American Museum of Natural History

Educator's Guide

The World's Largest Dinosaurs

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amnh.org/education/largestdinos

essential QUESTIONS

For 140 million years sauropods — humongous plant-eating dinosaurs — roamed the planet. This exhibition explores how scientists study fossils and living animals to understand sauropod biology, and what we can learn from these extinct animals about what it means to be big. Use the Essential Questions below to connect the exhibition to your curriculum.

What is a sauropod?

Sauropods were an extraordinarily successful group of dinosaurs notable for their enormous size. These **herbivores** were the biggest land animals ever. They inhabited every continent and lived from the Early Jurassic period, about 200 million year ago, until 65.5 million years ago, when most dinosaurs became extinct. Over that period sauropods evolved a range of shapes and sizes, although all walked on four legs, were covered in small bumps and scales, and had small heads. Their brains were small relative to body size, but sauropods were smart enough to engage in social behaviors like herding. Like many modern reptiles, they reproduced by laying many eggs and left the young to fend for themselves. The biggest eggs were about the size of a volleyball. Hatchlings grew fast — gaining weight more quickly than any other land animal that's ever lived.

How do sauropods vary?

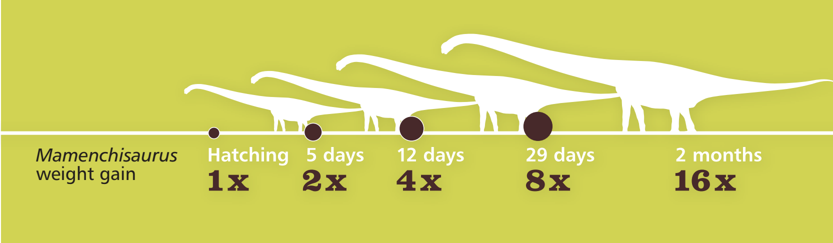
Like many groups of animals, sauropods came in different sizes and body shapes. Their average weight was a hefty 12 tons, with some dwarf species weighing only as much as a cow and *Argentinosaurus* tipping the scales at up to 90 tons (82,000 kg), which is 15 times heavier than the African elephant. Variations included: tail length, the relative proportion of hindlimbs to forelimbs, the shape of the skull and placement of teeth, and in a few cases, the presence of features such as scales and giant spikes down the neck. Teeth ranged from large spoon-shaped ones for biting branches to small pencil-shaped ones for raking and stripping leaves. Each species had only one type of tooth.

How do sauropod bodies work?

While some structures in sauropods' bodies look much like those in animals alive today, others are quite different. Many aspects of sauropod anatomy are key to their giant sizes. For example, a highly efficient breathing system enabled them to expend less energy breathing than other animals, including mammals. A system of air storage sacs ensured a constant flow of fresh air through the lungs. Today's birds breathe the same way. Sauropods swallowed without chewing, so they could eat massive amounts rapidly. They processed the food in their enormous stomachs. Bacteria in these "fermentation tanks" took up to two weeks to break down tough plants and extract energy. Another adaptation was cavities in the bones of sauropod necks (cervical **vertebrae**), which made those necks lighter and easier to maneuver. And those long, flexible necks — as long as 40 feet (12 meters)! — allowed sauropods to stand in one place and eat a lot. Their large, powerful hearts beat very slowly to move massive amounts of blood up to their brains and around their huge bodies.

How do scientists study sauropods?

To learn about ancient life, scientists study **fossils**. Finding these traces of ancient life takes time and experience. **Paleontologists** search carefully for bits of exposed bone, then typically transport the large piece of rock that contains the fossil back to the lab. **Trackways** provide some of the best clues about sauropod behavior. Studying living birds and other reptiles, which are related to dinosaurs, gives insight into behavior and biology. Paleontologists also turn to experts in other fields. For example, geochemists analyze fossil bones and teeth for clues about **paleoclimate**, while paleobotanists examine **coprolites** for the physical and chemical traces of ancient plants. Together, these scientists are filling in the picture of what these giant dinosaurs ate, how fast they grew, and how long they lived.



