ART TO ZOO

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# A Mouse Like a House? A Pocket Elephant?

## How Size Shapes Animals, and What the Limits Are

King Kong reaching into a high window of the Empire State Building . . . a family small enough to live in a matchbox, cooking meals on a thimble stove outside, chopping down dandelions with axes made from broken Christmas tree ornaments . . . a swarm of flies as big as blimps terrorizing a city. . . : Stories about familiar creatures grown huge or shrunk almost to the vanishing point have long fascinated readers and moviegoers. But could such creatures exist in real life? What real limits are there on animals' bigness and smallness? What effects does an animal's size have on the animal itself?

This issue of ART TO ZOO explores these questions. Size is a theme that cuts through the incredible diversity of biological forms. Exploring this theme can give your students a glimpse of basic patterns that help make sense of that diversity. Size provides examples of math operating in nature. And size is a subject of interest to children, who have to cope every day with being small and growing.

Large animals differ from small ones in various intriguing ways. One particularly interesting set of differences involves the decrease in metabolic rate that occurs as mammals increase in size—so that small mammals seem to live more intensely and rapidly than large ones do. The Lesson Plan in this issue of ART TO ZOO describes in detail one way you might approach the subject of animal size in relation to metabolic rate. The accompanying Pull-Out Page poster and the sidebar, "Animal Sizes and Size Limits" (on page 3), provide less detailed information about other size-related differences among animals.

## Background

### Shrews* and Elephants

In many ways, the contrast between a shrew-sized mammal and an elephant-sized mammal is like the contrast between the Keystone cops and a modern movie. The smaller animal scurries around with the speeded-up motions of an actor in an early screen comedy, while the larger animal proceeds at a pace that is steady and slow.

The life of a shrew is go, go, go. With its slender bones, a full-grown shrew can weigh as little as a penny (though most are somewhat heavier), and it must always be on the move. Its metabolic rate is so high that it has to spend a lot of its time eating to stay alive. Its heart may beat up to 20 times a *second* as it scurries around after food. The smallest shrews eat approximately their own body weight of food every 24 hours. Each day, a shrew may alternate many periods of activity (up to 24, depending on the kind of shrew) with periods of rest—because if it slept through the night, it would starve to death. (In fact, a small shrew could starve to death if it went six hours without eating.) A shrew can have babies when it is only two months old, and the babies develop inside the mother for only three weeks before they are born. It seems that for the tiny shrew, time itself has speeded up: the events of its existence follow each other in rapid succession, and its whole life is over in a year.

In contrast, the elephant, heavy and big-boned, is seldom in a rush. It puts its thick legs down deliberately, and its usual pace is unhurried. It munches its food steadily . . . breathes slowly . . . and takes time to rest. Its heart beats at half the speed of a human being's, and it draws a third as many breaths per minute. It doesn't have babies until it is in its early teens, and the baby grows for almost two years inside the mother before it is born. An elephant may live as long as 60 years.

### Metabolism

To begin to understand why shrews and elephants differ in these ways, it is important to understand what *metabolism* is. Here is a basic explanation.

An animal breaks down into simple chemicals the food it has digested. In this way, it releases *energy* (to heat its body and fuel its activities) and produces *matter* (to build the giant molecules that it needs to construct and repair its body).

The hundreds of chemical reactions involved in this breaking down and building up, which take place in the animal's cells, are together called *metabolism*. It is essential that metabolism take place, because the animal must have this energy and these body-building materials in order to survive and reproduce.

Shrews, the smallest of all mammals, move rapidly through their lives. (Ernest P. Walker, *Mammals of the World*, 3d ed., Johns Hopkins University Press, 1975)

For metabolism to happen, conditions in the cells must be just right. For one thing, there must be enough *oxygen* and *water*, and the *temperature* must be suitable. For another, there must be a means to carry away the *waste products* (like carbon dioxide) that metabolism releases, so they don't poison the animal.

The speed at which these chemical processes take place is called the *metabolic rate*. One way to determine an animal's metabolic rate is by measuring how much oxygen the creature uses. The more oxygen, the higher the metabolic rate—and the more active the animal. Different species have different metabolic rates, and the same animal's metabolic rate will vary depending on such factors as its activity level, the amount of food it has eaten, and its temperature.

### Body Temperature

Any animal, to survive, must find some way to keep its body within the temperature range that allows metabolism to take place. Warm-blooded animals solve this problem differently than cold-blooded animals do. Although the Lesson Plan is specifically about mammals, which are warm-blooded, the supplementary poster includes information about cold-blooded animals as well. For this reason, background about both groups is provided here, so you will have the information you need to give your students whatever explanations and answers they require.

- *Cold-blooded animals*. All animals except mammals and birds are cold-blooded, a term that is misleading, since the blood of these creatures is not always cold, but varies with the temperature of their surroundings. Cold-blooded animals depend on their *environment* to regulate their body temperatures. When a cold-blooded animal is too hot, it may move into the shade. On a chilly day, it may warm up by basking in the sun. If it is still too cold, it will become increasingly sluggish. Its metabolism slows down, so it produces and requires less energy—which is why cold-blooded animals become inactive in cold weather.
- *Warm-blooded animals*. Warm-blooded animals, on the other hand, have body mechanisms that allow them to regulate their internal temperatures to be more or less constant no matter what the temperature of their surroundings. Thus they can cool themselves in hot weather (by sweating, for example, or by increasing the blood flow just under their skin so they lose

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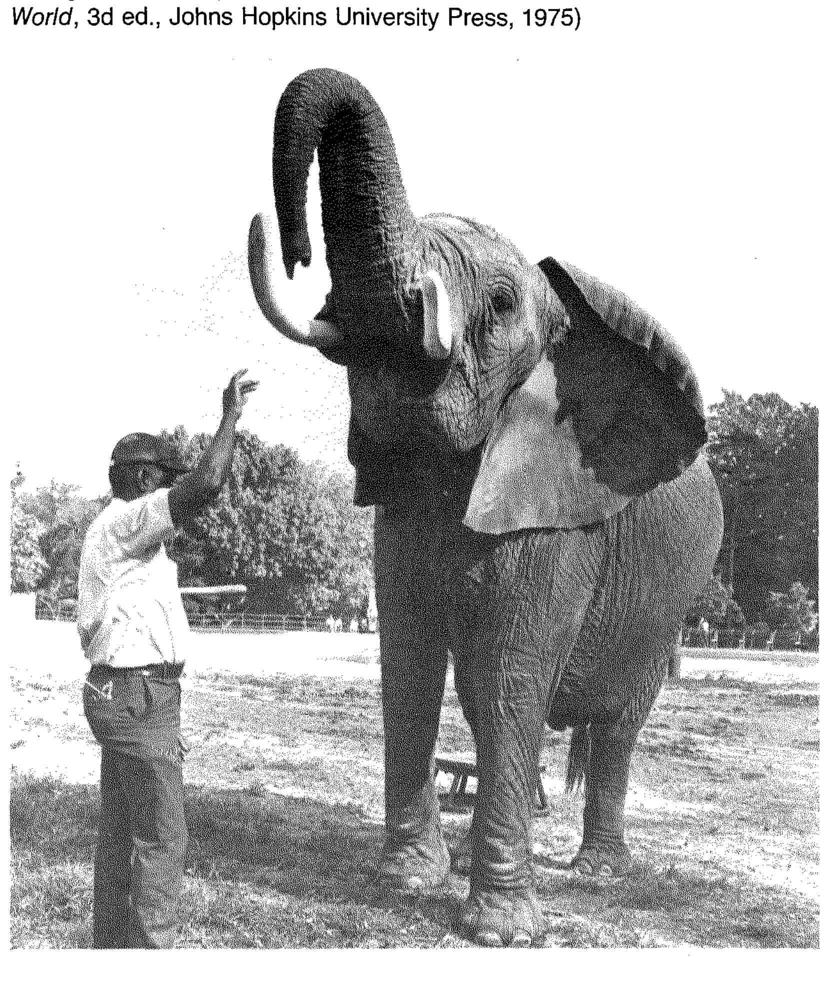
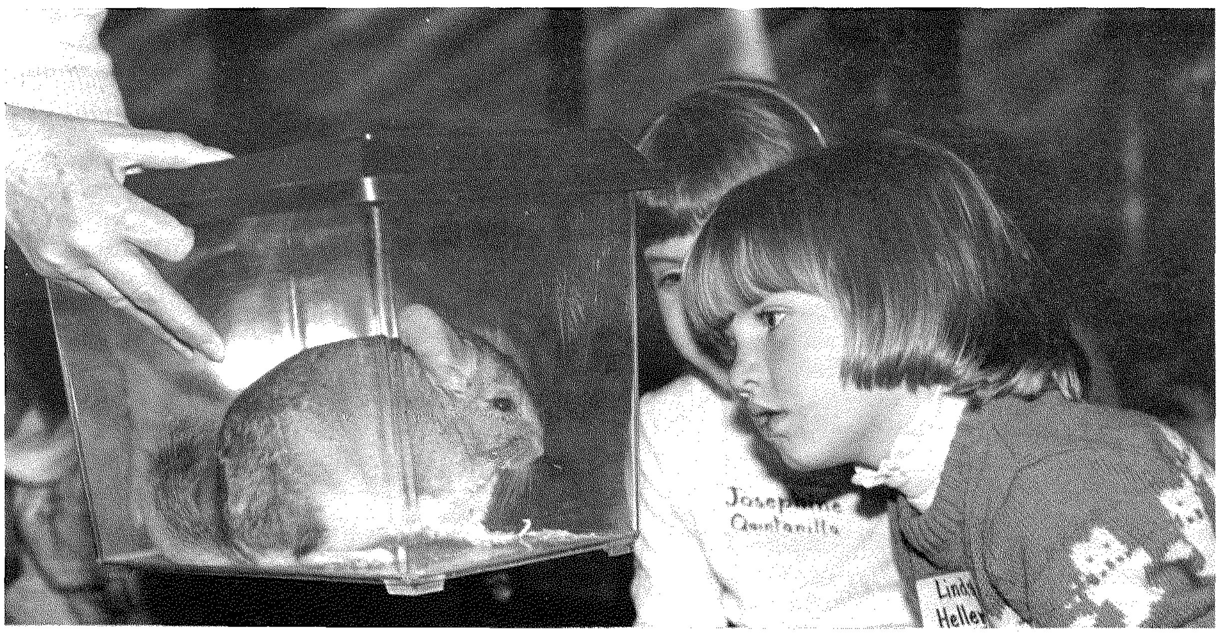


