

SCHOOL LAUNCH · EXPLORE TRACKS

EXPLORE DINOSAURS · EXPERT

The Dinosaurs track at the ● Expert level: five trails and fifty stops, from Tyrannosaurus rex and the first fossil hunters to Behemoth in Job 40, the sea and sky reptiles, and the Ice Age. Primary sources, real numbers, careful reasoning and hands-on projects.

First edition

*Behold now behemoth, which I made with thee; he eateth grass as an ox.
Job 40:15 (KJV)*

COURSE GUIDE

Explore Tracks are for students who want more of what they love. Each track is a set of short, stand-alone stops. At every stop the student reads a true account, studies a great picture, does something with his or her hands, plays a game and adds a page to a Field Notebook. At the ● Expert level each stop goes further: primary sources, measurements and calculations, the reasoning behind a scientist's claim, and a "go deeper" list of books, museum pages and a second video.

Trail A meets ten dinosaurs, from Tyrannosaurus rex to Argentinosaurus, with the bones and numbers behind each one. Trail B follows the dinosaur hunters, from Mary Anning's ichthyosaur (found 1811-1812) and William Buckland's Megalosaurus (1824) through Richard Owen's "Dinosauria" (1842), the Bone Wars, Barnum Brown, Roy Chapman Andrews and Sue, to Mary Schweitzer's soft tissue (2005), reading the discoverers' own words where they survive. Trail C asks how dinosaurs lived: teeth, eggs, trackways, growth, speed and feathers, and how much the fossils can and cannot tell us. Trail D reads Scripture alongside the fossils: day six, Behemoth and Leviathan in Job, the Ark, the Flood, dragon legends, extinction and how to read a museum sign. Trail E visits the ichthyosaurs, plesiosaurs, mosasaurs and pterosaurs of the sea and sky, then the mammoths, saber-toothed cats, ground sloths and La Brea Tar Pits of the Ice Age, and ends with a museum display the student builds.

The track uses the creation-friendly framing of the Earth Science course. Scripture is the King James Version, read as true history. Observations (what the bones show) are kept apart from interpretations (what people conclude from them), and where Christians differ, each view is stated fairly. Each stop links to the matching full lesson in Earth Science, Life Science, History, Geography, Art or Literature.

WHO IT IS FOR

Written for students about ages 14 and up who read on their own and keep their own notebook. A younger sibling can join in at the ● Scout or ● Ranger level of the same stop. Nothing earlier is required, though the Earth Science course pairs well with Trails C and D.

HOW TO USE THIS COURSE

1. **One stop at a time.** An Expert stop takes 25-40 minutes: read the account, work the numbers, study the picture, do the hands-on part and write the notebook entry. Two or three stops a week works well.
2. **Any order.** The five trails are independent, and so are the stops. Trail D reads best after a few stops in Trails A and B, but it is not required.
3. **Primary sources and go deeper.** Many stops quote a short passage from a scientist's paper, a museum record or a letter. Read it slowly, then answer the question under it in your own words. The "go deeper" list is optional.

4.  **dating boxes.** A stop marked  has a box with three parts: *What the sign says*, *What we observe* and *How Christians read it*. Fill in the first two before you read the third.
5. **Field Notebook.** Every stop ends with a notebook entry: a labeled sketch, a calculation, a summary or a short argument. At the end of each trail the pages become a booklet, and a parent signs the certificate.
6. **Badge quizzes.** Every five stops earns a badge, with a short optional quiz. They are for practice, not grades.

SCOPE AND SEQUENCE

Trail 1: Dinosaurs  **Trail A: Meet the Dinosaurs** (Self-paced)

Trail 2: Dinosaurs  **Trail B: Dinosaur Hunters** (Self-paced)

Trail 3: Dinosaurs  **Trail C: How Dinosaurs Lived** (Self-paced)

Trail 4: Dinosaurs  **Trail D: Dinosaurs and the Bible** (Self-paced)

Trail 5: Dinosaurs  **Trail E: Sea and Sky Reptiles, and the Ice Age** (Self-paced)

MATERIALS

- **Field Notebook (a sketchbook or composition book)** One for the whole track, or one per trail.
- **Pencils, colored pencils, a ruler, a metric tape measure and a calculator** For scale drawings, measurements and the numbers at each stop.
- **Household and craft things** Each hands-on project lists what it needs: plaster of Paris, modeling clay, sidewalk chalk, a shallow box and sand, string, cardboard.
- **Internet access with a parent's oversight** For museum collection pages, digitized primary sources and the second video.
- **A Bible (KJV)** For the verse at each stop and the readings in Trail D.

GRADING

Explore Tracks are not graded. A stop is done when the student has read the account, done the hands-on part and written a notebook entry that answers the stop's question.

Badges are earned every five stops and a certificate for each finished trail.

- Families who want to count the track toward a science credit can use the notebook as a portfolio: the scale drawings, calculations and  box entries show the work.

A NOTE TO PARENTS

You do not need to be an expert. Read the stop's question with your student and ask, "What do the bones actually show, and what is someone concluding from them?" Each stop has a short *For families* note with background, sources and any facts that scholars still discuss.

Dinosaur dates: museums give ages in millions of years. This track teaches the period names (Triassic, Jurassic, Cretaceous, Pleistocene) as museum words and treats the dates as interpretations. Stops marked 🕒 have a dating box, *What the sign says / What we observe / How Christians read it*, that sets the museum's claim beside the evidence. Many Christian families understand the fossils within a young earth and the Flood of Genesis 6-9; some Christians hold an older earth. Where they differ, both readings are stated fairly, and Scripture is never treated as myth. Stops B10 and D9 (soft tissue) give Mary Schweitzer's findings, her own old-earth reading as a Christian, and the young-earth reading.

Scientific names, sizes and speeds change as new fossils are found. The numbers in this track are those commonly given by museums and recent papers; where estimates vary widely (Argentinosaurus' weight, Spinosaurus' shape, T. rex's speed), the stop gives the range and says so.

Some stops describe predators, the Bone Wars rivalry or death in the Flood and the tar pits. These are told plainly and without gory detail. Hands-on projects with plaster or tools include a safety line; plaster of Paris gets warm as it sets and should never be used to cast hands or other body parts.

CONTENTS

Trail 1: Dinosaurs 🦖 Trail A: Meet the Dinosaurs

- 1.1 Tyrannosaurus rex
- 1.2 Triceratops
- 1.3 Stegosaurus
- 1.4 Brachiosaurus
- 1.5 Velociraptor, the Real Size
- 1.6 Ankylosaurus
- 1.7 Spinosaurus
- 1.8 Parasaurolophus and Its Crest
- 1.9 Pachycephalosaurus
- 1.10 Argentinosaurus, One of the Biggest

Trail 2: Dinosaurs 🦖 Trail B: Dinosaur Hunters

- 2.1 Mary Anning (1811)
- 2.2 William Buckland Names Megalosaurus (1824)
- 2.3 Gideon and Mary Ann Mantell's Iguanodon
- 2.4 Richard Owen Coins "Dinosauria" (1842)
- 2.5 Hawkins' Crystal Palace Dinosaurs (1854)
- 2.6 The Bone Wars: Cope and Marsh
- 2.7 Barnum Brown Finds T. rex (1902)
- 2.8 Roy Chapman Andrews and the Gobi Eggs (1923)
- 2.9 SUE the T. rex (1990)
- 2.10 Mary Schweitzer's Soft Tissue (2005) ⌚

Trail 3: Dinosaurs 🦖 Trail C: How Dinosaurs Lived

- 3.1 Teeth Tell Diet
- 3.2 Eggs and Nests
- 3.3 Footprints and Trackways
- 3.4 Herds
- 3.5 How Fast Could They Run?
- 3.6 Were They Warm-Blooded?
- 3.7 Feathers: What the Fossils Show
- 3.8 Babies and Growth
- 3.9 Sauropod Necks
- 3.10 Dinosaur Sounds

Trail 4: Dinosaurs 🦖 Trail D: Dinosaurs and the Bible

- 4.1 "Every Living Thing" on Day Six
- 4.2 Behemoth (Job 40)
- 4.3 Leviathan (Job 41)
- 4.4 Dinosaurs on the Ark?
- 4.5 Fossil Graveyards and the Flood ⌚
- 4.6 Dragon Legends Worldwide
- 4.7 What Happened to the Dinosaurs? Each View ⌚
- 4.8 Reading a Museum Sign ⌚

4.9 Soft Tissue and Dating ⌚

4.10 Fearfully Made: Design in Dinosaurs

Trail 5: Dinosaurs 🦖 Trail E: Sea and Sky Reptiles, and the Ice Age

5.1 Ichthyosaurs

5.2 Plesiosaurs

5.3 Mosasaurs

5.4 Pterosaurs

5.5 Quetzalcoatlus

5.6 Woolly Mammoths

5.7 Saber-toothed Cats

5.8 Giant Ground Sloths

5.9 La Brea Tar Pits

5.10 Build a Museum Display

Trails may be done in any order.

DINOSAURS TRAIL A: MEET THE DINOSAURS

The first trail of the Dinosaurs track meets ten famous dinosaurs up close: Tyrannosaurus rex, Triceratops, Stegosaurus, Brachiosaurus, the real-sized Velociraptor, Ankylosaurus, Spinosaurus, Parasaurolophus and its crest, Pachycephalosaurus and the giant Argentinosaurus. Each stop asks what the bones actually show, how scientists measure and estimate from them, and where honest scientists still disagree: hunter or scavenger, armor or display, swimmer or wader, head-butter or show-off, and how big is “biggest.”

This is the  **Expert** level, for ages 14 and up. Each stop takes 35 to 50 minutes and includes a longer reading with real numbers and named studies, key terms, a picture study of public-domain art or historic photographs, a hands-on project (often a measurement or a test), notebook work with a written **narration** paragraph for the parent to keep, six practice questions with at least two challenge problems, a game and a verse of Scripture (KJV). Six stops include a checked **primary source** from Project Gutenberg. The track is creation-friendly: dinosaurs are among the land animals God made on the sixth day (Genesis 1:24–25); period names such as Jurassic and Cretaceous are taught as museum vocabulary; and wherever a date in millions of years comes up, the  box sets out *What the sign says / What we observe / How Christians read it*.