GLOSSARY

coprolite: fossilized animal dung. Coprolites contain clues to what animals ate and how their digestive systems worked.

fossil: remains or traces of ancient life — including bones, teeth, shells, leaf impressions, nests, and footprints — that are usually buried in rocks

herbivore: an animal that eats only plants

metabolism: the set of chemical processes within organisms that convert food into the energy necessary for life — everything from growing and moving to thinking

paleoclimate: climate from the past, recorded in rocks, ice sheets, tree rings, sediment, corals, and shells

paleontologist: a scientist who studies the fossil record in order to understand the history of life on Earth

trachea: the tube that connects the nose and mouth to the lungs

trackway: a series of fossilized footprints. Trackways provide clues to the animal's size, speed, and behavior.

vertebrae (singular: vertebra)**:** the bones that form the backbone and give vertebrates their name. Sauropod necks have between ten to nineteen cervical vertebrae, whereas most mammals, including giraffes and humans, only have seven.

A human baby doubles in weight in 5 months, but this took a sauropod only 5 days.

At maturity (about age 20), a human is 17 times its weight at birth, while a mature sauropod (about age 30) weighed 10,000 times as much as it did as a hatchling.

COME PREPARED

Plan your visit. For information about reservations, transportation, and lunchrooms, visit **amnh.org/education/plan**.

Read the Essential Questions in this guide to see how themes in *The World's Largest Dinosaurs* connect to your curriculum. Identify the key points that you'd like your students to learn from the exhibition.

Review the Teaching in the Exhibition section of this guide for an advance look at the specimens, models, and interactives that you and your class will be encountering.

Review activities and student worksheets (coming soon). Designed for use before, during, and after your visit, these activities focus on themes that correlate to the NYS Science Core Curriculum:

- K–2: Structures & Functions
- 3–5: Observation & Evidence
- 6–8: Body Systems
- 9–12: Size & Scale

Decide how your students will explore *The World's Largest Dinosaurs*. Suggestions include:

- You and your chaperones can facilitate the visit using the **Teaching in the Exhibition** section of this guide.
- Your students can use the **student worksheets** to explore the exhibition on their own or in small groups.
- Students, individually or in groups, can use copies of the **map** to choose their own paths.

CORRELATIONS TO NATIONAL STANDARDS

Your visit to *The World's Largest Dinosaurs* exhibition can be correlated to the national standards below. See the end of this guide for a full listing of New York State standards.

Science Education Standards

All Grades • A2: Understanding about scientific inquiry

K–4 • C1: Characteristics of organisms • C3: Organisms and environments

5–8 • C1: Structure and function of living systems • C3: Regulation and behavior • C5: Diversity and adaptations of organisms • G2: Nature of science

9–12 • C6: Behavior of organisms • G2: Nature of science

teaching in the EXHIBITION

Size affects just about everything an animal does: eating, breathing, moving, and reproducing. This exhibition takes a look at how sauropods, the biggest land animals ever, pulled it off. You and your students will be exploring a large, open space surrounding a full-scale model of *Mamenchisaurus*, an exceptionally long-necked sauropod species that lived about 160 million years ago in present-day China. **Use the Explorations below, which are organized around body systems, to guide your visit.** Refer at any point to the Biology Theater in the center of the exhibition, where projections tie together all the processes that enabled sauropod dinosaurs to grow to enormous sizes.

The Importance of Size

In this introductory section students can compare skeletons representing the range of sizes of animals both living and extinct — from the tiny Rufous Hummingbird to the *Argentinosaurus* looming overhead.

GUIDED EXPLORATIONS

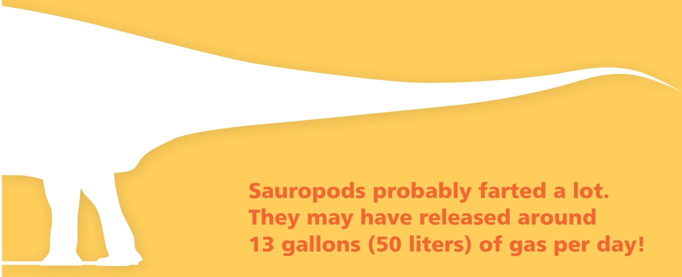
Teeth & Eating

Touchable teeth and skulls: Invite students to touch the teeth at this table and compare their shapes and sizes. Ask them what these teeth might be good for, and how that would help a huge animal get enough to eat.
(Answers may include: Sauropod teeth were made for raking leaves or tearing branches, not for chewing. By swallowing whole, sauropods could consume very large quantities of food very fast.)