Elephants, like the one shown here with keeper Jim Jones at the Smithsonian's National Zoological Park, seem to take their time at almost everything they do. (Jessie Cohen, National Zoological Park)

*For simplicity's sake throughout this issue, distinctions between different kinds of the same animal are almost never made. There are many kinds of shrews, for example, ranging in adult weight from 2 grams to about 35 grams.



A chinchilla can weigh up to 800 grams. It looks heavier than it is because of its thick fur. (Jessie Cohen, National Zoological Park)

# Lesson Plan

### Step 1: Introducing Size Differences and Metabolism

Ask your students what the biggest animal they can think of is. Then, what is the smallest?

This will lead to the question, what counts as an animal? Is a germ an animal? Tell the class that we'll say that *animals are living beings that use food from their surroundings to produce the energy they need to stay alive at least long enough to reproduce.* (Bacteria are animals. Viruses are not, because they are unable to reproduce without the help of a different species of animal.)

Now have the class look at the size scale on the Pull-Out Page. Point out that this chart goes from the smallest animal known, *Mycoplasma,* which is smaller than a bacterium but larger than a virus, all the way up to the great blue whale, the world's largest animal. Point out too that all the animals on the poster (and all the animals that the children will be learning about in this lesson) are *grown-up* animals.

Tell the children that they will have a chance later on to examine the poster more carefully, and to read about the smallest and largest animals. But first, they are going to examine a familiar group of animals of in-between size—mammals, in particular *mammals that live on land.* Remind the children that a mammal is an animal with a backbone that produces milk to feed its babies. Point out that a human being is a mammal; then have them find the human being on the scale.

Now have them find the shrew and the elephant on the scale. Tell them that the shrew is the smallest mammal that lives on land, and the elephant is the largest. The mammals that they are going to learn about now are in this shrew-to-elephant range (the gray block on the scale). Explain that, to see how these mammals change with size, they will begin by comparing the smallest and the biggest. Then draw on the "Shrews and Elephants" section of the background materials to give the children brief word-portraits of the two animals.

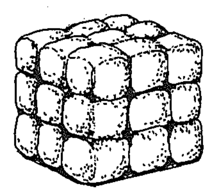
Next, explain to students that they are going to look at *why* shrews and elephants differ in these ways. Tell them that, to begin to understand why, they need to know what *metabolism* is. Then draw on the "Metabolism" section of the background materials to explain what metabolism involves. Emphasize that metabolism is absolutely essential to animals because it provides the energy and materials that they need to survive and reproduce.

Point out that it is easy to see the effects of metabolism in action, since metabolic rate increases with activity. To demonstrate, ask one of the children to go to the front of the class and do jumping jacks. When the jumper is breathing hard, have the other students count how many breaths the jumper takes in a minute; have them compare that to the number of breaths a nonjumper takes. Then ask them to make a similar comparison for heartbeat rate (you may need to show the children how to take a person's pulse).

Explain that the jumper's breath and heart rates have gotten faster because his metabolism rate went up as he became active. Metabolism requires oxygen; the jumper needs to breathe faster to get more air. And his faster-beating heart moves the blood around his body more quickly, bringing more food and oxygen to his cells, and carrying away the waste products of metabolism sooner. Like the jumper, the shrew has a fast breath and heart rate, and a high metabolic rate. But unlike the jumper, the shrew has a very high metabolic rate even when it is resting. Tell the children that they are now going to use marshmallows to find out why.

### Step 2: Size, Surface Area, and Heat

Have each child build a marshmallow representation of an "animal" shaped like a cube that is 3 marshmallows long, 3 marshmallows wide, and 3 marshmallows deep, using toothpicks to hold the marshmallows together. Draw the shape on the chalkboard:



When the children have finished, ask them how much their animal weighs, in marshmallow units (each weighs 27 marshmallows). Write this on the chalkboard, under the drawing.

Now tell the children that, since animals are covered with skin, they should paint their marshmallow animals to give them skin. (If they use diluted food coloring, they can safely eat their marshmallows later.) While the marshmallows are drying, remind the children that the painted part, the skin, is called the *surface area* of the animal. It is *where the animal touches its surroundings.*

Have the kids take their animals apart, and imagine that the 27 separate marshmallows are 27 little animals. Ask them how much all the little animals weigh together, and write the answer on the chalkboard—to emphasize that the weight of the 27 separate marshmallows is exactly the same as the weight of the 27 attached together. (Consider the toothpicks weightless.)

Now ask whether the big animal has the same amount of skin as the group of 27 little animals together. The children can see, by looking at their marshmallows, that the little animals as a group have much more skin than the single big animal did: the big animal had only colored skin; the little animals have all the colored skin *plus* a lot of white skin. This means that *little animals have more of their bodies touching the outside world than big animals do.*

Now carry the marshmallow analogy a little further by telling the children to imagine for a moment that every marshmallow produces heat, the same amount of heat as every other marshmallow. Ask the children to compare how much heat the 27 little animals produce together with how much heat the big animal produces. The answer is, of course, that the total heat produced is the same.

Then tell the children that when a warm animal's body touches cooler air, it loses heat. Ask which will lose more heat—the 27 little animals or the single larger one? Of course, the 27 little animals will lose more heat, because they have so much more surface (skin) to lose heat through. *Small animals lose more heat than big animals do, because they have more surface area.*

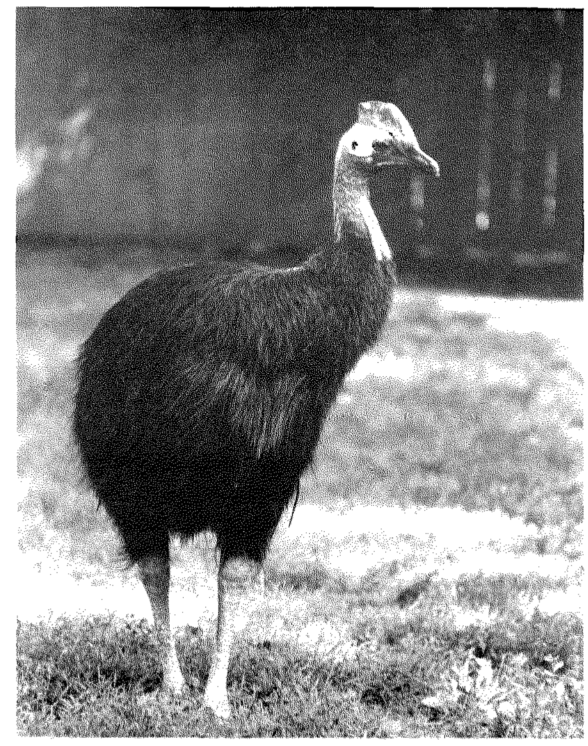
Now use the "Body Temperature" section of the background materials to explain to the children how warm-blooded animals have physiological ways to keep their body temperature constant, even when the temperature of their surroundings is changing.