Stops 1–5 earn the **Dinosaur Expert badge, part 1**; Stops 6–10 earn part 2 and the **Trail A certificate**. The two badge quizzes at the end are optional; badges are earned by doing the stops. Stops stand alone and may be done in any order, though Stop A1 introduces ideas (estimating mass, observation and interpretation) used throughout.

BEFORE YOU BEGIN

- Comfortable with ratios, percents, squaring and cubing numbers, and converting metric and customary units (a calculator is fine).
- Able to read a two-page article and write a clear paragraph that states a claim and supports it with evidence.

MASTERY CHECKLIST

- ☐ I can give the size, key features and history of discovery of each of the ten dinosaurs on this trail.
- ☐ I can explain how scientists estimate the mass, speed or bite of an extinct animal and name the assumptions behind each method.
- ☐ I can lay out both sides of a live scientific debate (such as Spinosaurus swimming or Pachycephalosaurus head-butting) and give a reasoned conclusion.
- ☐ I can read a primary source from 1915 or 1917 and say what it got right and what later discoveries changed.
- ☐ I can read a museum sign and separate what is observed from what is interpreted, including dates given in millions of years.

GO DEEPER: BOOKS, MUSEUM PAGES AND RESOURCES

- **Project Gutenberg: W. D. Matthew, Dinosaurs (1915) and C. H. Sternberg, Hunting Dinosaurs in the Bad Lands of the Red Deer River (1917)** (<https://www.gutenberg.org>): Free full texts of the two books quoted on this trail (eBooks #19302 and #77814).
- **Field Museum: SUE the T. rex** (<https://www.fieldmuseum.org>): Measurements, photos and the science of the most complete T. rex, for Stop A1; also Máximo the titanosaur for Stop A10.
- **Natural History Museum, London: Dinosaur Directory and Sophie the Stegosaurus** (<https://www.nhm.ac.uk>): Fact files on hundreds of dinosaurs and a free 3-D scan of Sophie for Stop A3.
- **Biodiversity Heritage Library** (<https://www.biodiversitylibrary.org>): Free scans of the original papers and plates by Marsh, Osborn, Brown, Parks and Stromer used in the picture studies.
- **Raymond M. Alf Museum of Paleontology: “Joe” the baby Parasaurolophus** (<https://www.alfmuseum.org>): Free 3-D scans and the story of a high-school student’s discovery, for Stop A8.

1.1 TYRANNOSAURUS REX

OBJECTIVES

- Give T. rex's main measurements (length, hip height, mass, tooth and skull size) and explain how each one is estimated.
- Weigh the evidence in the old "predator or scavenger?" debate and state a reasoned conclusion.
- Compare a 1915 description of T. rex with what the fossils show today, and tell the observation from the interpretation.

Warm-up. Before you read, write down three guesses: How long was a big T. rex, nose to tail? How tall at the hip? How heavy? Then pace out your length guess on a sidewalk or a field. Keep the guesses; you will check them against the real numbers and against a museum scientist's numbers from 1915.

Video slot. Video coming. Tyrannosaurus rex anatomy, bite force and growth; SUE the T. rex at the Field Museum; the remounting of the AMNH T. rex. Search approved channels (Field Museum, American Museum of Natural History, Natural History Museum London, Smithsonian National Museum of Natural History; for creation-friendly framing, Answers in Genesis or the Institute for Creation Research once vetted); preview first.

KEY TERMS

theropod

A member of the group of two-legged, mostly meat-eating dinosaurs with hollow bones and three main toes, such as T. rex and Velociraptor.

specimen

One individual fossil or skeleton kept in a museum, usually with a catalog number (SUE is FMNH PR 2081).

bite force

The pushing force of a closing jaw, measured in newtons (N). For extinct animals it is estimated from computer models of the skull and jaw muscles.

coprolite

Fossilized dung. It can show what an animal actually ate.

growth lines

Rings in a bone's cross-section, like tree rings, laid down as the animal grew. In living reptiles and birds they usually form once a year.

binocular vision

Sight in which both eyes see the same area at once, which lets an animal judge distance.

CORE IDEAS

The tyrant lizard king. In 1905 Henry Fairfield Osborn of the American Museum of Natural History named a set of huge bones from Montana *Tyrannosaurus rex*, “tyrant lizard king.” (Trail B tells how Barnum Brown dug them up.) More than a century later, T. rex is known from a few dozen partial skeletons, which makes it one of the best-studied large dinosaurs. The most complete is **SUE** at the Field Museum in Chicago, found in South Dakota in 1990, with roughly 90 percent of the skeleton by bulk. SUE is about 12.3 m (40.5 ft) long and about 4 m (13 ft) tall at the hip. The skull alone is about 1.5 m (5 ft) long.

How heavy, and how we know. No one has weighed a T. rex, so mass is an estimate. One method measures the thickness of the leg bones, because in living animals a heavier body needs thicker limb bones. Another builds a digital model of the body around a scanned skeleton and multiplies its volume by the density of flesh. For SUE the methods give answers from about 8 to about 9.5 metric tons, and some studies go higher. That spread is not a failure; it is an honest picture of what is measured (bones) and what is assumed (how much flesh, how many air sacs).

Teeth and bite. The largest T. rex teeth, root and all, are about 30 cm (12 in) long. They are thick, saw-edged on the front and back, and shaped more like bananas than knives, built to crush as well as cut. In 2012 Karl Bates and Peter Falkingham modeled the jaw muscles and estimated a bite of about 35,000 to 57,000 newtons at a single back tooth, many times that of a lion and more than any living land animal. The bones agree: a Triceratops hip bone carries nearly 80 T. rex tooth marks, and a large coprolite from Saskatchewan, almost certainly from a tyrannosaur, is packed with crushed bone.

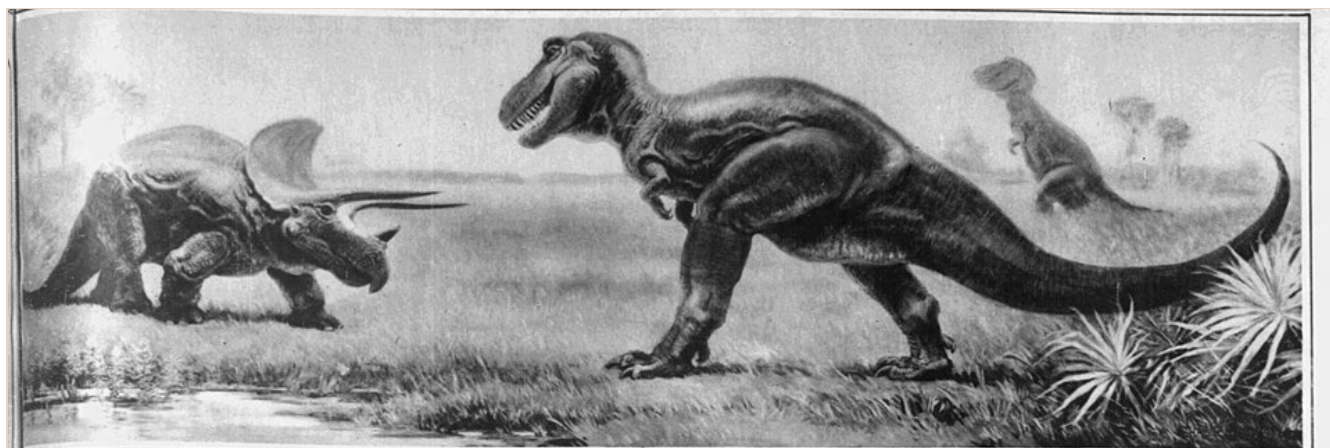
Tiny arms, strong arms. The arms are only about 1 m (3 ft) long, with two clawed fingers. They could not reach the mouth. Yet the bones show large muscle scars, and one study estimated that each arm could curl about 200 kg (440 lb). What they were for is still argued: holding a struggling animal close, pushing up from the ground, or very little at all. The honest answer is that we do not know.

Hunter or scavenger? In the 1990s some paleontologists argued that T. rex was mainly a scavenger, since its arms were small and its legs not built for long sprints. Others pointed to its senses. CT scans of the braincase show very large smell centers, and the eyes face forward enough to give wide binocular vision. Then came direct evidence: a duck-billed dinosaur tail vertebra from South Dakota with a T. rex tooth crown lodged in it and bone that had *healed* around it. That animal was bitten while alive and escaped. Most researchers now say T. rex hunted and also scavenged when it could, as lions and hyenas do.

Growing up fast. Thin slices of bone show growth lines. In 2004 Gregory Erickson’s team counted them in several tyrannosaurs and found a teenage growth spurt in which T. rex gained around 2 kg (4–5 lb) a day; SUE’s bones show about 28 lines. Counting one line per year is an assumption carried over from living reptiles and birds, but it is a reasonable one, and it gives a lifespan of decades, not centuries.

Old pictures, new pictures, and a fallen world. In 1915 the museum stood T. rex upright like a kangaroo with its tail on the floor, and W. D. Matthew described it that way (see the primary source). Today it is mounted with its back level and tail held high, because the hip joints and tail vertebrae fit that way and trackways of big theropods show no tail drag. Patches of fossil skin show small scales. Christians read T. rex as one of the land animals God made on the sixth day (Genesis 1:24-25). Many young-earth Christians read Genesis 1:30 to mean that animals ate plants before Adam's fall, so the teeth on display show what this creature became in a groaning creation (Romans 8:22); others read those verses differently. Either way, Psalm 104 says even the hunters "seek their meat from God."

PICTURE STUDY



Tyrannosaurus and Triceratops, mural for the Field Museum, Charles R. Knight, c. 1927 · Oil on canvas mural · Field Museum of Natural History, Chicago
Wikimedia Commons · Public domain

Charles R. Knight (1874-1953) painted a series of great murals for the Field Museum between 1926 and 1930, and this face-off became the most copied dinosaur picture of the twentieth century. Knight worked closely with scientists and painted what they believed in his day. Compare his T. rex with the description in this stop.