The spoon-shaped tooth (left) belonged to *Camarasaurus*, the pencil-shaped one to *Diplodocus*.

***Mamenchisaurus* head and foliage:** Look up! Tell students that sauropods were herbivores — they ate only plants. Have them observe the *Mamenchisaurus*' head and neck, and ask how these body parts help the animal find and eat a lot of food.
(Answers may include: Long necks could reach higher leaves. Small, light heads made long necks possible. Heads could be small because they didn't need big muscles for chewing.)

Check out the **Stomach & Digestion** section to learn more about sauropod diet and metabolism.



Sauropods probably farted a lot. They may have released around 13 gallons (50 liters) of gas per day!

Head, Neck & Movement

Model of *Diplodocus* brain: Point out that despite having small brains relative to body size, this group of dinosaurs flourished on Earth for 140 million years. Have students look at this "big-enough" brain. Ask them to consider, as they go through the exhibition, what behaviors this brain made possible.

***Camarasaurus* vertebra and vertebrae comparison interactive:** Point out that cavities in sauropod vertebrae made necks light and easy to move, without sacrificing strength. Have students look at the vertebra and ask them what's unique about these bones.
(Answer: The architecture of the vertebrae allows them to be both light and strong, with large points for powerful muscles to attach.)
Ask what the advantage of having such a long, flexible neck might be.
(Answers may include: Long necks gave them access to lots of vegetation without having to move the rest of their bodies.)
Invite them to use the interactive to compare how much giraffe and sauropod vertebrae weigh.

Cavities and hollows in neck bones like this one gave *Camarasaurus* its name. It means "chambered reptile."

teaching in the EXHIBITION

Heart & Circulation

Model of sauropod heart: Tell students that the bigger the animal, the more powerful its heart has to be. Have students observe the heart model and describe the characteristics that help a sauropod heart pump oxygen-rich blood from head to tail.
(Answer: Sauropod hearts were large and, like human and bird hearts, were four-chambered. Large hearts beat more slowly than smaller ones.)

Pumping heart interactive: Invite students to determine how much effort it takes to circulate blood throughout a sauropod's body, especially to its brain. Encourage them to experiment with other animals, like a giraffe.
(Answer: A sauropod's circulatory system was able to regulate blood pressure, whether the dinosaur's head was up or down.)

Lungs & Breathing

Scale model of lung and trachea: Have students look closely at the model of a sauropod lung and compare it to the diagram of a mammal lung. Ask what the differences are, and what the effects might be. Point out that the sauropod lung was twice as efficient as a mammal lung. Why is this important?
(Answer: Sauropods expended less energy breathing than other animals. Living dinosaurs, today's birds, breathe the same way. Big respiratory systems also made the animals' bodies lighter.)

Stomach & Digestion

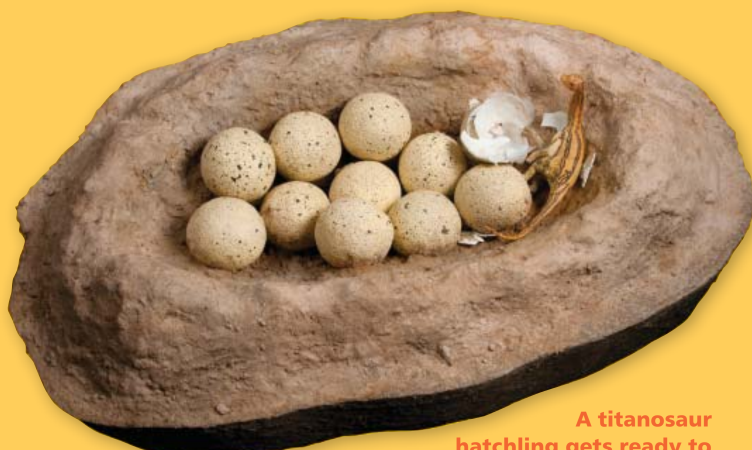
Column of leaves and metabolism interactive: Tell students that this case shows how much food this *Mamenchisaurus* might have had to eat in one hour. Invite students to use the interactive to learn about the relationship among body plans, food type, and energy requirements. Ask: What are some of the factors that influenced how much food the animal needed to consume?
(Answers may include: size, digestion period, time of day or time of year, nutritional content of food, the animal's energy requirements, and its age.)