### Step 3: The Shrew-to-Elephant Table

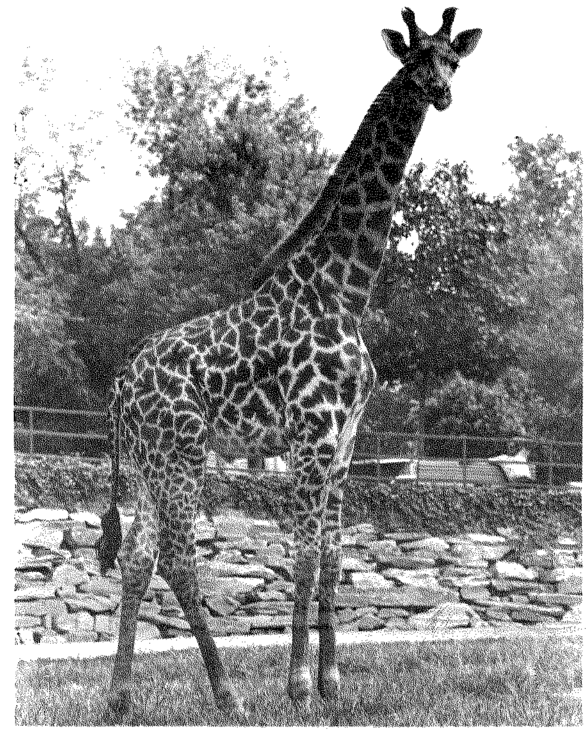
Now your students are ready to use the Shrew-to-Elephant Table that appears on this page, in an activity with two goals. The first goal is for the children to extend what they have learned to the whole range of land mammals that are between shrews and elephants in size. The second goal is for them to practice laying out numbers in a table and reading information off a table—two very important skills.

Here is how the table can be used to do this.

First, read aloud, in random order, the names of the mammals that appear as headings across the top of the table. Ask the children to figure out how to arrange the names in order of increasing size. Write the children's answers across the top of the chalk-

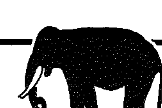


A cassowary, which weighs about 50 kilograms, never takes to the air, because birds above 10 kilograms are too heavy to fly. (Jessie Cohen, National Zoological Park)



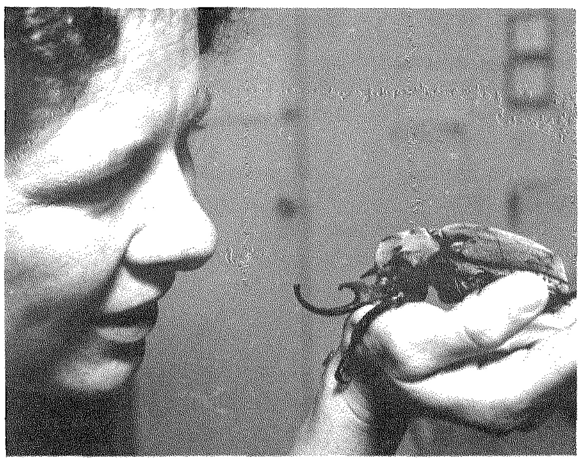
A very big adult giraffe can be almost twice as tall as an elephant. But it is only about one-seventh as heavy. (Jessie Cohen, National Zoological Park)

## Shrew-to-Elephant Table



| | Shrew | Mouse | Dog | Human | Horse | Elephant |
|---|---|---|---|---|---|---|
| How much does it weigh? (in grams) | 4.8 | 25 | 11,700 | 70,000 | 650,000 | 3,800,000 |
| How much oxygen does its *whole body* use each hour? (in microliters* per hour) | 35,000 | 41,000 | 3,900,000 | 14,800,000 | 71,000,000 | 270,000,000 |
| How much oxygen does *each gram of its body* use? (in microliters per gram per hour) | 7,300 | 1,640 | 330 | 210 | 110 | 70 |
| How fast does its heart beat when it is resting? (in beats per minute) | 800 | 600 | 95 | 70 | 36 | 30 |
| How long do its babies develop inside the mother before they are born? (in weeks) | 3 | 3 | 8 | 38 | 46 | 90 |
| What is its lifespan? (in years) | 1 | 2 | 13 | 72 | 25 | 60 |

*A microliter is a millionth of a liter.



Goliath beetles can be as long as 10 centimeters. How long, would you guess, is this one at the Insect Zoo in the National Museum of Natural History? (Chip Clark, National Museum of Natural History)

board. (Throughout this activity, you are going to be reproducing the table on the chalkboard; format everything you write on the board accordingly.)

Now write the first question, "How much does the animal weigh?" in the appropriate place on the chalkboard. Then state each animal's weight as a sentence ("A shrew weighs 10 grams."). After each statement, fill in the animal's weight under its name, explaining what you are doing.

Then write the other questions where they belong on the table, and draw the lines of the grid. Tell the children that you are now going to give them pieces of information—out of order, and in sentence form. They are to put each piece of information, as a number, in the box where it belongs.

You will want to emphasize to the children that all the answers on each line should be given in the same *measurement units*. Point out how this is so in the sample line. Explain that if the units were not the same, it would be much harder to compare the different animals. For example, if the small animals were measured in grams, and the big animals in kilograms, users of the table would have to change all the answers into grams (or all the answers into kilograms) before they could glance at the table quickly and know which animal was bigger than which. Remind the children that this principle will apply when they make tables in the future.

Now have each student reproduce the headings and the grid on a piece of paper. Ask one child to go to the chalkboard while the others continue to work individually at their seats. Give one piece of information at a time, for example, "A dog's heart beats 95 times a minute" or "An elephant lives for about 60 years." After each statement, give the children time to figure out where the piece of information should go. Then, as a check, have the student at the chalkboard write the answer in the correct box.

After the table has been completed, you may want to warn the children not to be surprised if they see somewhat different answers in other tables or books. There are tremendous variations among living creatures. No scientist can know for sure what the exact average is for all animals, because no one can measure every animal. Think, for example, of how many different sizes of dogs there are. No wonder that the numbers you find in the "dog" column depend on which kinds of dogs the person who figured out the numbers was looking at.

Now it is time for the children to use the table they have created. Have them go over it line by line. For each line, ask them to describe the pattern that emerges from the numbers in the line. For example, the heartbeat line shows that big animals have hearts that beat less often than the hearts of the smaller animals. The patterns that will emerge from the numbers in the table are some of the ones described in "How Are Small Mammals Different from Big Ones?" (in the background materials).

The pair of questions about oxygen consumption ("How much oxygen does its *whole body* use in one hour?" and "How much oxygen does *each gram of its body* use in one hour?") are the only ones in the table that may be confusing. The difference between a value for the whole body of an animal and the value for each gram of the animal's body weight has cropped up repeatedly in this issue of ART TO ZOO. It came up in connection with food consumption, for example, when the children learned that an elephant ate a larger total amount than a shrew, but that each gram of the elephant's body used a smaller amount. Now is a good chance to make sure that the class clearly understands this important difference.

If the children had a pet elephant and a pet shrew, they would have to spend a lot more money buying the elephant's food than buying the shrew's. This is what the *whole body* amount refers to. Yet each gram of the elephant's body needs less food than does each gram of the shrew's body. Tell the children that they might think of the elephant as a huge but fuel-efficient car, and of the shrew as a compact gas-guzzler. (This analogy is *very loose*, but it may help the children grasp the difference.)

The two questions on oxygen consumption in the table reflect exactly the same distinction:

- The question, "How much oxygen does its *whole body* use each hour?" asks about the amount of oxygen that the *whole animal* needs: bigger animals need more.
- The question, "How much oxygen does *each gram of its body* use?" asks about the amount of oxygen that *each gram of the animal* needs: bigger animals "run on" less.

The rest of the table should be easy for the children to understand. A good way to conclude Step 3 is by telling the class about the other size-related patterns described in "How Are Small Mammals Different from Big Ones?"

You bet I'm big—for a frog! I'm an African bullfrog and I weigh almost half a kilogram. (Jessie Cohen, National Zoological Park)

**Step 4:** Following-Up

After the children have finished these activities, give them a chance to examine the poster (on the Pull-Out Page) in as much detail as they want. You *may* wish to spend some class time discussing the poster (the sidebar, "Animal Sizes and Size Limits," provides background information).

Then the kids are ready to have fun applying what they have learned about animal size by writing and illustrating a science fiction adventure based on real facts. Here is the topic:

- You are a scientist who has invented a size potion that can make you any size an animal can be. How big or little you get depends on how much of the potion you drink. Write a science fiction story describing the adventures you had two different times you drank the potion. The first time, you became bigger than you are in normal life; the second time, you became smaller. You stayed each new size for one hour.

Tell exactly what size you became in each case. Based on what you have learned about how size shapes animals, describe at least four ways you changed as you changed size. Tell about the adventures you had. Then say which size you preferred being, and why you liked life at that size better. Illustrate your story.

## Animal Sizes and Size Limits

Mammals, the group of animals discussed in the Lesson Plan, represent only a fraction of all the animals that exist. The scale on the Pull-Out Page gives you a picture of the full range of animal sizes. Here are some questions about the scale that the children may ask, and some points that you may want to bring out, as you move up the scale from the smallest to the largest animals. (Any of these questions could be a research topic for students who wish to look further into the subject of animal size.)