Look closely

- Look at the T. rex's posture: the angle of the back, the position of the tail and the head height. Is it upright or level?
- Look at the skin. What texture did Knight give it?
- Look at the Triceratops. How is it using its body to defend itself?

Talk about it

1. List two things Knight painted that the fossils now show differently, and one thing he got right.
2. Knight showed a fight. What evidence from this stop shows that T. rex really did meet Triceratops?

HANDS-ON: A LIFE-SIZE T. REX IN CHALK

Draw SUE life-size on a driveway, parking lot or field and see the numbers with your own eyes. This uses a scale drawing, so it also practices ratios.

You will need

- Sidewalk chalk (or string and tent stakes on grass)
- A tape measure of at least 10 m, or a 1 m string to step off lengths
- A side-view skeleton picture of T. rex (from the Field Museum SUE page or a library book)
- A ruler and pencil

Steps

1. On the skeleton picture, measure the total length with a ruler. Divide 12.3 m by that length to find your scale (for example, a 20 cm picture gives $12.3 \text{ m} \div 0.20 \text{ m} = 61.5$, so 1 cm on paper = 61.5 cm on the ground).
2. Mark a straight 12.3 m baseline on the ground. Mark the hip about 4 m above it, the skull (1.5 m long) at one end and the tail tip at the other.
3. Scale six more points from your picture (shoulder, knee, ankle, top of skull, base of tail, end of arm) and mark them. Connect the dots into an outline.
4. Lie down inside the skull outline. Stand a family member at the hip mark. Photograph the drawing from a high window or step if you can.
5. Compare: Matthew in 1915 gave 47 feet (14.3 m) long and 18 to 20 feet tall standing. Mark his length with a different color.

Check your work

- My outline is 12.3 m long and about 4 m high at the hip.
- I worked out my scale factor and wrote it down.
- I marked Matthew's 1915 length and can explain why it differs from today's.

FIELD NOTEBOOK

1. Draw a side view of a T. rex skull with the teeth, the eye socket and the large openings labeled. Write SUE's length, hip height, skull length and a mass range beside it.
2. Make a two-column table, "Observed" and "Inferred," with at least four rows (for example: "teeth up to 30 cm" / "bite of 35,000–57,000 N").
3. **Narration (the parent keeps this).** Write one paragraph answering: Was T. rex a hunter, a scavenger or both? Use at least two pieces of fossil evidence from this stop.

Did you know? SUE was sold at auction in 1997 for about \$8.4 million, the most ever paid for a fossil at the time, and the Field Museum bought it with help from donors. SUE's bones show injuries and illness, including a healed broken rib and holes in the lower jaw

that may be from an infection like one found in birds today. In 2018 SUE's skeleton was moved to its own room so it could be remounted with its belly ribs (gastralia) in place.

 **What the sign says / What we observe / How Christians read it.**  **What the sign says:** "Tyrannosaurus rex lived 68 to 66 million years ago, at the end of the Cretaceous Period." **What we observe:** T. rex bones are found in the upper part of rock layers called the Hell Creek and Lance Formations in Montana, the Dakotas and Wyoming, and similar layers in Canada; above them lie layers with no dinosaur bones. The date comes from measuring radioactive elements in volcanic ash beds near the bones and assuming steady decay rates, known starting amounts and no gain or loss of atoms over time. **How Christians read it:** many young-earth Christians read these layers as laid down quickly during the Flood year, a few thousand years ago, and treat "Cretaceous" as a name for a set of rock layers, not an age. Other Christians accept the long ages. Everyone agrees on the order of the layers and what bones lie in them.

Primary source. *W. D. Matthew, Dinosaurs, with Special Reference to the American Museum Collections (American Museum of Natural History, 1915), from the chapter on carnivorous dinosaurs. Project Gutenberg eBook #19302.*

The "Tyrant Saurian" as Professor Osborn has named him, was the climax of evolution of the giant flesh-eating dinosaurs. It reached a length of forty-seven feet, and in bulk must have equalled the mammoth or the mastodon or the largest living elephants. The massive hind limbs, supporting the whole weight of the body, exceeded the limbs of the great proboscideans in bulk, and in a standing position the animal was eighteen to twenty feet high, as against twelve for the largest African elephants or the southern mammoth. The head (see frontispiece) is 4 feet 3 inches long, 3 ft. 4 inches deep, and 2 ft. 9 inches wide; the long deep powerful jaws set with teeth from 3 to 6 inches long and an inch wide.

Go deeper. Field Museum, "SUE the T. rex" pages (fieldmuseum.org). W. D. Matthew, *Dinosaurs* (1915), free at Project Gutenberg (eBook #19302); read the whole T. rex section and list what has changed. Peter Larson and Kenneth Carpenter, eds., *Tyrannosaurus rex, the Tyrant King* (Indiana University Press, 2008), a technical but readable collection. Second video topic: "How scientists estimate dinosaur weight" (look for limb-bone and 3-D model methods).

Goes deeper in. Life Science, high-school Biology, the unit on classification and animal design (coming soon); Earth Science, the fossils and rock-layers units; and Arithmetic, ratios and scale drawings.

For families. Figures: SUE 12.3 m (40.5 ft) long and about 4 m (13 ft) at the hip (Field Museum); mass estimates of roughly 8–9.5 t vary by method (e.g., Hutchinson et al. 2011). Bite force: Bates and Falkingham, *Biology Letters* 2012. Triceratops tooth marks: Erickson and Olson 1996. Coprolite: Chin et al., *Nature* 1998. Healed hadrosaur tail: DePalma et al., *PNAS* 2013. Arm strength: Carpenter and Smith 2001. Growth: Erickson

et al., *Nature* 2004. Skin scales: Bell et al. 2017. The primary source was checked word for word against Project Gutenberg eBook #19302. The Genesis 1:30 paragraph names the common young-earth reading and notes that Christians differ; you may want to discuss your own view.

PRACTICE

1. **EASY** Give SUE's approximate length, hip height and skull length in both metric and feet.
2. **MEDIUM** Name two methods for estimating a dinosaur's mass and one assumption each method makes.
3. **MEDIUM** What single fossil is the strongest evidence that T. rex attacked living animals, and why?
4. **CHALLENGE** **Primary source.** Matthew gave T. rex a length of 47 feet. SUE is 40.5 feet. By what percent did Matthew overestimate the length (compared with SUE)? Then give one reason, from the source itself, why his numbers came out the way they did.
5. **CHALLENGE** If a young T. rex gained about 2 kg a day during a growth spurt from age 14 to age 18, about how much would it gain in those four years? Compare with SUE's estimated adult mass of 8,000–9,500 kg.
6. **MEDIUM** Sort each into observation or interpretation: (a) The largest teeth are about 30 cm long. (b) T. rex was the top predator of its land. (c) A Triceratops hip bone carries nearly 80 tooth marks. (d) T. rex lived 66 million years ago.

Make it a game • Fossil Court. One player is the prosecutor ("T. rex was a hunter"), one the defense ("T. rex was a scavenger"), and the rest are the jury. Each side gets two minutes and may only cite real evidence from this stop: teeth, bite marks, coprolites, the healed tail, brain scans, eyes, legs, arms. The jury votes and must give a reason. Then switch sides.

Scripture. "The young lions roar after their prey, and seek their meat from God." (Psalm 104:21, KJV)

Psalm 104 praises God for every creature in its place. Even the fiercest hunters depend on Him for their food. A T. rex skull in a museum is a picture of strength, but it is a creature's strength, given and limited by its Maker.

Practice: answers

1. About 12.3 m (40.5 ft) long, about 4 m (13 ft) at the hip, and a skull about 1.5 m (5 ft) long.
2. (1) Limb-bone scaling: measures leg-bone thickness and assumes the same bone-to-weight relationship as living animals. (2) Volume models: builds a body around the skeleton and assumes how much flesh, how many air spaces and what density to use.
3. The duck-billed dinosaur tail vertebra with a T. rex tooth in it and healed bone around it. Bone only heals in a living animal, so it was bitten while alive and got away.

4. $(47 - 40.5) \div 40.5 = 6.5 \div 40.5 \approx 0.16$, so about 16 percent too long. He was working from incomplete skeletons and pictured the animal standing upright with its tail on the ground ("in a standing position the animal was eighteen to twenty feet high"), which changes how the tail and body were reconstructed. He also wrote only a decade after the first skeletons were found.
5. $2 \text{ kg} \times 365 \text{ days} \times 4 \text{ years} = 2,920 \text{ kg}$, close to 3 metric tons, or roughly a third of an adult's mass, put on in four years.
6. (a) observation; (b) interpretation; (c) observation (who made them is an interpretation, though a strong one); (d) interpretation (a date resting on assumptions about decay rates).

1.2 TRICERATOPS

OBJECTIVES

- Describe the skull of Triceratops (horns, frill, beak and dental battery) with measurements, and explain what each part was likely used for.
- Explain how growth changes the skull and why that makes the Triceratops-Torosaurus question hard.
- Read a 1917 fossil hunter's report and turn its measurements into metric units and comparisons.

Warm-up. Hold a meter stick (or a yardstick plus 9 cm) out from your forehead. That is about the length of a big Triceratops brow horn with its horn sheath. Now picture a skull so big that two of those horns are only part of it. Guess how long the whole skull was before you read.

Video slot. Video coming. Triceratops skull anatomy, horn growth and the Triceratops-Torosaurus debate; Triceratops dental batteries. Search approved channels (Smithsonian National Museum of Natural History, Museum of the Rockies, Natural History Museum of Los Angeles County, American Museum of Natural History; for creation-friendly framing, Answers in Genesis or the Institute for Creation Research once vetted); preview first.

KEY TERMS

ceratopsian

A member of the horned and frilled plant-eating dinosaurs with a parrot-like beak, such as Triceratops and Protoceratops.

frill

The broad shelf of bone that sweeps back from a ceratopsian's skull over the neck.

rostral bone

A bone found only in ceratopsians that forms the tip of the upper beak.

dental battery

Hundreds of teeth packed in columns, with new teeth growing up underneath to replace worn ones, forming one long grinding and slicing surface.

ontogeny

The growth and change of one animal from hatchling to adult.

holotype

The single specimen chosen to carry a species name; all other specimens are compared with it.