The tough but nutritious horsetail was a staple of the sauropod diet.

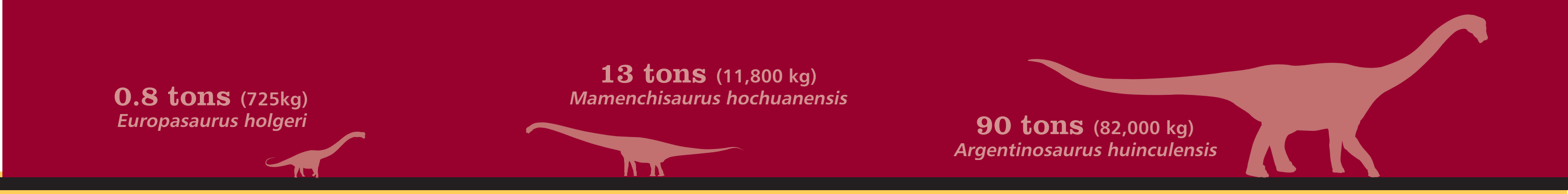
Eggs & Reproduction

Display of model eggs: Have students look at a range of eggs laid by both living and extinct species. Ask them why the eggs of sauropods are similar in size to those of much smaller animals. Ask them to compare sauropod eggs to those of other dinosaurs, including birds. What do they observe?
(Answers may include: There are physical limits on egg size. The bigger the egg, the thicker the shell has to be, but the shell has to stay thin enough to allow oxygen to pass through pores to the developing embryo. The size of an egg is not necessarily proportional to the size of the animal that laid it. All species of sauropods, regardless of how big they were, laid eggs that were very similar in size.)

Eggshell magnifier interactive: Have students use the magnifier to look at the pores, or tiny holes, of the eggshells of modern animals. Then invite students to look at the diorama and touch the fossil eggs to see the evidence for what sauropod nests, eggs, and embryos were like.



A titanosaur hatchling gets ready to leave the nest. It's on its own!



WHAT DO FOSSILS TELL US?

How massive were sauropods?

Calculate weight and size interactives: Point out that scientists study living animals to understand the biology of extinct ones. Have students use both the computer interactive and the hands-on interactive to understand how scientists extrapolate the weight of an animal from a single bone.
(Answer: They use mathematical equations, computer modeling, and comparisons of fossil bones with those of living animals.)

What did sauropods look like?

Skin interactive: Ask students why it's so challenging to determine the color and pattern of sauropod skin.
(Answer: Dinosaur skin is rarely preserved, so we only have limited information.)

How did sauropods behave?

Sauropod footprints and zoetrope: Guide students' attention to the stickers on the floor that represent a series of life-size footprints, called a trackway. Ask them what kinds of clues to sauropod behavior are contained in trackways.
(Answers may include: Trackways contain evidence of how fast sauropods might have moved, and suggest that herds included animals of different ages and species.)
Invite them to spin the zoetrope for a 3-D image of what moving dinosaurs may have looked like.

HOW DO PALEONTOLOGISTS EXCAVATE FOSSILS?

Dig pit: Have students look at the wall graphic surrounding the dig site to familiarize themselves with the kinds of bones they'll be uncovering. Ask them to watch the video of paleontologists at work for a sense of what it's like to be on a dig and to see the tools they use. Suggest that they think about how to uncover fossils without damaging them, and then try it themselves in the dig pit. Make sure each student collects a sticker on the way out.

Have students go to
amnh.org/ology/livinglarge
to gather clues about sauropod fossils.

online RESOURCES

The World's Largest Dinosaurs

amnh.org/wld
Access featured content from the exhibition, including videos, interactives, fun facts, and behind-the-scenes photos.