- ***How small can an animal be?*** The bottom limits of animal size are set by biochemistry: all animals need to carry out metabolic processes and to reproduce, so the smallest animal must be big enough to contain the necessary metabolic and genetic equipment.

The tiniest truly living creature known that can reproduce without the help of another organism is *Mycoplasma*. It is smaller than a bacterium but larger than a virus: over 1,300 of these tiny beings could fit on the dot of this i.

- ***Why are microscopic animals so different from the animals we can see and touch?*** One reason is that the very small size of microscopic animals permits them to be simple in shape and still have plenty of surface area. These smallest creatures (bacteria and one-celled animals, for example) have so much surface area—and such small total requirements—that they can absorb all the oxygen and nutrients they need right through their outside surface.

Slightly larger animals could not get enough oxygen and nutrients this way if they stayed so simple in shape—so their shapes tend to be *more complicated* than those of their tiniest counterparts. The larger animals have folds, knobs, and holes on the outside and inside surfaces of their bodies. These make their surface area bigger, increasing absorption.

Larger animals also have different ways of moving essential materials to the places in their body where they are needed. The oxygen and nutrients that the smallest animals absorb through their outside surface don't have far to travel. Sugar molecules, for example, diffuse (spread around) through a single cell in a matter of seconds. By contrast, if a human-sized animal depended on diffusion for its food, it would wait most of its lifetime before sugar in its stomach spread all the way to its hands and feet. It would be lucky if, during its whole life, it could get enough energy from the sugar to take a few steps.

Of course, no animal could survive that way. Most animals above about one millimeter in length have specialized systems to carry materials through their body. Our own circulatory system—including blood that can carry substances, and a heart that can pump the blood around—is a good example.

- ***Why are there no warm-blooded animals smaller than shrews?*** What we have learned about shrews suggests an answer. A warm-blooded animal smaller than a shrew would have an even higher metabolic rate than a shrew does. It would have to eat so much compared to its weight that it would never have time to rest: it would either starve or drop dead of exhaustion.

Not only are all animals smaller than shrews cold-blooded, but *most* animals in the world are cold-blooded. There are far more animals below the shrew in size than above it. Consider insects, for example: for each human being that exists, there are almost one *billion* insects. And insects are just one kind of cold-blooded animal. One reason for the preponderance of small-sized animals is that, generally speaking, the smaller an animal is, the more young it produces.

- ***Why don't big animals collapse?*** If too heavy a person sits on a spindly-legged chair, the chair breaks. In the same way, the weight of a big animal would bend or break its legs—if it weren't for the fact that *big animals have thicker bones (and shells) compared to their size* than small ones have. Big animals also have thicker muscles, compared to their size, to move their heavier bodies.

Clearly, there are limits to this. A huge animal's legs could in principle be thicker than the animal's midsection—clearly an absurdity. And the huge animal's muscles could become so thick that there would be no more space inside the animal's body for them.

Weight is less of a problem for animals that live in water, because the water holds the animals up. (Think of the damage a diver would inflict on himself if he jumped off a high board into an empty pool. Yet he can safely and happily jump into a filled pool over and over again—because the water holds up his weight, slowing, and finally stopping, his plunge.) For this reason, the blue whale (the largest of all animals) can live quite well in the ocean even though it is about 14 times as heavy as an elephant. However, a beached whale will die of suffocation under the weight of its own body.

- ***What is the biggest animal possible?*** No one really knows. Clearly an elephant is not the largest land animal possible, since scientists know that *Baluchitherium*, a prehistoric relative of the rhinoceros, definitely lived on land even though it weighed as much as four elephants.

- ***What about dinosaurs?*** *Brachiosaurus* was the biggest dinosaur that ever lived, weighing about as much as 14 elephants. Scientists used to think that *Brachiosaurus* could get that big because it spent most of its time in the water. Now they are not so sure; it may be that *Brachiosaurus* lived mostly on land. If so, upper limits of weight go very high. Perhaps food supply is what keeps animals smaller now.

- ***Could giants exist?*** Well, a giant could have a human *face*, but his body could not look like a person's or work like a person's. He would need to have limbs like tree trunks and muscles to match. It would be very hard for him to get the food he needed, since he would probably not be able to stand because of his weight. Even if he somehow could manage to get up, and even to move slowly along, he could certainly not run or jump, because his bones would smash on impact. And he would not dare walk upright for fear of falling: even a very small giant, one just twice the size of an ordinary man, would kill himself if he fell. His head would hit the ground with about 30 times the impact of an ordinary adult's head (and about 100 times the impact of an ordinary child's).

So, if you ever look back over your shoulder and see a giant running down the street after you—relax, you must be asleep and dreaming!

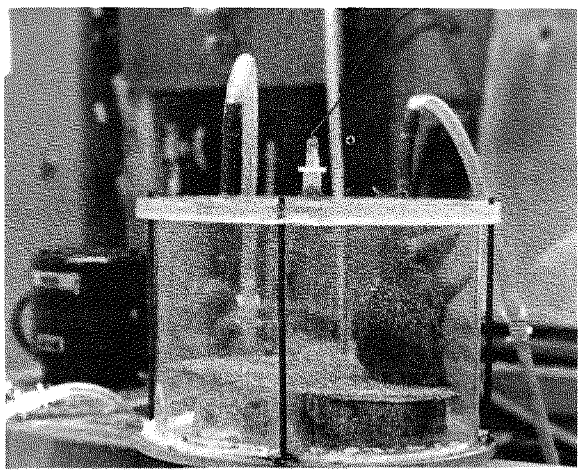
continued from page 1

heat). And they can stay active even in cold weather.

But heating itself costs a warm-blooded animal a lot of energy. To fuel its more intense metabolic processes, it has to eat considerably more than does a cold-blooded animal. To minimize these energy costs, it may also reduce its heat loss by other means—by migrating to a warmer climate, by hibernating, by insulating itself with fur or fat, by building an insulated nest, or by huddling with others of its kind. But if these means are not enough to keep the animal warm, it shivers, increasing its activity level and raising its metabolic rate.

Because not all animals lose (or gain) heat at the same rate, not all animals are affected equally by being in cold (or hot) surroundings. *Small animals lose and gain heat more easily than do big animals.*

One reason for this is that heat transfer between an animal and its surroundings takes place at the surface of the animal's body, and *a small animal has more surface, compared to its size, then does a large animal of the same shape.* (This is a simple fact of geometry, true of any object, whether living or nonliving: when the volume of the object triples, its surface area only doubles.)



Dr. Steve Thompson, a zoologist at the National Zoological Park in Washington, D.C., has just determined the metabolic rate of this tenrec by measuring how much oxygen it uses. (Aaron Eisendrath)

The fact that small animals lose heat more easily than do large animals accounts for** many of the differences between the shrew and the elephant—and between small and large mammals in general. The shrew, being very tiny, has a relatively large surface area; consequently, it loses a lot of heat. By maintaining a high metabolic rate, it also produces a lot of heat, so it is able to keep its internal body temperature constant despite its high rate of heat loss.

### How Are Small Mammals Different from Big Mammals?

The shrew is the most extreme case, but it is generally true that the smaller the mammal, the higher its metabolic rate. And when we consider what metabolism involves, it is no surprise that a number of different body processes related to metabolism also change with size. Here are some of them:

- *A small mammal has a higher oxygen turnover.* Every hour, a resting mouse needs about 2,000 microliters of oxygen per gram of body weight; a man, about 200 microliters; and an elephant, only about 100 microliters.
- *A small mammal breathes faster.* While a mouse may take 150 breaths a minute, a man takes about 16, and an elephant only 6.
- *The heart of a small mammal beats faster.*
- *The blood of a small mammal circulates through its body faster.* A shrew's blood circulates all the way around in 4 seconds, a horse's in 90 seconds, and an elephant's in 140 seconds. This, and the fast heartbeat, make sense when you consider that the blood must carry food and oxygen to the cells for use in metabolism, and must carry away the waste products that metabolism creates.
- *A small mammal eats more per gram of its body weight.* In other words, the total amount of food that it eats is less, but it provides more food for each of its cells.
- *A small mammal develops inside its mother for a shorter time before it is born.* A mouse has a gestation time of about 3 weeks; a horse, of 11 months; and an elephant, of about 22 months.
- *A small mammal has babies when it is younger.* The length of a generation can range from 2 months for a shrew, to almost 15 years for an elephant.
- *A small mammal has a shorter lifespan.*

What is even more surprising than these differences is that *the total number of breaths and the total number of heartbeats in a lifetime are approximately the same for most mammals* (330 million breaths, and 1½ billion heartbeats). Just as an inheritance that lasts a miser a lifetime passes through a spendthrift's hands in a year, so an elephant manages to make its allotted number of breaths and heartbeats last six decades, while a shrew has consumed them all in 12 months.