CORE IDEAS

A buffalo that wasn't. In 1887 a pair of large horn cores dug up near Denver reached Othniel Charles Marsh at Yale. He named them *Bison alticornis*, a giant fossil bison. Within two years his collector John Bell Hatcher sent him complete horned skulls from eastern Wyoming, and Marsh saw his mistake. In 1889 he named *Triceratops*, “three-horned face.” Marsh corrected himself in print; good scientists do. Hatcher went on to find dozens of Triceratops skulls, and today it is one of the most common large dinosaurs in the rock layers of the American West that museums call Late Cretaceous (the same Hell Creek and Lance layers that hold T. rex).

The numbers. A big Triceratops was about 8 to 9 m (26–30 ft) long. Mass estimates run from about 6 to 12 metric tons, depending on method and specimen; a fair middle guess is that of a large African bull elephant. The skull is the marvel: up to about 2.5 m (8 ft) long, among the largest skulls of any land animal. The brow horns had cores of bone up to about 1 m long, and in life a horny sheath, like a cow's horn, made them longer still. Unlike most of its relatives, Triceratops had a solid frill with no large windows in it, edged with small bony points called epioassifications.

A beak and a battery. At the front, the rostral bone and the lower beak bone formed a deep, narrow beak for cropping tough plants. Behind it, each side of each jaw held a dental battery of roughly 36 to 40 tooth columns, with three to five teeth stacked in each column. As the top tooth wore down, the next pushed up beneath it. The teeth met like scissors, slicing rather than grinding, and the jaw muscles ran up into the frill. Large, strong jaw muscles and hundreds of teeth point to a diet of tough, fibrous plants such as palms, cycads and ferns, though no stomach contents have been found to prove it.

What were the horns for? Knight's paintings show horns used against T. rex, and that surely happened: Stop A1 mentioned a Triceratops hip with T. rex tooth marks, and some Triceratops bones show bites that healed. But the strongest evidence points to fights between Triceratops. In 2009 Andrew Farke and colleagues compared Triceratops skulls with those of its relative Centrosaurus and found many more healed wounds on the Triceratops cheek and frill bones, just where a rival's horns would strike if two animals locked horns and shoved. Horns and frills may also have helped animals recognize each other and show maturity, as antlers do in deer.

Growing up changes everything. A Triceratops hatchling's skull was only about the size of a man's hand. Studies of growth series by Jack Horner and Mark Goodwin (2006) showed that the brow horns of young animals curved *backward*, straightened in teenagers, and curved *forward* in adults, while the frill's edge points flattened out with age. This is called ontogeny, and it matters, because two skulls that look like different species might be one species at two ages.

The Torosaurus question. In 2010 John Scannella and Jack Horner proposed that *Torosaurus*, a horned dinosaur from the same layers with a longer frill pierced by two large holes, was simply the fully grown Triceratops. If so, the name Triceratops (1889) would

stand and *Torosaurus* (1891) would be dropped. Headlines announced that “Triceratops never existed,” which was exactly backward. Other researchers, including Nicholas Longrich and Daniel Field (2012), answered that some *Torosaurus* skulls look young and some Triceratops skulls look old, so the two were separate kinds. The debate is not settled. It shows how hard it is to tell growth from kind when all you have is bone.

Searching out a matter. The Triceratops story is a chain of corrections: bison horns that were dinosaur horns, young horns that point the wrong way, perhaps two names for one animal. None of that is a reason to distrust careful study. It is the normal work of “searching out a matter” (Proverbs 25:2): gathering more specimens, measuring them and changing your mind when the evidence calls for it. Christians can do this work gladly, because the order in God’s creatures is real and can be found.

PICTURE STUDY



Triceratops, Charles R. Knight, 1901 · Watercolor and gouache (painting made for the American Museum of Natural History) · American Museum of Natural History, New York
Wikimedia Commons · Public domain

Knight painted this Triceratops in 1901, only twelve years after Marsh named it, working from the Yale and American Museum skulls. It set the pattern for how Triceratops looked in books for most of the twentieth century.

Look closely

- Measure by eye: about what fraction of the whole body length is the skull and frill?
- Look at the legs. Are the front legs straight under the body or bent out to the sides?
- Look at the frill’s edge and the skin. What did Knight have to guess?

Talk about it

1. Using this stop's description of growth, is Knight's animal a young one or an adult? Give your evidence from the horns.
2. Why might a painter in 1901 choose a calm side view instead of a battle scene for a new animal?

HANDS-ON: FIELD REPORT: MEASURING A TRICERATOPS SKULL

Read Charles H. Sternberg's 1917 report (in the Primary source box), convert his measurements, and build a life-size paper outline of the skull to compare with your own body.

You will need

- The primary source excerpt
- Large paper (taped-together grocery bags or butcher paper, about 2.5 m long), or chalk on pavement
- A tape measure and a marker
- A calculator

Steps

1. Underline every measurement in the excerpt. Convert each one: 1 foot = 30.48 cm and 1 inch = 2.54 cm.
2. Using a side-view skull picture from a book or museum site, mark out a skull outline life-size, using Sternberg's skull length (over five feet). Add the brow horns at 33½ inches.
3. Compare with the largest known Triceratops skulls, about 2.5 m long. What fraction of that size was Sternberg's skull?
4. Lie down beside the outline. Write your height as a fraction of the skull length.
5. Write a two-sentence field report as Sternberg would, giving the place, the size and the condition of the fossil.

Check your work

- I converted all of Sternberg's measurements correctly.
- My outline is drawn to life size with the horns in the right place.
- I wrote a field report with a place, a size and a condition.

FIELD NOTEBOOK

1. Draw a Triceratops skull from the side. Label the rostral bone, beak, nose horn, brow horns, eye socket, frill and epioassifications, and give a measurement beside two of them.
2. Draw three small brow-horn outlines in a row: baby (curved back), teen (straight), adult (curved forward).

3. **Narration (the parent keeps this).** Write one paragraph explaining the Triceratops-Torosaur debate to someone who has never heard of it. Give the evidence on both sides and say why it is hard to settle.

Did you know? Triceratops is the state fossil of South Dakota and the state dinosaur of Wyoming. Some Triceratops skin impressions show large, rounded scales. The “Bison alticornis” horn cores Marsh misnamed in 1887 still exist in a museum collection, and most paleontologists now treat them as belonging to Triceratops or a close relative.

Primary source. *Charles H. Sternberg, Hunting Dinosaurs in the Bad Lands of the Red Deer River, Alberta, Canada (1917), recalling his family’s earlier work in Wyoming. Project Gutenberg eBook #77814.*

In 1909 Charles M. Sternberg discovered the magnificent skull of a *Triceratops*, also sold to the American Museum, and mounted there. This is the best skull of this species known, with the notable exception of the Utterback specimen at Carnegie Museum, Pittsburgh. Charlie’s specimen was found on Seven Mile creek, two and a half miles northeast of the McKeon Sheep Ranch. The skull was over five feet long. The horns 33½ inches in length.

Go deeper. Smithsonian National Museum of Natural History, the “Nation’s T. rex” and Triceratops pages in the David H. Koch Hall of Fossils (naturalhistory.si.edu); the Smithsonian’s Triceratops “Hatcher” was one of the first dinosaur skeletons to be digitally scanned and rebuilt. Museum of the Rockies (museumoftherockies.org) for the Horner growth-series research. Peter Dodson, *The Horned Dinosaurs: A Natural History* (Princeton, 1996). Second video topic: “How ceratopsian horns change as they grow.”

Goes deeper in. Life Science, high-school Biology, the units on growth and development and on classification (coming soon); and Earth Science, the fossils unit.

For families. Facts: *Bison alticornis* (Marsh 1887) and *Triceratops* (Marsh 1889) as stated; Hatcher’s Wyoming collecting 1888–1892. Size and mass ranges are deliberately broad because published estimates differ. Horn growth: Horner and Goodwin, *Proc. R. Soc. B* 2006. Combat lesions: Farke, Wolff and Tanke, *PLoS ONE* 2009. Torosaurus: Scannella and Horner, *JVP* 2010; Longrich and Field, *PLoS ONE* 2012. The Sternberg excerpt was checked word for word against Project Gutenberg eBook #77814; the 1909 skull came from the Lance beds of Wyoming. Diet is inferred from the jaws; no stomach contents are known. Proverbs 25:2 is applied to scientific inquiry as a principle; its first meaning concerns kings and wisdom.

PRACTICE

1. **EASY** What did Marsh first call Triceratops horn cores in 1887, and what corrected him?
2. **MEDIUM** How did the brow horns change as a Triceratops grew up?

3. **MEDIUM** What evidence suggests Triceratops used its horns on each other, not only on predators?
4. **CHALLENGE** **Primary source.** Convert Sternberg's skull length ("over five feet") and horn length (33½ inches) to centimeters. What fraction of a 2.5 m record skull is his skull, at least?
5. **CHALLENGE** Each side of each jaw (four in all: upper left, upper right, lower left, lower right) had about 36 to 40 tooth columns, with 3 to 5 teeth stacked in each. Find the smallest and largest total number of teeth in the mouth at once.
6. **CHALLENGE** Explain in three or four sentences why the Triceratops-Torosaurus question cannot be settled by looking at only one or two skulls.

Make it a game · Young or Old? A parent draws (or prints) eight simple ceratopsian heads with different horn curves, frill edges and sizes, numbered on the back. Players sort them into a growth line from hatchling to adult, then argue whether any two belong to different species. Reveal the parent's answer key and give a point for each head placed right.

Scripture. "It is the glory of God to conceal a thing: but the honour of kings is to search out a matter." (Proverbs 25:2, KJV)

God has built His world with real order and left it for us to discover. The patient search, with its mistakes and corrections, is an honorable work, not a threat to faith.

