question, "Is bigger always better?" in the context of a cell's ability to carry out its life functions. Encourage them to develop a way to research and test their idea and have them share their results.
- Ask students why a paramecium can never be the size of human. Develop the idea of why single-celled organisms must be microscopic to carry out the same life processes carried out by multicellular organisms.

Related NSTA Science Store Publications and Journal Articles

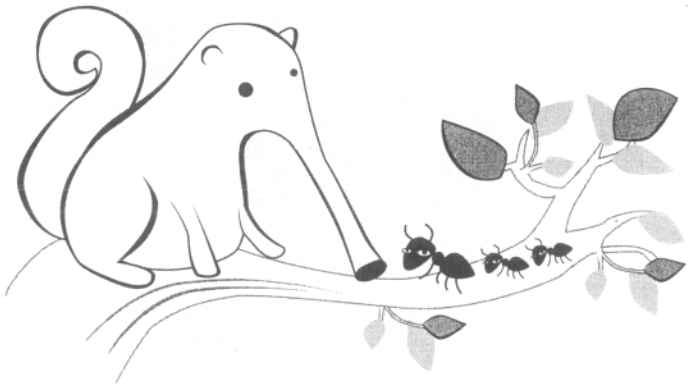
American Association for the Advancement of Science (AAAS). 1993. *Benchmarks for science literacy.* New York: Oxford University Press.

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

Keeley, P. 2005. *Science curriculum topic study: Bridging the gap between standards and practice.* Thousand Oaks, CA: Corwin Press.

Habitat Change

A small, short-furred, gray animal called a divo lives on an island. This island is the only place on Earth where divos live. The island habitat is warm and provides plenty of the divos' only food—tree ants. The divos live high in the treetops, hidden from predators.



One year the habitat experienced a drastic change that lasted for most of the year. It became very cold and even snowed. All of the ants died. The trees lost their leaves, but plenty of seeds and dried leaves were on the ground.

Circle any of the things you think happened to most of the divos living on the island after their habitat changed.

A The divos' fur grew longer and thicker.

B The divos switched to eating seeds.

C The divos dug holes to live under the leaves or beneath rocks.

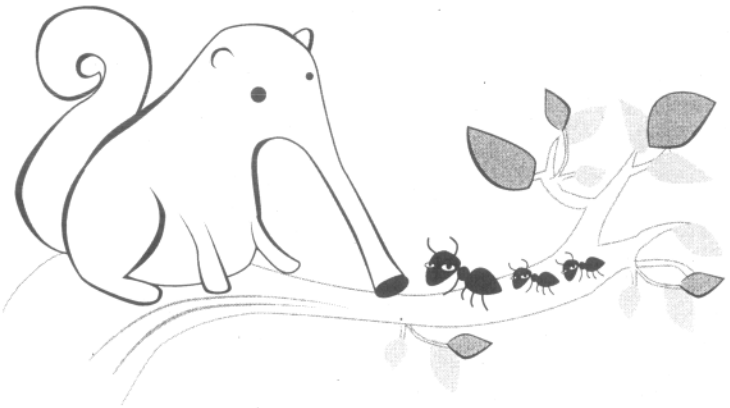
D The divos hibernated through the cold period until the habitat was warm again.

E The divos died.

Explain your thinking. How did you decide what effect the change in habitat would have on most of the divos?

Habitat Change

Teacher Notes



Purpose

The purpose of this assessment probe is to elicit students' ideas about adaptation. The probe is designed to reveal whether students think individuals intentionally change their physical characteristics or behaviors in response to an environmental change.

Related Concepts

adaptation, behavioral response

Explanation

There is no one completely right answer to this question, but the best answer is E: The divos died. In common usage the term *adapt* is understood as any type of change over any span of time. Individuals generally do not intentionally adapt to drastic changes in their environment by changing their physical characteristics (such as fur length or ability to eat certain foods based on teeth or mouth structure) or inherited behaviors (such as where they seek shelter or hibernation). Some individual divos may have been born with variations that made them better suited to survive a change in the environment and to reproduce, passing on their traits to new generations that would be better adapted to the changed environment. However, most of the divos probably died because the physical structures, physiology, and behaviors they were born with no longer fit the

changed environment. Populations can adapt over time, but individuals do not change during their lifetimes.

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. The idea that organisms depend on their environment is not well developed in young children. The focus in the early elementary grades should be on establishing the primary association of organisms with their environments, followed by the upper elementary ideas of dependence on various aspects of the environment and structures and behaviors animals were born with that help various organisms survive (NRC 1996). Students should have opportunities to investigate a variety of habitats of plants and animals and identify ways animals and plants depend on the environment and each other.