Scientists do not know why this is so. Maybe one of your students will figure out why, sometime in the future. There are exceptions to these patterns. Human beings, in fact, are an exception to the pattern. According to our size, we should have a lifespan of less than 30 years.

**At one time, scientists thought that the surface area explanation given here could in itself fully explain why small animals have higher metabolic rates. However, as they studied more animals, they found that, although surface area and metabolism increase together, they increase at somewhat different rates—so surface area is not a full explanation. Nevertheless, it is a clear and pedagogically fruitful one, and surface area *is* an important constraint on the metabolic rate that a warm-blooded animal can have.

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This issue of ART TO ZOO is particularly indebted to the teaching suggestions in "You and a Shrew," in Ranger Rick's *NatureScope*, Amazing Mammals, Part II (pages 56–58), published by the National Wildlife Federation, Washington, D.C., 1986.

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## Smithsonian National Seminar for Teachers

You don't have to live in Washington to study at the Smithsonian!

"Teaching Writing Using Museums and Other Community Resources," a special one-week course, will be offered by the Smithsonian Institution this summer for elementary and secondary teachers living more than 75 miles outside the Washington, D.C., metropolitan area.

The course carries graduate credit from the University of Virginia. Tuition and materials fees will total approximately $275. No scholarships are available.

"Teaching Writing Using Museums" will survey ways in which teachers can use local museum exhibits and such diverse resources as cemeteries and houses as tools for teaching writing. In addition to working on formal and informal exercises, participants will interview several Smithsonian staff writers to learn about various approaches to writing.

The course, worth three graduate credits, is open to full-time classroom teachers (grades 5 through 12), school librarians (media specialists), and curriculum specialists. Interpreters for hearing-impaired individuals can be provided for all class work.

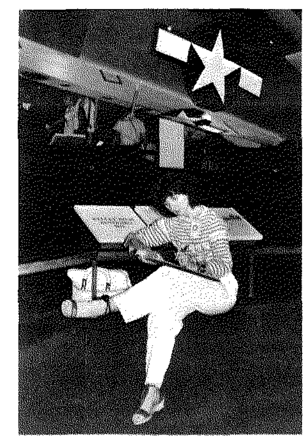
Classes will meet from July 7 to 16 in Washington, D.C. Specially priced housing may be available in a conveniently located college dormitory. Participants will arrange their own meals.

Enrollment is limited. Applications must be postmarked no later than April 13. Notices of acceptance will be mailed by May 4.

For an application form, including complete information, write:

National Seminars<br>
Office of Elementary and Secondary Education<br>
Arts and Industries Building, Room 1163<br>
Smithsonian Institution<br>
Washington, D.C. 20560

Or, telephone (voice) 202/357-3049 or (Telecommunications Device for the Deaf) 202/357-1696.



During a class exercise, a National Seminar participant writes about an airplane exhibited in the Smithsonian's National Air and Space Museum.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*Editor:* Betsy Eisendrath

*Regular Contributors:*<br>
THE ANACOSTIA NEIGHBORHOOD MUSEUM<br>
THE ARTHUR M. SACKLER GALLERY<br>
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ART TO ZOO brings news from the Smithsonian Institution to teachers of grades three through eight. The purpose is to help you use museums, parks, libraries, zoos, and many other resources within your community to open up learning opportunities for your students.

Our reason for producing a publication dedicated to *promoting the use of community resources among students and teachers nationally* stems from a fundamental belief, shared by all of us here at the Smithsonian, in the *power of objects.* Working as we do with a vast collection of national treasures that literally contain the spectrum from "art" to "zoo," we believe that objects (be they works of art, natural history specimens, historical artifacts, or live animals) have a tremendous power to educate. We maintain that it is equally important for students to learn to use objects as research tools as it is for them to learn to use words and numbers—and you can find objects close at hand, by drawing on the resources of your own community.

Our idea, then, in producing ART TO ZOO is to share with you—and you with us—methods of working with students and objects that Smithsonian staff members have found successful.


Special thanks to the following Smithsonian staff members for their help in preparing this issue of ART TO ZOO:

National Museum of Natural History: Robert Hoffman, Director; Joan Madden, Chief, Office of Education.

National Zoological Park: Steve Thompson, Research Associate.

Office of Elementary and Secondary Education: Ann Bay, Thomas Lowderbaugh, Janice Majewski, and Barbara Robinson.

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National Zoological Park: Jessie Cohen, Edwin Gould, William Xanten.

# Animal Sizes and Size Limits

*To get an idea of the size range that this scale covers: the blue whale is 1,000,000,000,000,000,000,000, (one sextillion) times bigger than* Mycoplasma. *If an animal existed that was that many times bigger than the blue whale, this imaginary animal would have 100 times the volume of the earth.*

The *upper limits* of size are mostly physical ones resulting from gravity.

Bigger animals weigh more. Their bones have to hold up this greater weight, and their muscles have to move it around. There comes a size where they can no longer do this.

Animals that live in water can be much heavier than animals that live on land, because the water helps hold up their weight. This is why a whale can be so much larger than an elephant—and than all the dinosaurs—as long as it stays in the water. A blue whale washed onto a beach will die of suffocation, because the weight of its own body will keep it from breathing.

This is one reason that giants could not exist—unless they lived underwater, or on a planet where gravity was much weaker than it is on earth.

**blue whale** (100 tons)—Largest animal alive and largest that has ever existed.

***Brachiosaurus*** (80 tons)—Largest dinosaur. People used to think it lived mostly in water, but now think it may have spent a lot of its time on land.

***Baluchitherium*** (30 tons)—Largest land mammal of all time.

**elephant** (6 tons)—Largest living land animal.

**giant squid** (3 tons)—Largest animal without a backbone.

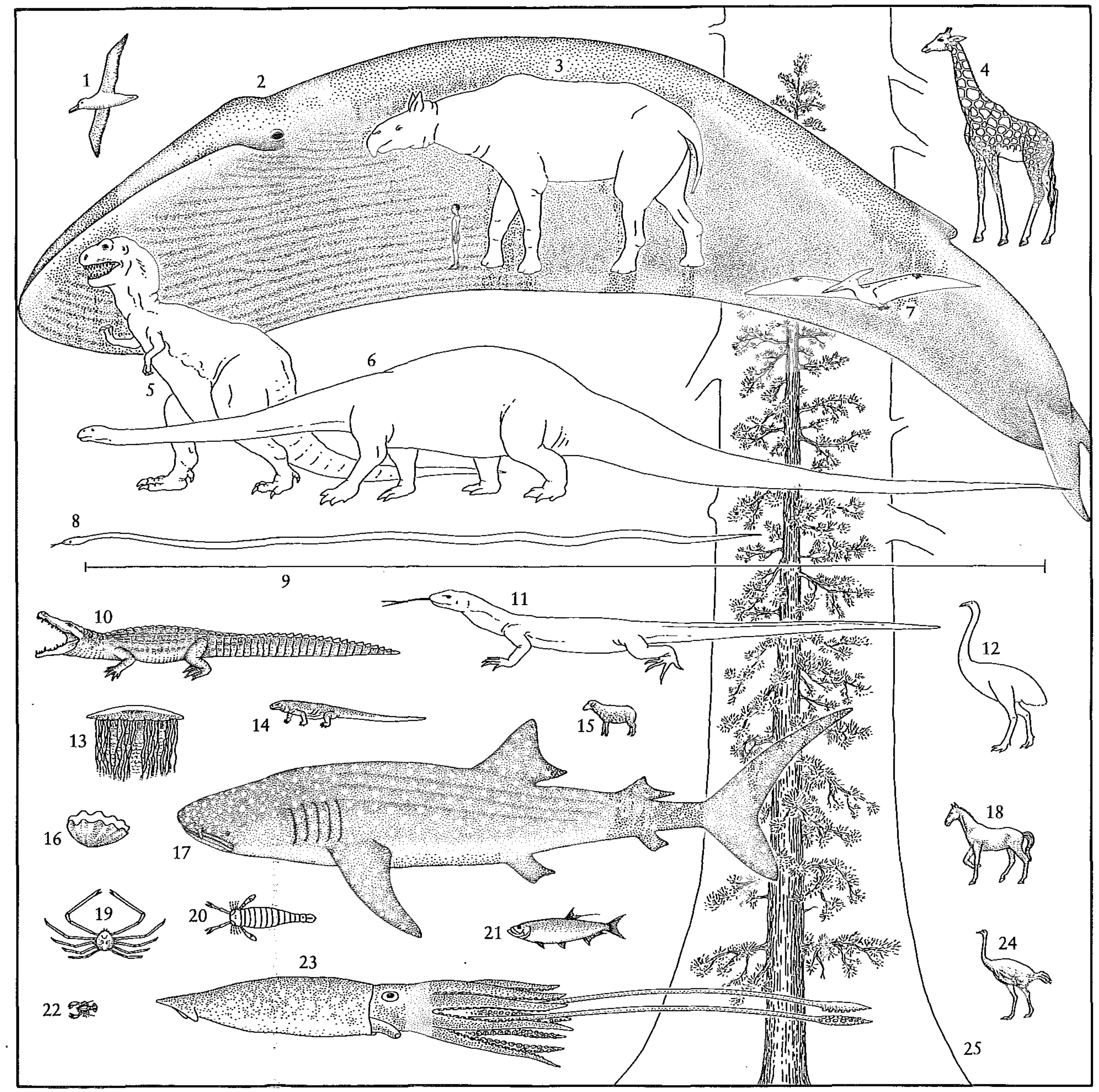
**giraffe** (2 tons)—Very tall, but not a weight champion.