Practice: answers

1. *Bison alticornis*, a giant bison. Complete horned skulls sent from Wyoming by John Bell Hatcher showed the horns belonged to a dinosaur, and Marsh named Triceratops in 1889.
2. In young animals they curved backward; in teenagers they straightened; in adults they curved forward. The points on the frill edge also flattened with age.
3. Farke and colleagues (2009) found many healed wounds on Triceratops cheek and frill bones, where a rival's horns would hit when two animals locked horns, and far more than on Centrosaurus skulls.
4. $5 \text{ ft} \times 30.48 = 152.4 \text{ cm}$, so more than about 1.52 m. $33.5 \text{ in} \times 2.54 = 85.09 \text{ cm}$, about 85 cm. $1.52 \div 2.5 \approx 0.61$, so at least about three-fifths of the largest skulls (larger if "over five feet" was well over).
5. Smallest: $4 \times 36 \times 3 = 432$. Largest: $4 \times 40 \times 5 = 800$. So roughly 430 to 800 teeth at once.
6. Skulls change shape a great deal as an animal grows, so a difference between two skulls could be age, not kind. To tell growth from species you need many skulls of known ages, which bone-tissue studies try to supply. If some "Torosaurus" skulls are young and some "Triceratops" skulls are old, the growth idea is weakened; if every Torosaurus is older than every Triceratops, it is strengthened. Only a large sample can show which pattern is real.

1.3 STEGOSAURUS

OBJECTIVES

- Describe the plates, tail spikes, brain and teeth of Stegosaurus, with measurements.
- Compare the main ideas about what the plates were for and judge the evidence for each.
- Design and run a simple test of one hypothesis, and say what the test can and cannot show.

Warm-up. Hold a walnut in one hand and a lime (or a small lemon) in the other. Books often say Stegosaurus had a brain “the size of a walnut.” By the end of this stop you will know which fruit is closer, and whether a small brain means a foolish animal.

Video slot. Video coming. Stegosaurus plates and tail spikes; “Sophie” the Stegosaurus at the Natural History Museum, London; the Morrison Formation at Dinosaur National Monument. Search approved channels (Natural History Museum London, Smithsonian National Museum of Natural History, Denver Museum of Nature & Science, National Park Service; for creation-friendly framing, Answers in Genesis or the Institute for Creation Research once vetted); preview first.

KEY TERMS

stegosaur

A member of the four-legged, plant-eating dinosaurs with two rows of plates or spikes along the back and spikes on the tail.

osteoderm

A bone that grows inside the skin rather than as part of the skeleton. Stegosaurus plates and spikes are osteoderms.

thagomizer

An informal name for the four spikes at the end of a stegosaur’s tail, taken from a 1982 cartoon and later used by paleontologists.

thermoregulation

The way an animal controls its body temperature, by gaining or losing heat.

endocast

A cast of the inside of the braincase, showing the size and shape of the space the brain filled.

hypothesis

A proposed explanation that can be tested by observation or experiment.

CORE IDEAS

A roof lizard. In 1877 Arthur Lakes, an English-born teacher and amateur geologist in Colorado, found huge bones in the hills near the town of Morrison and sent them to O. C. Marsh at Yale. Among them were broad, flat plates of bone. Marsh pictured them lying flat over the animal's back like roof tiles and named it *Stegosaurus*, "roof lizard." Better skeletons soon showed the plates stood upright. The rock layer where Lakes dug, the Morrison Formation, runs through Colorado, Utah and Wyoming, and has yielded more big dinosaurs than almost any other; museums call it Late Jurassic.

The animal. The largest *Stegosaurus* reached about 9 m (30 ft) long and perhaps 5 metric tons. The best skeleton in the world is "Sophie" at the Natural History Museum in London, found in Wyoming in 2003 and displayed since 2014: a smaller adult about 5.6 m (18 ft) long and 2.9 m (9.5 ft) tall, with most of its bones present and many still in place. The hind legs are much longer than the front legs, so the back arches high over the hips and the small head hangs low, mostly less than a meter off the ground. The teeth are small and leaf-shaped, and models of the skull suggest a weak bite, so *Stegosaurus* likely cropped soft, low plants.

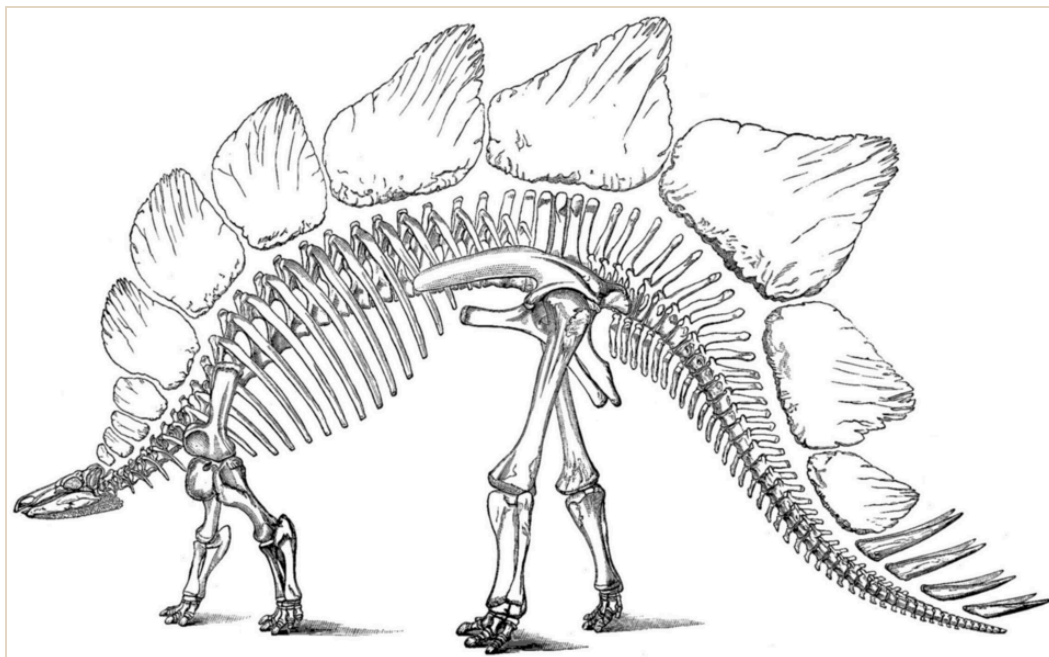
The plates. Seventeen plates stood in two rows along the neck, back and tail, staggered so they alternated left and right rather than standing in pairs. The largest were around 60 cm (2 ft) tall. They were not joined to the backbone but set in the skin, which is why their arrangement was argued about for a century and was settled only by skeletons found with the plates still lying in order. The surface of each plate is lined with grooves where blood vessels ran, and the inside is a honeycomb of spongy bone, so the plates were light and not strong enough to work well as armor.

Three hypotheses. (1) *A armor*: weakened by the thin, spongy structure and by the open flanks the plates leave unguarded. (2) *Heat control*: in 1976 James Farlow and colleagues tested model plates in a wind tunnel and found the staggered arrangement shed heat well; blood running over the plates could have warmed the animal in the sun or cooled it in the wind. (3) *Display*: in 2005 Russell Main and colleagues studied the bone tissue and argued the blood-vessel grooves mostly fed the growing plate and its horny covering, and that big, showy plates are best explained as signals for recognizing their own kind or for mates and rivals, like a peacock's tail or a deer's antlers. Many researchers now favor display, with some heat exchange as a side effect. The fossils allow more than one answer.

The tail spikes. The tail ended in four spikes, each up to roughly 60 cm long in big animals. They were weapons. When Kenneth Carpenter and colleagues examined dozens of *Stegosaurus* spikes in 2005, about one in ten had broken tips that had healed, so they had struck something hard while the animal lived. They also described an *Allosaurus* tail vertebra from the Morrison with a hole punched through it, the right size and shape for a *Stegosaurus* spike. The nickname "thagomizer" comes from a 1982 cartoon by Gary Larson, in which a caveman names the spikes after "the late Thag Simmons." Paleontologists began using it as a joke, and it stuck.

A small brain and a myth. Marsh made an endocast of a Stegosaurus braincase and found a brain space of only a few ounces, now estimated at no more than about 80 grams, nearer a lime than a walnut, in an animal of several tons. He also found a space in the spine above the hips about twenty times larger than the brain, which grew into the legend of a “second brain” in the hips. Birds today have a similar space holding a glycogen body, a store of energy-rich tissue, and that is the likeliest explanation. A small brain was enough for the life God designed it for: Stegosaurus thrived, by fossil count, across a wide region of the West, and has even been reported from Portugal.

PICTURE STUDY



Restoration of Stegosaurus ungulatus, from The Dinosaurs of North America, O. C. Marsh (drawing prepared under his direction), 1896 · Printed skeletal restoration · From Marsh's The Dinosaurs of North America, U.S. Geological Survey, Sixteenth Annual Report (1896)
Wikimedia Commons · Public domain

Twenty years after naming Stegosaurus, Marsh published this skeleton drawing for the U.S. Geological Survey. He had given up the “roof” idea and stood the plates up. This was the first full restoration of a stegosaur and it shaped museum models for decades.

Look closely

- Count the plates. Are they in one row or two? In pairs or staggered?
- Count the tail spikes. How many do you see, and how many pairs would that be?
- Compare the length of the front and hind legs and the height of the head.

Talk about it

1. Name two things in Marsh's drawing that later skeletons (such as Sophie) corrected.
2. Why would a scientist publish a drawing he knew might be wrong in places?

Safety first. Kitchen safety: use warm tap water, not boiling water, and have an adult handle any kettle or stove. Wipe up spills so no one slips.

HANDS-ON: TESTING THE HEAT-FIN HYPOTHESIS

Farlow's 1976 wind-tunnel test asked whether plates could shed heat. You can run a kitchen version with fins made of foil and see what such a test can and cannot prove.