Middle School Students

Understanding adaptation can be particularly troublesome at this level. Many students think *adaptation* means that individuals change in major ways in response to environmental changes (i.e., if the environment changes, individual organisms deliberately adapt) (NRC 1996, p. 156). Teachers need to carefully select activities that do not imply to students that an individual organism can change its structures and behaviors at will when the habitat changes. Students at this level should develop the idea of variations organisms are born with that can lead to an individual's survival and reproduction.

High School Students

At the high school level students shift from thinking about the selection of individuals with certain traits that help them survive in their environment to the changing proportion of such traits in a population of organisms. The idea of natural selection, leading to the culminating idea of biological evolution, is a major focus in biology. However, some students still believe that a change in an organism's structures or behaviors in response to its environment can be controlled by the organism and passed along to future generations.

Administering the Probe

Explain to students that the divo is an imaginary organism. However, the challenges it faces, due to the drastic change in its environment, would produce similar responses from real organisms. Consider adding additional distracters for structural changes (such as growing stronger teeth for cracking open seeds) or behavioral changes (such as learning to swim so it could get off the island).

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

K–4 The Characteristics of Organisms

- Organisms have basic needs. For example, animals need air, water, and food; plants require air, water, nutrients, and light. Organisms can survive only in environments where their needs can be met.

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, grow, reproduce, and maintain stable internal conditions while living in a constantly changing external environment.
- Behavior is one kind of response an organism can make to an internal or environmental stimulus. A behavioral response requires coordination and communication at many levels, including cells, organ systems, and whole organisms. Behavioral response is a set of actions determined in part by heredity and in part from experience.

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.

★ Extinction of a species occurs when the environment changes and the adaptive characteristics of a species are insufficient to ensure its survival.

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

K–2 Diversity of Life

- Plants and animals have features that help them live in different environments.

K–2 Heredity

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

3–5 Interdependence of Life

- For any particular environment, some kinds of plants and animals survive well, some survive less well, and some cannot survive at all.

★ Changes in an organism's habitat are sometimes beneficial to it and sometimes harmful.

6–8 Interdependence of Life

★ In any particular environment, the growth and survival of organisms depend on the physical conditions.

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

9–12 Diversity of Life

- The variation of organisms within a species increases the likelihood that at least some members of the species will survive under changed environmental conditions.

9–12 Heredity

- An altered gene may be passed on to every cell that develops from it. The resulting features may help, harm, or have little effect on the offspring's success in its environment.

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 school 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 they 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).
- Most students seem to think that adaptation involves individual organisms changing in major ways as a response to survive a change in their environment (Driver et al. 1994).
- Students appear to confuse an individual's adaptation during its lifetime and inherited changes in a population over time. A large number of students appear to adopt a Lamarckian view of adaptation (Driver et al. 1994).

Suggestions for Instruction and Assessment

- Some "adaptations" are controlled by an organism. When dealing with individual organisms, *acclimatization* would be a better term to use for noninheritable changes in structure or behavior made by an organism during its lifetime.
- Be aware that Lamarckian interpretations of an individual's adaptation to its environment may impede understanding of Darwinian evolution.
- A common activity used in elementary and middle school science is to have students design an imaginary organism that is adapted to a particular habitat. Be aware that this activity may perpetuate the misconception that organisms intentionally adapt.
- Compare and contrast with students the everyday common use of the word *adaptation* with the scientific meaning of the word. Add this to students' growing number of examples of the ways we use words in our society that are not always the same as the scientific use of the words.

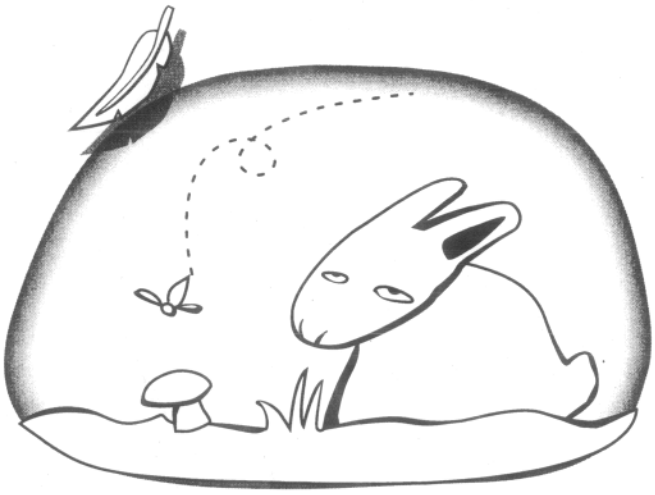
Related NSTA Science Store Publications and Journal Articles

American Association for the Advancement of Science (AAAS). 1993. *Benchmarks for science lit-*

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

Is It an Animal?