PaleontOLogy

amnh.org/ology/paleontology
Games, puzzles, and activities help kids explore fossils and the clues they provide about ancient life and Earth's history.

How Big Were Dinosaurs?

amnh.org/resources/rfl/pdf/dino_05_big.pdf
Could all of your students' footprints fit into that of an *Apatosaurus*? Find out with this hands-on activity.

Body and Trace Fossils

amnh.org/resources/rfl/pdf/dino_15_body_trace.pdf
What kind of fossil is a tooth? How about a nest of eggs? Examine the differences between body and trace fossils.

Be a Sleuth: How Dinosaurs Behaved

amnh.org/resources/rfl/pdf/dinoactivity_trackway.pdf
Like today's crime-scene investigators, paleontologists study clues left behind. See firsthand what trackways — fossilized footprints — can tell them about dinosaur behavior.

Dinosaur Names

amnh.org/resources/rfl/pdf/dino_04_names.pdf
Some dinosaur names are short, while others are lengthy tongue twisters. But all are infused with meaning. Examine the linguistic roots of these terrible (deinos) lizards (sauros).

Understanding Geological Time

amnh.org/resources/rfl/pdf/dino_10_time.pdf
How long have humans been on Earth compared to the length of time dinosaurs roamed the planet? Gain a new understanding of time by mapping out Earth's history.

DID YOU KNOW?

The **largest sauropod** we know of is *Argentinosaurus*. The Museum's fossil specimen is so big, and the rock around it so hard, that it's taking years for scientists to excavate all of it from South America.

Sauropods had the **longest necks** and **longest tails** of any known dinosaurs.

The **head** of *Diplodocus*, a 13-ton (11,800-kg) sauropod, is the same size as the head of a half-ton (450-kg) horse.

Many sauropods grew new **teeth** as often as once a month, as old ones wore out.

Some titanosaurs, one family of sauropods, were covered with **bony plates** called osteoderms.

Scientists think that sauropods might have been **brightly colored**, like many modern-day birds and reptiles.

We know from **trackway** evidence, which shows smaller sauropods in the middle, that some sauropods traveled in herds.

Will even bigger dinosaurs be discovered some day? Probably!