You will need

- Two identical mugs or jars
- Two kitchen thermometers (or one, read quickly in turn)
- Heavy aluminum foil and tape
- Warm tap water and a measuring cup
- A fan (optional) and a timer

Steps

1. Write your hypothesis: "A mug with fins will cool faster than a mug without fins."
2. Cut six foil plates about 8 cm tall. Fold a flap at the base of each and tape them in a staggered double row up the outside of one mug so they touch the mug well.
3. Fill both mugs with the same amount of warm tap water from the same pitcher. Record each temperature at the start and every 2 minutes for 20 minutes.
4. Repeat with the fan blowing gently across both mugs.
5. Graph both runs. Then write three sentences: what your test shows, what it does *not* show about Stegosaurus, and what evidence would be needed to decide between heat control and display.

Check your work

- I kept everything the same except the fins (a fair test).
- I recorded and graphed at least 10 readings per mug.
- I wrote what my test can and cannot prove.

FIELD NOTEBOOK

1. Draw Stegosaurus from above with the 17 plates staggered in two rows and the four tail spikes. Label one plate "osteoderm" and add its approximate height.
2. Make a three-row table: Armor / Heat control / Display. For each, write one piece of evidence for and one against.
3. **Narration (the parent keeps this).** Write one paragraph explaining what the plates of Stegosaurus were most likely for. Name at least two hypotheses and the evidence that leads you to your choice.

Did you know? Stegosaurus became Colorado's state fossil in 1982 after a campaign by schoolchildren and their teachers. Arthur Lakes, who found the first bones, was also a

fine painter and drew watercolors of the dig. That same year, crews working for Marsh's rival E. D. Cope were digging the same rock layer near Cañon City, Colorado, and the two men raced for the best bones (Trail B, Stop B6).

 **What the sign says / What we observe / How Christians read it.**  **What the sign says:** "Stegosaurus lived about 155 to 150 million years ago, in the Late Jurassic." **What we observe:** Stegosaurus bones lie in the Morrison Formation, a widespread layer of mudstone and sandstone with river-channel deposits and huge bone beds, such as the wall of bones at Dinosaur National Monument where many animals were jumbled together. The date comes from radioactive minerals in volcanic ash within the formation, assuming constant decay rates, known starting amounts and closed systems. **How Christians read it:** many young-earth Christians read the Morrison bone beds as animals swept together and buried quickly by water during the Flood, and "Jurassic" as the name of a set of layers, not an age. Other Christians accept the long ages. Everyone can observe the layers, the order and the bones.

Go deeper. Natural History Museum, London, "Sophie the Stegosaurus" pages and 3-D scan (nhm.ac.uk). Dinosaur National Monument, National Park Service, "Quarry Exhibit Hall" (nps.gov/dino); the Project Gutenberg booklet *The Dinosaur Quarry* (eBook #49288) describes it. Kenneth Carpenter, ed., *The Armored Dinosaurs* (Indiana University Press, 2001), for advanced readers. Second video topic: "How Sophie the Stegosaurus was prepared and mounted."

Goes deeper in. Life Science, high-school Biology, the units on heat and the body and on the scientific method (coming soon); and Earth Science, the rock-layers and Flood units.

For families. No public-domain Stegosaurus excerpt could be checked word for word for this stop, so there is no Primary source box; the project uses an experiment instead. Sources: Sophie, NHM London (5.6 m long, 2.9 m tall; Maidment et al. 2015). Plate heat test: Farlow, Thompson and Rosner, *Science* 1976. Display: Main et al., *Paleobiology* 2005. Spike injuries and the Allosaurus vertebra: Carpenter et al. 2005. Brain: endocast data commonly given as no more than about 80 g. Plate and spike sizes are rounded and vary by species and specimen. The "thagomizer" cartoon is copyrighted and is described, not reproduced.

PRACTICE

1. **EASY** Why did Marsh name the animal "roof lizard," and what did later skeletons show?
2. **MEDIUM** Give two reasons most paleontologists doubt the plates were armor.
3. **MEDIUM** What evidence shows the tail spikes were used as weapons?
4. **CHALLENGE** A Stegosaurus of 4,500 kg had a brain of about 80 g. A 70 kg person has a brain of about 1,400 g. Find each brain-to-body ratio as "1 to ____." Then explain why this ratio alone does not tell us how "smart" an animal needed to be.
5. **CHALLENGE** Your foil-fin mug cooled 2 °C faster than the plain mug in 20 minutes. Write the strongest conclusion the test allows and two reasons it cannot prove Stegosaurus

used its plates for heat control.

6. **MEDIUM** What is the likeliest explanation for Marsh's "second brain" space above the hips?

Make it a game • Plate Debate Draft. Write twelve evidence cards (spongy bone, blood-vessel grooves, staggered rows, set in skin, wind-tunnel test, showy shape, open flanks, and so on). Two teams take turns drafting cards for "heat control" or "display." After the draft, each team has one minute to argue its case using only its cards. A parent judges which team used the evidence best.

Scripture. "But ask now the beasts, and they shall teach thee; and the fowls of the air, and they shall tell thee: Or speak to the earth, and it shall teach thee: and the fishes of the sea shall declare unto thee." (Job 12:7-8, KJV)

Job tells his friends that the creatures themselves bear witness to God's hand. When we study a Stegosaurus plate patiently and honestly, we are "asking the beasts," and they teach us about the wisdom of their Maker.

Practice: answers

1. He thought the plates lay flat over the back like roof tiles. Later skeletons showed they stood upright in two staggered rows.
2. Any two: they are thin with spongy bone inside and would break easily; they leave the sides of the body unprotected; they were set in the skin, not fixed firmly to the skeleton.
3. About one in ten spikes studied has a broken tip that healed during life, and an Allosaurus tail vertebra has a hole that matches a Stegosaurus spike.
4. Stegosaurus: $4,500,000 \text{ g} \div 80 \text{ g} = 56,250$, so about 1 to 56,000. Human: $70,000 \div 1,400 = 50$, so 1 to 50. The ratio says little about what an animal needs: large animals usually have small brains for their size, and Stegosaurus needed only to find low plants, keep with its kind and defend itself, which it did well across a wide region. Human minds are a different kind of gift altogether.
5. Conclusion: thin fins with a large surface area increase heat loss from a warm object, so plates could have shed heat. It cannot prove use because (1) foil is not living bone with skin and blood flow, and (2) a structure can affect heat without having heat control as its main purpose; the display evidence (bone growth, showy shape) must still be weighed. A single run is also a small sample.
6. A glycogen body, a store of energy-rich tissue like the one found in the same place in birds, not a second brain.

1.4 BRACHIOSAURUS

OBJECTIVES

- Tell how Brachiosaurus was found and named, and why the famous Berlin skeleton now has a different name.
- Explain three engineering problems of a very tall animal (weight, breathing, blood pressure) and the design features that answer them.
- Calculate the blood pressure needed to lift blood to a raised head.

Warm-up. Stand at the bottom of a staircase and look up to a second-floor window: that is roughly 6 m. A big Brachiosaurus with its neck raised could hold its head about twice that high. Before reading, write down one problem you think an animal would have if its head were that far above its heart.

Video slot. Video coming. Brachiosaurus and Giraffatitan; the Berlin Tendaguru skeleton; sauropod necks, air sacs and blood pressure. Search approved channels (Field Museum, Museum für Naturkunde Berlin, Natural History Museum London, American Museum of Natural History; for creation-friendly framing, Answers in Genesis or the Institute for Creation Research once vetted); preview first.

KEY TERMS

sauropod

A member of the giant, long-necked, long-tailed, four-legged plant-eating dinosaurs, such as Brachiosaurus and Argentinosaurus.

humerus

The upper arm bone. Brachiosaurus (“arm lizard”) was named for its very long humerus.

pneumatic bone

Bone hollowed out by air sacs from the lungs, as in birds. It is strong but much lighter than solid bone.

genus

The first part of a scientific name (Brachiosaurus in Brachiosaurus altithorax), naming a group of closely related species.

blood pressure

The pressure the heart puts on the blood, measured in millimeters of mercury (mmHg). It must be high enough to push blood up to the brain.

type specimen

The specimen to which a name is permanently tied. If other fossils differ from it enough, they need a different name.

CORE IDEAS

An arm bone in Colorado. In the summer of 1900 Elmer Riggs led an expedition from the Field Columbian Museum in Chicago to the Morrison rocks near Grand Junction, Colorado. His assistant Harold Menke found a bone so large that at first the team took it for a damaged thighbone. It was an upper arm bone, a humerus over 2 m (7 ft) long. With it came backbones, ribs, part of the hip and a thighbone. In 1903 Riggs named the animal *Brachiosaurus altithorax*: “arm lizard” with a “deep chest.” Its front legs were longer than its hind legs, which no other known sauropod shared, so its back sloped down from shoulders to hips like a giraffe’s.

The Berlin giant. Between 1909 and 1913 a German expedition led by Werner Janensch dug at Tendaguru in German East Africa (now Tanzania). Hundreds of local workers carried more than 200 tons of bones on foot to the coast, a journey of several days. Janensch found sauropod bones with the same long arms and named them *Brachiosaurus brancai* in 1914. The mounted skeleton at the Museum für Naturkunde in Berlin, first raised in 1937, stands about 12 to 13 m (40 ft) tall and was long called the tallest mounted dinosaur in the world. Most pictures of “Brachiosaurus” in older books are really of this skeleton.

One name or two? W. D. Matthew, writing in 1915, accepted the Berlin identification but added a careful “if” (see the primary source). That caution proved wise. In 1988 Gregory Paul suggested the African animal was different enough to deserve its own name, and in 2009 Michael Taylor compared the bones one by one and found many differences in the backbones, hips and limb proportions. The African animal is now usually called *Giraffatitan brancai*. So the real *Brachiosaurus* is the Colorado animal, known from fewer bones, and the famous Berlin skeleton is its close cousin. Some researchers still keep both in one genus; names follow judgment as well as measurement.

How big? *Brachiosaurus altithorax* was perhaps 20 to 22 m (65–72 ft) long. Mass estimates have ranged widely, from around 28 metric tons to more than 50, because so much of the skeleton is missing and because the air spaces inside the bones are hard to account for. With the neck raised, the head could be roughly 9 m (30 ft) or more above the ground, and some estimates go higher.