**human being** (70 kilograms)

**albatross** (10 kilograms)—Largest bird that flies.

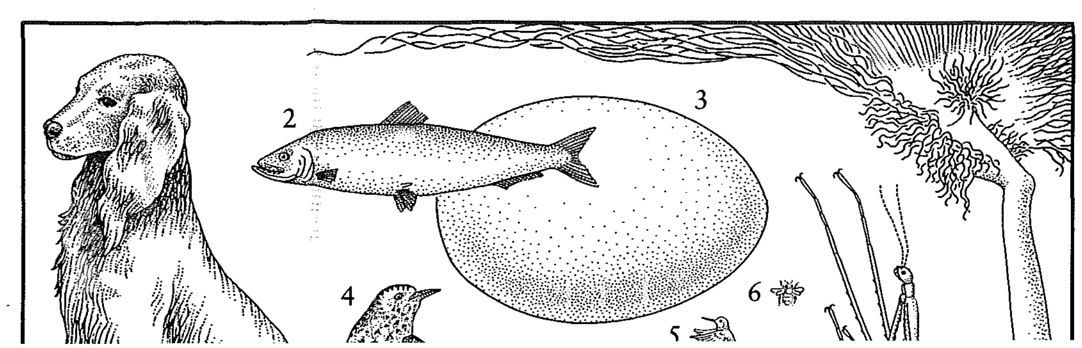
***Achatina*** (up to about 400 grams)—A snail, the

Animals this big have lungs or gills that increase the surface area through which they absorb oxygen. They also have blood that carries oxygen around their body.



The largest animals. Do you see the human being (who looks as if he were standing inside the blue whale)? Look at the picture of the elephant in this issue of ART TO ZOO, and try to figure out how big it would be if it was in this box. Cut out a paper elephant and try it here for size!

1, the largest flying bird (albatross); 2, the largest known animal (blue whale); 3, the largest extinct land mammal *(Baluchitherium)* with a human figure shown for scale; 4, the tallest living land animal (giraffe); 5, the dinosaur *Tyrannosaurus*; 6, another dinosaur, *Diplodocus*; 7, one of the largest flying reptiles *(Pteranodon)*; 8, the largest extinct snake; 9, the length of the largest tapeworm found in man; 10, one of the largest living reptiles (American crocodile); 11, the largest extinct lizard; 12, the largest extinct bird; 13, the largest jellyfish; 14, the largest living lizard (Komodo dragon); 15, sheep; 16, the largest bivalve mollusk; 17, the largest fish (whale shark); 18, horse; 19, the largest crustacean (Japanese spider crab); 20, the largest extinct sea scorpion; 21, large tarpon; 22, the largest lobster; 23, the largest mollusk (deep-water squid); 24, ostrich; 25, the lower 32 meters of the largest organism (giant sequoia tree), with a 30-meter larch tree drawn in front of it



heaviest animal without a backbone that lives on land.

- **mouse** (30 grams)

- **hummingbird** (4 grams)—Smallest bird.

- **pygmy shrew** (2.5 grams)—Smallest mammal.

- **ant** (under 1 gram)—An average ant colony, with over a million ants, together weighs less than a heavy man.

- **flea** (0.3 milligrams)—If you ordered a kilogram of fleas, your package would contain 3 million of them.

- **large amoeba** (0.1 milligrams)

- **rotifer** (considerably under 0.0001 milligrams)—Smallest many-celled animal

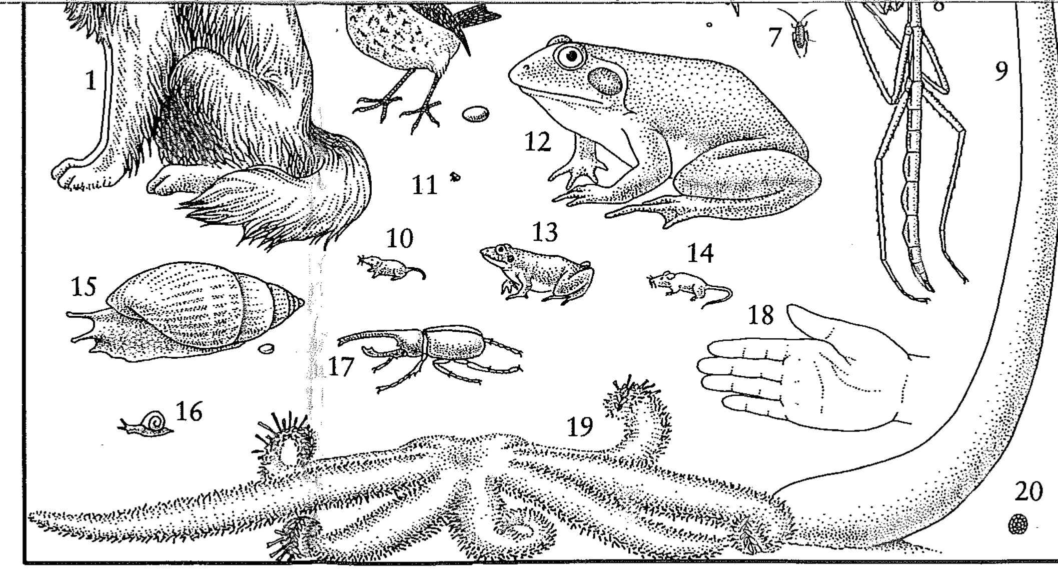
- **average bacterium** (0.0000000001 milligrams)

- *Mycoplasma* (under 0.0000000000001 milligrams)—Smallest single-celled organism.

Insects this big pump air through holes in their skin into air tubes in their body. From the air tubes, the air spreads through the animal by diffusion.

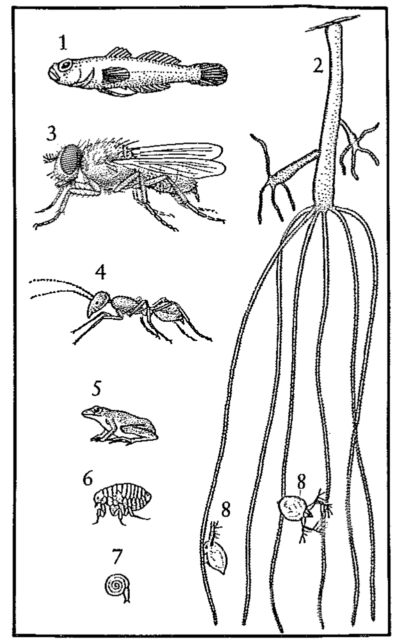
Animals this big can absorb the oxygen they need through the surface of their body.

*The lower limit* of size is set by biochemistry. You have learned that animals need to metabolize to stay alive—so they have to be at least large enough to hold the metabolic and genetic equipment they need.



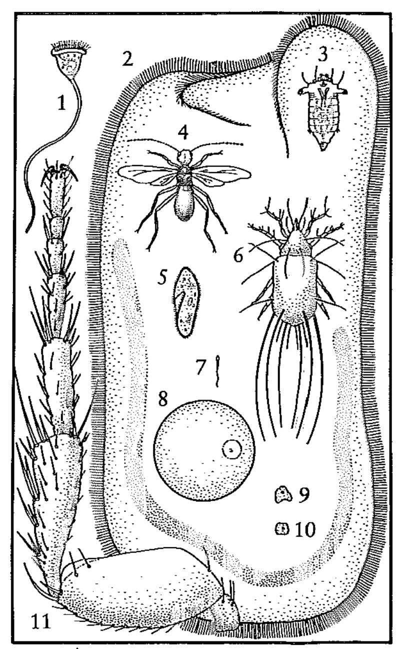
Medium-sized animals. The adult human hand (18) gives you a scale of comparison.