CREDITS

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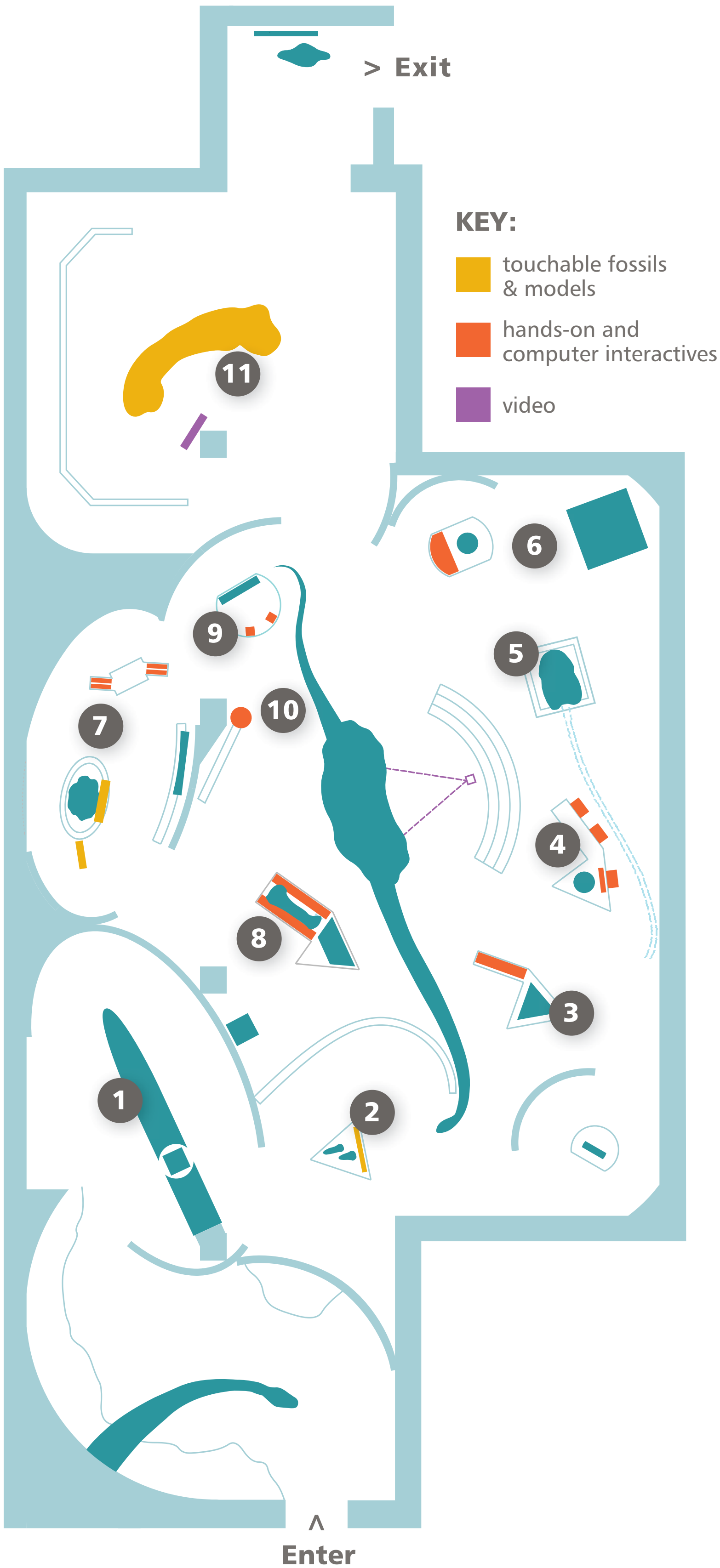
MAP of the exhibition



THE WORLD'S LARGEST DINOSAURS

Size matters. It affects just about everything an animal does. As you move through the exhibition, examine *Mamenchisaurus* — an exceptionally long-necked sauropod species — for clues to a fascinating scientific question: **What did it take to be so big?**

1. The Importance of Size
2. Teeth & Eating
3. Head, Neck & Movement
4. Heart & Circulation
5. Lungs & Breathing
6. Stomach & Digestion
7. Eggs & Reproduction
8. How massive were sauropods?
9. What did sauropods look like?
10. How did sauropods behave?
11. How do paleontologists excavate fossils?

Look for these icons throughout the exhibition.

- Explore what these fossilized bones tell us about how sauropods lived and behaved.
- Can you find any of these bones in the dig pit?

What does it mean to be **big?**

Size affects just about everything an animal does. Small animals breathe faster than big ones, eat more relative to their size, and produce more offspring. Big animals are generally stronger, have fewer predators, and live much longer. If being big has such huge advantages, why are most animals so small? Because when length doubles, weight is *cubed* (weight X weight X weight). And the more an animal weighs, the more energy it uses to move and the more it needs to eat. Sauropods were about as big as land animals can get. Oceandwellers have water to support their bulk, which is why blue whales are even more massive than sauropods.