Which of the organisms listed are animals? Put an X next to each organism that is considered to be an animal.

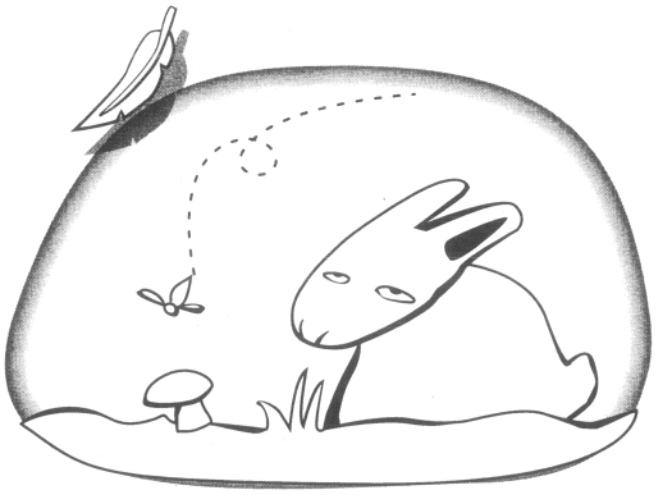


___ cow	___ spider	
___ tree	___ snail	
___ mushroom	___ flower	
___ human	___ monkey	
___ worm	___ beetle	
___ tiger	___ whale	
___ shark	___ frog	___ mold
___ starfish	___ chicken	___ snake

Explain your thinking. Describe the "rule" or reasoning you used to decide if something is an animal.

Is It an Animal?

Teacher Notes



Purpose

The purpose of this assessment probe is to elicit students' ideas about animals. The probe specifically seeks to find out what characteristics students use to determine whether an organism is classified as an animal.

Related Concepts

animals, classification

Explanation

The cow, human, worm, tiger, shark, starfish, spider, snail, monkey, beetle, whale, frog, chicken, and snake are biologically classified as animals. The tree and flower are classified as plants, and the mushroom and mold are classified as fungi. Biological classification at the kingdom level places more emphasis on cellular details (including molecular details), anatomical details (internal and external structures), and embryology than on general appearance or behavior. Animals have body plans and internal structures that enable them to obtain their food from an external source, making them consumers (or heterotrophs). All animals are consumers; however, not all consumers are animals. Animals are multicellular and their cells do not contain cell walls. Their embryonic development starts with a diploid zygote (product of the union of egg and sperm), and a defining characteristic of all animals that differentiates them from other heterotrophs is that they develop from a blastula (this is a complex idea that isn't developed until later in high school or college). The animal kingdom contains a vast variety of life forms,

including diverse examples from phyla such as sponges, coelenterates (e.g., jellyfish), mollusks (e.g., snails), worms, arthropods (e.g., insects), echinoderms (e.g., starfish), and vertebrates (including the classes of fish, amphibians, reptiles, birds, and mammals).

Curricular and Instructional Considerations

Elementary Students

By the time children enter school they are quite familiar with animals (from barnyards, backyards, and zoos and as pets) and have begun to form an operative definition for whether or not something is considered to be an animal. Their ideas are quite concrete and they tend to associate animals with pets or animals kept in a zoo, based on their everyday experiences. Their instruction focuses on a variety of animals and their needs and characteristics. However, students' learning may become quite limited if they focus only on familiar animals, particularly mammals or other vertebrates. This probe is useful in determining what characteristics students initially use to help them decide if a living organism is an animal, based on their familiarity with a variety of animals.

Middle School

In middle school, students begin to develop formal distinctions between plants and animals based on whether plants and animals make their own food and on their internal structures. Animals are considered consumers, but students may fail to recognize that a variety of different types of consumers are also animals. This idea is a grade-level expectation in the national standards. Biological diversity is addressed; however, students may still have a limited view of what an animal is.

High School

Students at this level exhibit a general understanding of taxonomic classification and use hierarchical groupings to understand that seemingly different organisms in different phyla belong to the animal kingdom. This probe is useful in determining whether students revert to their own operative definitions of an animal, even after formal biological instruction in middle or high school.

Administering the Probe

Eliminate any organisms that students are not familiar with. Elementary teachers may want to include pictures with each example. In lower elementary grades, it is helpful to have students complete the top part of the task on their own, followed by individual student interviews or a group discussion, enabling the teacher to more fully capture students' thinking. Teachers may also wish to tailor the list of items to better fit their teaching context. Middle and high school teachers may want to add organisms from all the kingdoms of life. This probe also works well in a group situation, having students vote on whether or not they think an organism is an animal and then discuss their reasons with the class. This probe can also be

used as a card sort. Ask students to work in small groups or pairs to sort cards of the names and/or pictures of organisms into two groups: those that are considered to be animals and those that are not. Observe and listen to students discuss their reasons with their peers as they sort the cards.