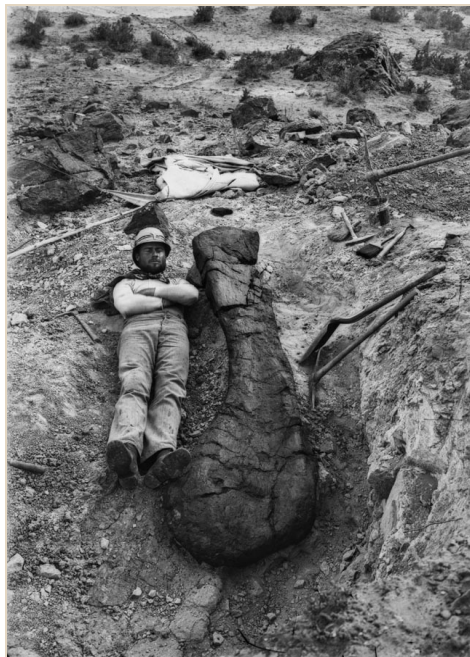
Light bones and bird-like breathing. A neck that long would be impossibly heavy if made of solid bone. *Brachiosaurus* vertebrae are hollowed by large cavities, and the bone between them forms thin plates and struts, like the girders of a bridge. In birds, the same kind of cavities are filled by air sacs that branch from the lungs. Air sacs let birds move air through the lungs in one direction, which is very efficient, and they make the skeleton light. Sauropods appear to have had a similar system, which helps explain how such big animals could breathe through such long necks.

Pumping blood uphill. Here is the hardest problem. To push blood up a column 8 m above the heart takes about 590 mmHg of pressure just to hold the column up, before any is left to drive blood through the brain. A human’s blood pressure is about 120 mmHg; a giraffe’s, with a head about 2 m above its heart, is roughly twice that. Some physiologists have argued

that a Brachiosaurus holding its head high would need a very large, thick-walled heart; others suggest it fed with the neck held lower much of the time, raising it only now and then. Scientists still disagree.

Old snorkel, new snout. The bony nose openings of Brachiosaurus sit high on the top of the skull, so older books showed it living in lakes with only its head above water, breathing like a swimmer through a snorkel. In 1951 Kenneth Kermack showed water pressure on the chest at that depth would have made breathing impossible, and footprints show sauropods walked on land. In 2001 Lawrence Witmer showed that in living animals the fleshy nostril sits near the front of the snout even when the bony opening is farther back, so Brachiosaurus probably breathed from the tip of its nose. Psalm 104:24 is fitting here: God made His works “in wisdom,” and every solution that looks impossible at first turns out to be part of a well-made design.

PICTURE STUDY



Harold W. Menke with the humerus of Brachiosaurus altithorax, Photographer of the Field Columbian Museum expedition, 1900 · Black-and-white photograph · Field Museum of Natural History, Chicago (expedition photograph, western Colorado)
Wikimedia Commons · Public domain

This photograph was taken in the field in 1900 after the humerus was exposed. Menke lies beside it to show its size. Field photographs like this were part of the scientific record: they showed how bones lay before they were moved.

Look closely

- Use Menke as a scale bar. About how many times longer than his forearm is the bone?
- Look at the rock and ground around the bone. What tools or materials can you see?
- Look at the ends of the bone. Which end do you think joined the shoulder?

Talk about it

1. Why did fossil hunters put a person or tool beside a bone before photographing it?
2. What would you need to find besides this bone to know how tall the animal was?

Safety first. Do the water-tube demonstration outdoors or over a sink, use clean tap water only, and keep the tubing on the steps, not underfoot. An adult should steady anyone on a ladder or stair rail.

HANDS-ON: THE BLOOD-COLUMN PROBLEM

Use a clear tube of water to see why lifting a liquid takes pressure, then calculate what a Brachiosaurus heart would need.

You will need

- About 3 m of clear vinyl tubing (hardware store) and a funnel
- A bucket of tap water with a little food coloring
- A tape measure, tape and a calculator

Steps

1. Tape the tubing up a wall or stair rail. Put the funnel in the top and the bottom end in a bucket.
2. Pour colored water in until the tube is full, then lift the bottom end to the funnel's height and lower it slowly. Notice that water always settles to the same level in both ends: lifting a column higher needs more push.
3. Learn the rule: each 1 m of water (or blood, which is about the same) takes about 74 mmHg of pressure to hold up.
4. Calculate the pressure needed for a heart-to-head height of 1 m (an upright person's brain is about 0.3–0.5 m above the heart), 2 m (giraffe) and 8 m (Brachiosaurus with neck raised). Add about 70 mmHg for each to drive blood through the brain.
5. Write a paragraph: Which of the solutions in this stop (big heart, lower neck) seems most reasonable, and why?

Check your work

- I saw that water levels even out unless something pushes.
- I calculated the pressure for all three heights.
- I wrote a reasoned paragraph using my numbers.

FIELD NOTEBOOK

1. Draw Brachiosaurus and a giraffe side by side to the same scale (use 1 cm = 1 m). Mark the heart and head on each and write the head height.
2. Copy the primary source's last sentence and underline the word that shows Matthew's caution.

3. **Narration (the parent keeps this).** Write one paragraph telling how the Berlin “*Brachiosaurus*” became *Giraffatitan*. Use the words *type specimen* and *genus* correctly.

Did you know? The humerus was mistaken at first for a thighbone because no sauropod had been known with arms so long. The Tendaguru workers carried the bones in loads on foot to the port of Lindi, about 60 km away, and from there they went to Berlin by ship. The Berlin skeleton was taken apart and remounted in a more up-to-date pose in 2007, with the neck raised and the tail held off the ground.

Primary source. *W. D. Matthew, Dinosaurs, with Special Reference to the American Museum Collections (1915), on the sauropods. Project Gutenberg eBook #19302.*

At the date of writing this handbook only preliminary accounts have been given of the marvellous finds made near Tendaguru by the expedition from Berlin. From these it appears that in length of neck and fore limb this East African Dinosaur greatly exceeded either *Brontosaurus* or *Diplodocus*. The hinder parts of the skeleton however, were relatively small. The proportions and measurements given tally closely with the American *Brachiosaurus*, a gigantic sauropod whose incomplete remains are preserved in the Field Museum in Chicago and to this genus the Berlin authorities now refer their largest and finest skeleton. If the Berlin specimens are correctly referred to *Brachiosaurus* they indicate an animal somewhat exceeding *Diplodocus* or *Brontosaurus* in total bulk.

Go deeper. Museum für Naturkunde Berlin, the Dinosaur Hall and *Giraffatitan* (museumfuernaturkunde.berlin, English pages). Field Museum (fieldmuseum.org), *Brachiosaurus* pages and the Elmer Riggs expedition. Michael P. Taylor, “A Re-evaluation of *Brachiosaurus altithorax* Riggs 1903,” *Journal of Vertebrate Paleontology* 2009 (free online; advanced). Second video topic: “How birds breathe: air sacs and one-way airflow.”

Goes deeper in. Life Science, high-school Biology, the units on the heart and circulation and on breathing (coming soon); Arithmetic, rates and unit conversions; and Geography (Tanzania and the Colorado Plateau).

For families. Riggs 1903 named *B. altithorax*; Janensch 1914 named *B. brancai*; Paul 1988 proposed *Giraffatitan*; Taylor 2009 separated it fully. Mounted height of the Berlin skeleton is given as about 12–13 m in different sources. Mass and head-height figures are rounded ranges because estimates differ widely. The 74 mmHg per meter figure comes from the density of blood (about that of water; 1 mmHg $\approx$ 13.6 mm of water). Snorkel test: Kermack 1951; nostrils: Witmer, *Science* 2001. The Tendaguru labor was by hired local workers under German colonial rule; the stop states this plainly. The excerpt was checked word for word against Project Gutenberg eBook #19302. No millions-of-years date is given in this stop.

PRACTICE

1. **EASY** What does the name *Brachiosaurus altithorax* mean, and what feature does it describe?
2. **MEDIUM** **Primary source.** Which word in Matthew's last sentence shows he was not certain the Berlin skeleton was *Brachiosaurus*? Was his caution justified?
3. **MEDIUM** How do pneumatic bones help a sauropod?
4. **CHALLENGE** Using 74 mmHg per meter, find the pressure needed just to lift blood 8 m above the heart, and then add 70 mmHg to drive blood through the brain. How many times a human's 120 mmHg is that?
5. **CHALLENGE** Explain why Kermack's 1951 argument ended the "snorkel sauropod" idea. Think about what happens to pressure on the chest as you go deeper in water.
6. **EASY** Where was the Berlin skeleton dug up, and what is it usually called today?

Make it a game • Same Genus?. Gather six pairs of similar things (two kinds of apples, two breeds of dog in photos, a pen and a pencil, and so on). For each pair, players list similarities and differences for one minute, then vote: same "genus" or separate? Each voter must give the single difference or likeness that decided them. Discuss how scientists face the same choice with *Brachiosaurus* and *Giraffatitan*.

Scripture. "O LORD, how manifold are thy works! in wisdom hast thou made them all: the earth is full of thy riches." (Psalm 104:24, KJV)

"Manifold" means many and varied. A creature with hollow bones, bird-like lungs and a heart strong enough to lift blood many meters shows wisdom in the making, not chance.

Practice: answers

1. "Arm lizard" with a "deep chest." It describes the very long upper arm bones (front legs longer than hind legs) and the deep body.
2. "If" ("If the Berlin specimens are correctly referred ..."). Yes: after a full comparison, Taylor (2009) and most researchers since place the Berlin animal in a separate genus, *Giraffatitan*.
3. Air sacs from the lungs hollow out the vertebrae, making the long neck much lighter while thin bony struts keep it strong; the air-sac system may also have made breathing efficient, as in birds.
4. $8 \times 74 = 592$ mmHg; $592 + 70 = 662$ mmHg. $662 \div 120 \approx 5.5$ times a typical human blood pressure.
5. Water pressure increases with depth (about one extra atmosphere every 10 m). An animal standing in water deep enough to cover its body, breathing through a raised nose several meters up, would have water pressing on its chest far harder than its breathing muscles could push against, so it could not fill its lungs. Footprints on land and limb bones built for walking agree that sauropods lived on land.
6. At Tendaguru, in what is now Tanzania (then German East Africa); it is usually called *Giraffatitan brancai*.