1, dog; 2, herring; 3, the largest egg; 4, song thrush with egg; 5, the smallest bird (hummingbird) with egg; 6, queen bee; 7, common cockroach; 8, the largest stick insect; 9, the largest polyp; 10, the smallest mammal (shrew); 11, the smallest vertebrate (a tropical frog); 12, the largest frog (goliath frog); 13, common grass frog; 14, house mouse; 15, the largest land snail *(Achatina)* with egg; 16, common snail; 17, the largest beetle (goliath beetle); 18, adult human hand; 19, the largest starfish; 20, the largest free-moving protozoan (an extinct nummulite)



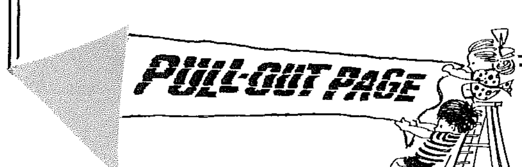
Animals that are small, but big enough to see with your naked eye. The frog (5) is the same one that is the smallest creature in the second box.

1, one of the smallest fishes; 2, common brown hydra, expanded; 3, housefly; 4, medium-sized ant; 5, the smallest vertebrate (a tropical frog); 6, flea; 7, the smallest land snail; 8, common water flea *(Daphnia)*



Some of the largest microscopic animals and cells, and the smallest creatures that you can see with your naked eye. Note the flea's front leg (11). The whole flea appears in the third box.

1, *Vorticella*, a ciliate; 2, the largest ciliate protozoan *(Bursaria)*; 3, the smallest many-celled animal (a rotifer); 4, smallest flying insect *(Elaphis)*; 5, another ciliate *(Paramecium)*; 6, cheese mite; 7, human sperm; 8, human ovum; 9, dysentery amoeba; 10, human liver cell; 11, the front leg of a flea



# Tamaños de Animales y Limites de Tamaño

*Para hacerse una idea de las proporciones que abarca esta escala, la ballena azul es 1,000,000,000,000,000,000,000 veces más grande que la* Mycoplasma. *Si existiera un animal que fuera tantas veces más grande que la ballena azul, ese animal imaginario tendriá 100 veces el volumen de la Tierra.*

El tamaño de los animales gigantescos es limitado por la fuerza de gravedad.

Los animales más grandes pesan más. Sus huesos tienen que ser capaces de sostenerlo, y sus músculos capaces de mobilizarlo. Esto ya no es posible cuando un animal alcanza cierto tamaño.

Los animales que viven en el agua pueden ser mucho más pesados que los que viven en la tierra, porque el agua les ayuda a sostener su peso. Es por eso que una ballena puede ser en tal medida más grande que un elefante—y más grande que todos los dinosaurios—mientras permanezca en el agua. Una ballena azul arrastrada por las olas hacia la playa moriría de asfixia porque su propio peso no la dejaría respirar.

Esta es una de las razones por las cuales no pueden existir los gigantes, a menos que vivieran bajo el agua o en un planeta donde la fuerza de gravedad sea mucho menor que en la Tierra.

**Ballena azul** (100 toneladas)—El animal más grande en existencia, tanto en el pasado como actualmente.

***Brachiosaurus*** (80 toneladas)—El dinosaurio más grande. Antes se creía que vivía básicamente en el agua, pero ahora se cree que puede haber pasado gran parte del día en la tierra.

***Baluchitherium*** (30 toneladas)—El mamífero terrestre más grande de todos los tiempos.

**El elefante** (6 toneladas)—El animal terrestre más grande en existencia.

**El calamar gigante** (3 toneladas)—El más grande de los animales sin columna vertebral.

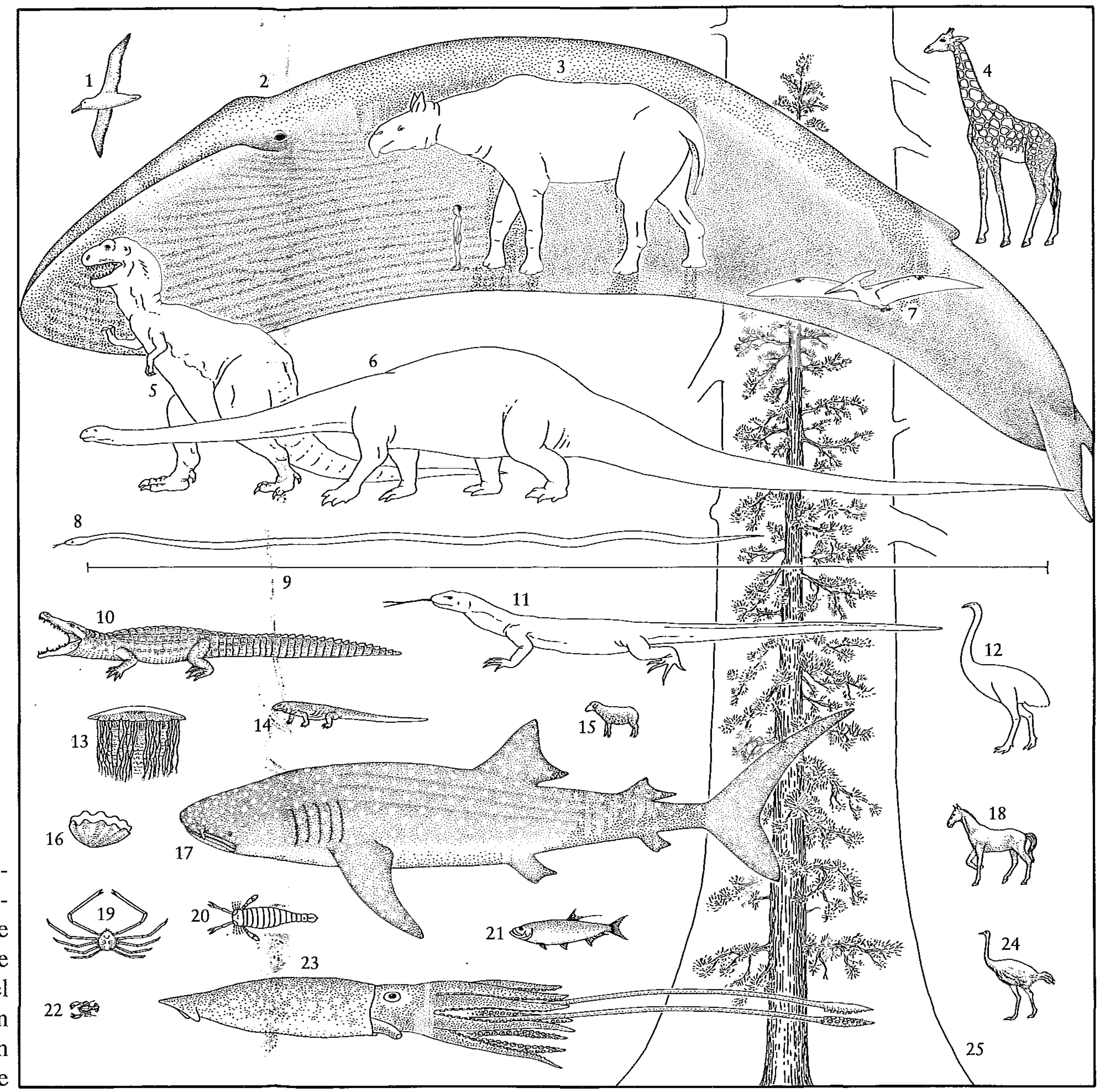
**La jirafa** (2 toneladas).

**Ser humano** (70 kilos).

**El albatrós** (10 kilos)—El ave más grande que vuela.

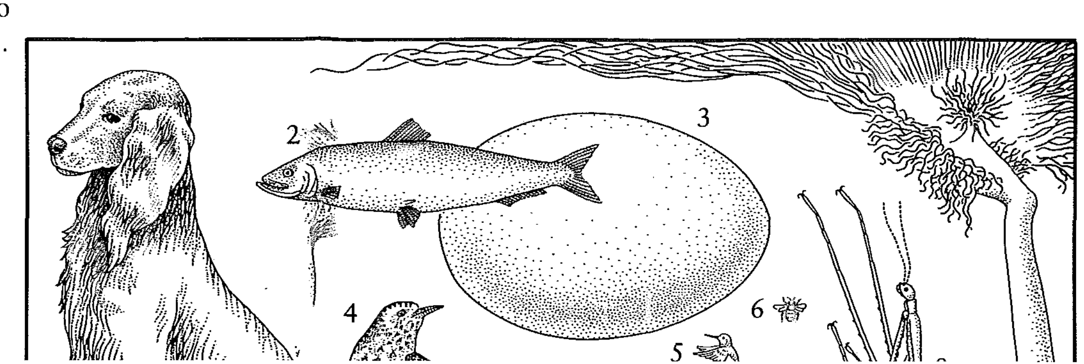
***Achatina*** (puede ser 400 o

Animales de este tamaño tienen pulmones o agallas que aumentan el área de superficie a través del cual ellos absorben oxígeno. También tienen sangre que transporta el oxígeno a través de su cuerpo.