Small Heads

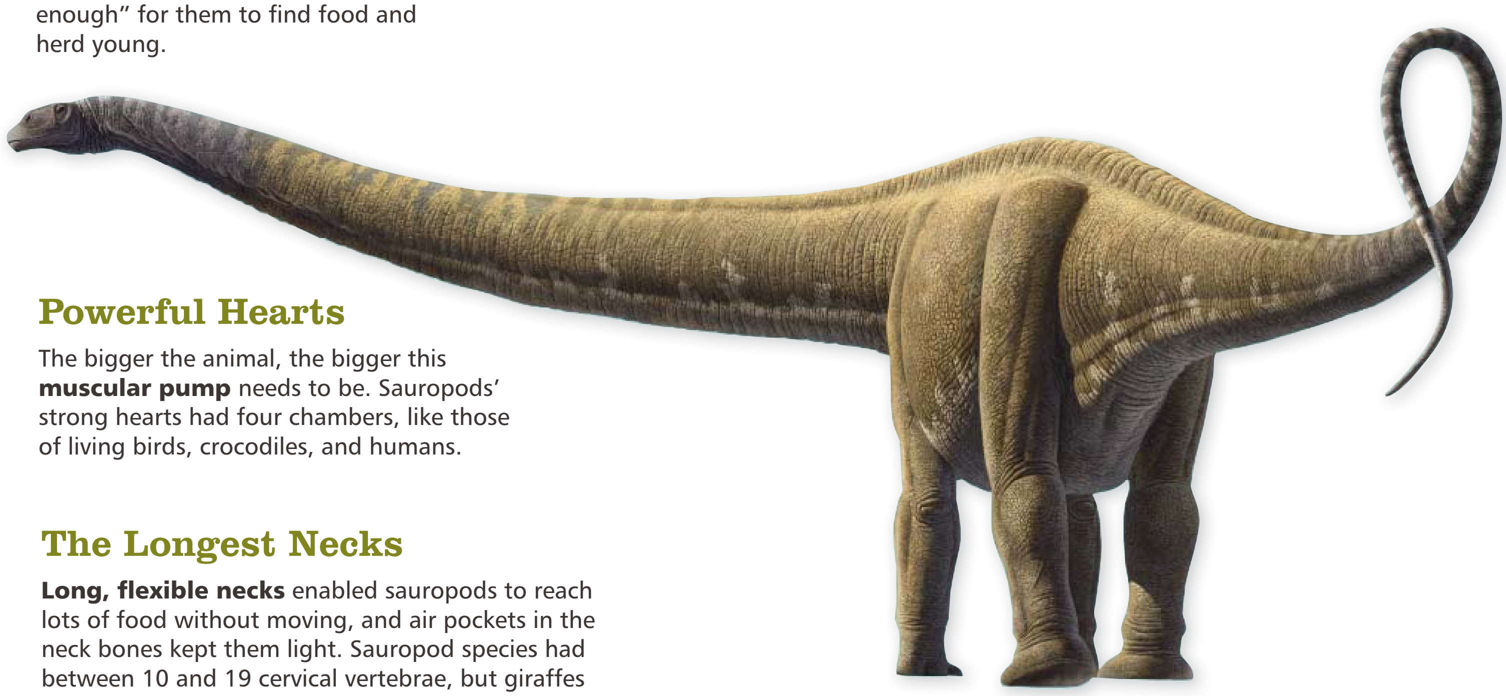
Despite their massive bodies, sauropods had surprisingly **small heads relative to body size**. This had its advantages — sauropod heads were light enough for long necks to support. If your head were the same size relative to your body, it would be only a little bigger than a baseball! Sauropod brains were "big enough" for them to find food and herd young.

Efficient Lungs

Very different from mammal lungs, **sauropod lungs worked like those of modern-day birds**. Sauropods could extract more oxygen from each breath than humans can. Big lungs and multiple air sacs also reduced body weight.

Tough Stomachs

Sauropods had to eat enormous amounts every day, and swallowed food whole. **Stomachs functioned like giant compost heaps**, taking as long as two weeks to digest tough vegetation and releasing as much as 13 gallons (50 liters) of gas a day. Humans typically digest their food in about two days.



Powerful Hearts

The bigger the animal, the bigger this **muscular pump** needs to be. Sauropods' strong hearts had four chambers, like those of living birds, crocodiles, and humans.

The Longest Necks

Long, flexible necks enabled sauropods to reach lots of food without moving, and air pockets in the neck bones kept them light. Sauropod species had between 10 and 19 cervical vertebrae, but giraffes have only 7 — just like you!

Starting Out Small: Eggs and Hatchlings

There are limits on how big eggs can get. Larger eggs require thicker shells, and if the eggshell is too thick, air can't pass through to the developing chick. Even giant parents can't lay giant eggs. Sauropod hatchlings generally weighed less than 11 pounds (5 kg), making them easy prey. Although they grew very fast — gaining as much as 4,000 pounds (1,800 kg) a year! — relatively few survived. Like other reptiles, sauropods laid many eggs to ensure that some reached adulthood.