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. For example, humans have distinct body structures for walking, holding, seeing, and talking.

5–8 Diversity and Adaptations of Organisms

* 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

- Biological classifications are based on how organisms are related. Organisms are classified into a hierarchy of groups and subgroups based on similarities that reflect their evolutionary relationships.

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

K–2 Diversity of Life

- Some animals (and plants) are alike in the way they look and in the things they do, and others are very different from one another.

3–5 Diversity of Life

* A great variety of kinds of living things can be sorted into groups in many ways using various features to decide which things belong to which group.

6–8 Diversity of Life

* One of the most general distinctions among organisms is between plants, which use sunlight to make their own food, and animals, which consume energy-rich foods. Some kinds of organisms, many of them microscopic, cannot be neatly classified as either plants or animals.

Related Research

- People of all ages have a much narrower definition of an animal than biologists. Typically, students think of "animals" as large, terrestrial mammals. Animal qualities commonly include the following: having four legs, being large in size, having fur, making noise, and living on land. A study of 15-year-olds found that 10% identified animals as a biologist would from an assortment of organisms. About half of these

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

students identified fish, boy, frog, snail, snake, and whale as animals (Bell 1981).

- Older students often apply more general characteristics that apply to all living things (i.e., respiration and reproducing) to animals (Trowbridge and Mintzes 1985).
- Some students, although they recognize feeding as an attribute, see it as a general characteristic of living things rather than in terms of the heterotrophic nature of the way animals feed (Driver et al. 1994).
- Studies show that preservice elementary teachers, as well as experienced elementary teachers, also hold restricted meanings for the concept of "animal" (Driver et al. 1994). This may affect students' opportunities to learn the scientific view of "animal."
- Humans are often not thought of as animals; rather they are contrasted with animals. Humans, insects, birds, and fish are often thought of as alternatives other than animals, not as subsets of animals (Driver et al. 1994).

Suggestions for Instruction and Assessment

- National standards suggest the study of living organisms begin with those that are most familiar to younger students—those found in their immediate environment. Be careful that this does not limit the child's experience to only vertebrates, particularly mammals. In later years, have students study a variety of animals representing the diversity of animal life.
- When students group organisms as animals, it is important that instruction is geared toward getting students to carefully examine the characteristics to see if they are truly exclusive.
- Instruction related to animals is often focused on a specific organism or organisms (e.g., butterflies or barnyard animals). This may help students develop an understanding of the special characteristics of butterflies or barnyard animals that define them as animals, but students may fail to generalize to other vertebrate and invertebrate classes.
- Encourage students to examine animals carefully. Identify attributes in common, even though the animals may appear to be very different.
- Provide multiple experiences in sorting and classifying animals, emphasizing the characteristics that are consistent with a particular grouping. Introduce students to the hierarchical nature of groupings (e.g., A robin is both a bird and an animal.)
- Explicitly develop the idea that all animals are consumers, but make sure that older students understand that not all consumers are animals (e.g., protists). Use nutrition as the initial way to distinguish animals from plants.
- Help students understand that the way we use words in everyday life may be different from the way words are used in science. Remind them that the word *animal* has a much more precise meaning in science than in everyday language. Be aware that the more commonly used a word is in everyday language, such as *animal*, the more likely students are to revert back to a lay

definition. Once students develop a formal definition of *animal*, challenge them to think of everyday usages of the word that would be limiting. For example, if a sign outside a store says, "No animals allowed," would you be allowed to enter the store?

- Use the interview protocol developed by Charles Barman (Barman et al. 1999) to further examine students' ideas about animals. Combine this with several other types of ways to categorize animals versus non-animals.
- Be aware that accepting humans as animals may be more than a shift in scientific thinking. Some students may have cultural or religious traditions that may make them resistant to considering humans as animals. Teachers can respect these beliefs by balancing the scientific notion that humans are biologically classified in the animal kingdom with the notion that humans are a unique and very special kind of animal.

Related NSTA Science Store Publications and NSTA Journal Articles

Barman, C., N. Barman, K. Berglund, and M. Goldston. 1999. Assessing students' ideas about animals. *Science and Children* (Sept.): 44–49.

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 Guides

(Keeley 2005)
"Animal Life"
"Biological Classification"
"Biodiversity"

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Trowbridge, J., and J. Mintzes. 1985. Students' alternative conceptions of animal classification. *School Science and Mathematics* 85 (4): 304–316.