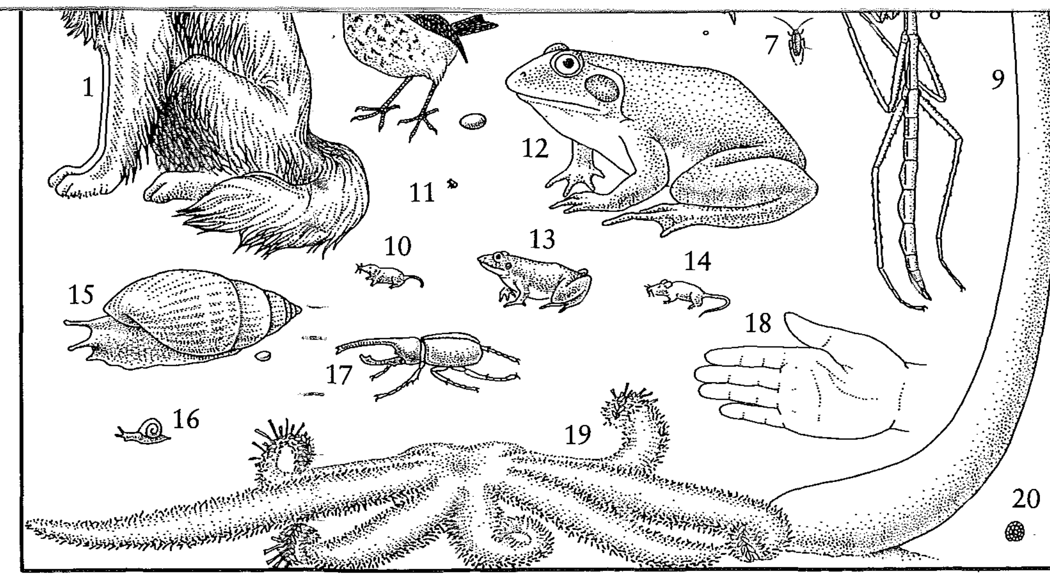
Los animales más grandes. ¿Ve usted al ser humano que se ve como si estuviera parado dentro de la ballena azul? Mire la figura del elefante en este ejemplar de Art to Zoo, y trate de imaginar cuán grande sería si estuviera en este cuadro. Recorte un elefante de papel y trate de ver como cuadra en este espacio.

1, El ave voladora más grande (albatrós); 2, el animal más grande que se conoce (ballena azul); 3, el mamífero terrestre extinto más grande *(Baluchitherium)* con una figura humana presentada como referencia de escala; 4, el animal terrestre viviente más alto (jirafa); 3, el dinosaurio *Tyrannosaurus*; 6, otro dinosaurio, *Diplodocus*; 7, uno de los reptiles voladores más grandes *(Pteranodon)*; 8, la culebra más grande extinta; 9, la longitud de la lombriz solitaria más grande que se ha encontrado en un hombre; 10, uno de los reptiles vivientes más grandes (cocodrilo americano); 11, el más grande de los lagartos extintos; 12, el ave extinta más grande; 13, la medusa más grande; 14, el lagarto más grande viviente (dragón de Komodo); 15, oveja; 16, el molusco bivalve más grande; 17, el pez más grande (tiburón ballena); 18, caballo; 19, el crustáceo más grande (cangrejo araña japonés); 20, el escorpión marino extinto más grande; 21, tarpón grande; 22, la langosta más grande; 23, el molusco más grande (calamar de aguas profundas); 24, avestruz; 25, los 32 metros inferiores del organismo más grande (árbol sequoia gigante) con un alerce (lárice) de 30 metros dibujado en frente.



más gramos)—Un caracol, el más pesado de los animales terrestres sin columna vertebral.

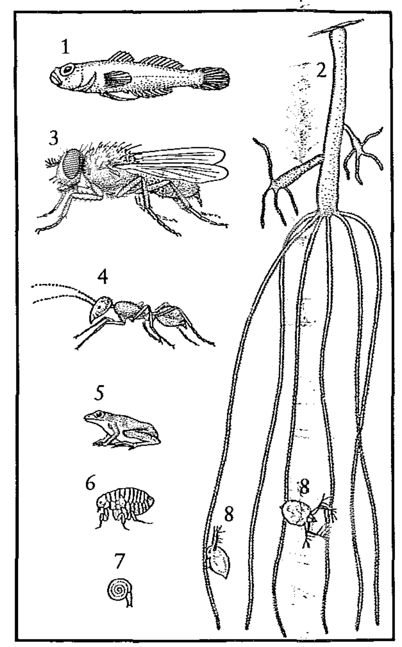
- **El ratón** (30 gramos).
- **El picaflor** (4 gramos)—El pájaro más pequeño.
- **La musaraña pigmea** (2.5 gramos)—El mamífero más pequeño.
- **La hormiga** (menos de 1 gramo)—Una colonia promedio—de más de un millón de hormigas—pesa menos que un hombre fornido.
- **La pulga** (0.3 miligramos)—Si Ud. quisiera comprar un kilo de pulgas, el paquete contendría 3 millones de ellas.
- **La ameba grande** (0.1 miligramos).
- **El rotífero** (considerablemente menos de 0.0001 miligramos)—El animal multicelular más pequeño.
- **Una bacteria de tamaño promedio**—(0.0000000001 miligramos).
- ***Mycoplasma*** (menos de 0.00000000000001 miligramos)—El organismo unicelular más pequeño.



Algunos animales de tamaño mediano. La mano de un adulto les da una comparación.

1, Perro; 2, arenque; 3, el huevo más grande; 4, tordo (zorzal), con huevo; 5, el pájaro más pequeño (picaflor) con huevo; 6, abeja reina; 7, cucaracha común; 8, el más grande los insectos-palo; 9, el pólipo más grande; 10, el mamífero más pequeño (musaraña); 11, el vertebrado más pequeño (una rana tropical); 12, la rana más grande (rana goliat); 13, rana de pasto común; 14, un ratón casero; 15, el caracol terrestre más grande *(Achatina)* con huevo; 16, caracol común; 17, el escarabajo más grande (escarabajo goliat); 18, mano humana adulta; 19, la estrella de mar más grande; 20, el protozoo móvil más grande (un nummulite extinto).

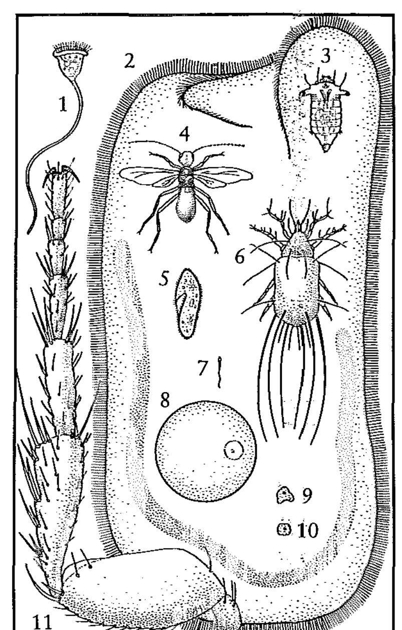
Los insectos de este tamaño bombean el aire a través de agujeros en su piel hacia tubos respiratorios en su cuerpo. De estos tubos el aire se extiende a través de todo el cuerpo del animal por difusión.



Algunos animales que son pequeños pero lo suficientemente grandes como para poder ser observados a simple vista. La rana (5) es la misma que aparece como la criatura más pequeña en el segundo recuadro.

1, Uno de los peces más pequeños; 2, hidra común, ampliada; 3, mosca doméstica; 4, hormiga de tamaño promedio; 5, el vertebrado más pequeño (una rana tropical); 6, pulga; 7, el caracol terrestre más pequeño; 8, pulga común de agua *(Daphnia)*.

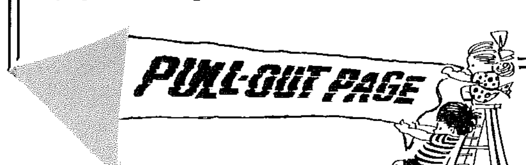
Los animales de este tamaño puede absorber el oxígeno que necesitan a través de la superficie de su cuerpo.



Vista de algunas células y animales microscópicos de mayor tamaño y algunas de las criaturas más pequeñas que se pueden ver a simple vista. Fíjense en la pata delantera de la pulga (11). La pulga entera aparece en el tercer recuadro.

1, *Vorticella*, una ciliada; 2, el protozoo ciliado más grande *(Bursaria)*; 3, el animal multicelular más pequeño (un rotífero); 4, el insecto volador más pequeño *(Elaphis)*; 5, otro ciliado *(Paramecium)*; 6, ácaro; 7, espermatozoide humano; 8, óvulo humano; 9, ameba de la disentería; 10, célula del hígado humano; 11, pata delantera de una pulga.

La bioquímica determina el límite inferior en cuanto al tamaño. Uds. saben que los animales tienen que metabolizar para mantenerse vivos. Así es que deben tener el tamaño mínimo como para poder contener el aparato metabólico y genético que necesitan.

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