1.5 VELOCIRAPTOR, THE REAL SIZE

OBJECTIVES

- Give the real size of Velociraptor and explain how and why popular pictures made it larger.
- Explain what quill knobs are and what they show about Velociraptor's feathers.
- Use the square-cube law to compare the mass of animals of different lengths.

Warm-up. Fill a backpack with books until a bathroom scale reads 15 kg (33 lb), then lift it. That is about what a grown Velociraptor weighed. Now hold your hand flat at the height of your knee. That is about how tall it stood at the hip. Is this the animal you pictured?

Video slot. Video coming. Velociraptor real size and feathers; the "Fighting Dinosaurs" fossil from Mongolia; quill knobs on a Velociraptor arm bone; the Central Asiatic Expeditions at the Flaming Cliffs. Search approved channels (American Museum of Natural History, Natural History Museum London, Smithsonian National Museum of Natural History; for creation-friendly framing, Answers in Genesis or the Institute for Creation Research once vetted); preview first. Movie clips are not needed; parents may decide whether to show any.

KEY TERMS

dromaeosaur

A member of the family of small to medium feathered theropods with a large curved claw on the second toe, including Velociraptor, Deinonychus and Utahraptor; often called "raptors."

sickle claw

The enlarged, curved claw on the second toe of a dromaeosaur, held up off the ground when walking.

quill knobs

A row of small bumps on a bird's forearm bone (ulna) where the large wing feathers are anchored by ligaments.

Central Asiatic Expeditions

The American Museum of Natural History's expeditions to Mongolia and China in the 1920s, led by Roy Chapman Andrews.

square-cube law

When an animal's lengths are all scaled up by a factor, its surface grows by the square of that factor and its volume and mass by the cube.

CORE IDEAS

A skull at the Flaming Cliffs. On August 11, 1923, Peter Kaisen of the American Museum's Central Asiatic Expeditions found a crushed skull and a large curved claw in the red sandstone of the Flaming Cliffs in Mongolia, the same place where the team found famous dinosaur eggs that summer (Trail B, Stop B8). In 1924 Henry Fairfield Osborn named the animal *Velociraptor mongoliensis*, "swift seizer from Mongolia." Since then, Polish, Mongolian, Russian and American teams have found more skeletons in the same sandy layers, which museums call Late Cretaceous.

The real size. A grown Velociraptor was about 1.5 to 2 m (5–6.5 ft) long, but half of that was a stiff, slender tail. It stood about 0.5 m (20 in) at the hip and probably weighed around 15 kg (33 lb), the size of a large turkey or a medium-sized dog. Its skull was long, low and about 25 cm (10 in) long, with an upturned snout and some two dozen saw-edged, back-curved teeth in each side of the upper jaw. The sickle claw on the second toe had a bony core about 6.5 cm (2.5 in) long around its curve, and in life a horny sheath made it longer.

How it got bigger on screen. In 1969 John Ostrom of Yale described *Deinonychus* from Montana, a relative about 3.4 m (11 ft) long and perhaps 70 kg or more. Ostrom showed it was an agile, active hunter much like a bird, and that started a revolution in how dinosaurs were pictured. In 1988 the artist and researcher Gregory Paul proposed that *Deinonychus* be placed in the genus *Velociraptor*. Michael Crichton followed that book for his 1990 novel *Jurassic Park*, and the 1993 film made its "Velociraptors" larger still, taller than a man. Most paleontologists never accepted Paul's lumping, so the film's animals are closer to *Deinonychus* or even *Utahraptor*, a much bigger dromaeosaur described in 1993. The name stuck to the wrong size.

Feathers, proved from a bone. Feather impressions need very fine-grained rock, and the sandstone of Mongolia rarely preserves them. But in 2007 Alan Turner, Peter Makovicky and Mark Norell reported quill knobs on the forearm bone of a Velociraptor: a row of small bumps exactly like those where large wing feathers attach in birds such as turkeys and vultures. Their spacing suggested about fourteen large feathers along the arm. Closely related dromaeosaurs from China are preserved with full feathered wings. So Velociraptor had real, vaned feathers on its arms and very likely a feathered body, though it could not fly. What the feathers were for (display, shading eggs, balance while running or pinning prey) is debated.

The Fighting Dinosaurs. In 1971 a Polish–Mongolian expedition found one of the most remarkable fossils in the world: a Velociraptor and a *Protoceratops*, a sheep-sized horned dinosaur, locked together. The Velociraptor's sickle claw lies at the Protoceratops's throat, and the Protoceratops's beak has closed on the Velociraptor's right arm. Both were buried where they fought, probably by a collapsing sand dune or a sudden sand-laden storm. The fossil is a national treasure of Mongolia. It shows the raptor attacking an animal several times its weight, and it shows the claw in use.

What the claw did. Older books said the sickle claw slashed open prey. In 2006 Phil Manning's team tested a robotic model of a dromaeosaur leg and found that the claw punctured but did not slice well; they argued it was built to hook and grip, perhaps even to climb. In 2011 Denver Fowler and colleagues compared it with hawks and eagles, which pin prey with their feet and hold on while they feed; they proposed that dromaeosaurs did the same, using their feathered arms to keep balance on top of a struggling animal. The Fighting Dinosaurs fit more than one of these ideas.

Hearing both sides. Velociraptor is a lesson in checking a popular claim against the evidence. A film or book can be vivid and still wrong, and a name can travel farther than the facts behind it. Proverbs 18:17 says the first to tell his story "seemeth just" until someone else "searcheth him." A careful student keeps asking: What fossil shows this? How big is the actual specimen? Who measured it?

PICTURE STUDY



Leaping Laelaps, Charles R. Knight, 1897 · Watercolor (painted for the American Museum of Natural History) · American Museum of Natural History, New York
Wikimedia Commons · Public domain

This painting does not show Velociraptor. It shows *Laelaps* (now called *Dryptosaurus*), a large meat-eater from New Jersey, as E. D. Cope pictured it. Knight painted it seventy years before Ostrom's *Deinonychus*, yet he already imagined theropods as fast, leaping animals. Compare his vision with what we know about raptors now.

Look closely

- Look at the leaping animal's feet. Which part of its body is it attacking with?
- Look at the skin. Did Knight give these animals scales, feathers or something else?
- Look at the setting: what is the ground like, and where is the light coming from?

Talk about it

1. Knight's Laelaps leaps feet-first. How does that compare with Fowler's idea of how dromaeosaurs used their claws?
2. Which parts of this 1897 painting have held up, and which would a painter change today?

HANDS-ON: REAL RAPTOR, FILM RAPTOR: A FLOOR OUTLINE

Mark the real Velociraptor and its larger cousins on the floor, then calculate their masses with the square-cube law.

You will need

- Painter's tape or chalk
- A tape measure
- A bathroom scale and a backpack of books
- A calculator

Steps

1. Tape a 1.8 m line on the floor for Velociraptor's length (snout to tail tip). Mark the hip 0.9 m from the snout end and stand a ruler at the hip to show 0.5 m.
2. Tape a 3.4 m line beside it for Deinonychus, and if you have room, a 6 m line for Utahraptor.
3. Fill the backpack to 15 kg and have each person lift it: Velociraptor's mass.
4. Use the square-cube law: mass grows by the cube of the length ratio. Calculate what Deinonychus would weigh if it were shaped exactly like a 1.8 m, 15 kg Velociraptor. Compare your answer with published estimates of 70 kg or more.
5. Photograph your outlines with a family member lying beside the Velociraptor line for scale.

Check your work

- My outlines are the right lengths and the hip height is marked.
- I lifted 15 kg and can describe how heavy it felt.
- I calculated a scaled mass and explained why it might differ from the published estimate.

FIELD NOTEBOOK

1. Draw Velociraptor at true scale beside a person (use 1 cm = 10 cm). Give it feathered arms with long quill feathers, a feathered body and the sickle claw held up. Label the length, hip height and mass.
2. Draw the ulna with its row of quill knobs, and beside it a turkey's wing bone.
3. **Narration (the parent keeps this).** Write one paragraph explaining how the name Velociraptor came to be attached to a much larger animal in the public mind, and what

evidence shows its real size and covering.

Did you know? Osborn's 1924 paper named three dinosaurs at once from the expedition: Velociraptor, Oviraptor and Saurornithoides. The Fighting Dinosaurs fossil belongs to Mongolia and is kept in its capital, Ulaanbaatar. The bones of Velociraptor's tail were stiffened by long bony rods, which made the tail a balancing pole, like a tightrope walker's.

Go deeper. American Museum of Natural History, Velociraptor and the Central Asiatic Expeditions pages (amnh.org). Mark Norell, Eugene Gaffney and Lowell Dingus, *Discovering Dinosaurs* (University of California Press), and Roy Chapman Andrews, *On the Trail of Ancient Man* (1926), his own account of the expeditions (check your library). Second video topic: "Dromaeosaurs and modern hawks: how raptors use their feet."

Goes deeper in. Life Science, high-school Biology, the units on birds and on the scientific method (coming soon); Arithmetic, scale and the square-cube law; and Geography (Mongolia and the Gobi).

For families. Discovery date (August 11, 1923, Peter Kaisen) and Osborn's 1924 naming are from the AMNH record. Size: about 1.5–2 m long and roughly 15 kg (Turner et al. 2007 and standard references). Quill knobs: Turner, Makovicky and Norell, *Science* 2007. Claw studies: Manning et al. 2006; Fowler et al., *PLoS ONE* 2011. Fighting Dinosaurs: found 1971 at Tugrikin Shireh. The *Jurassic Park* film is rated PG-13 and contains frightening scenes; it is mentioned here only for its effect on the name, and no viewing is required. Whether Velociraptor descends from flying ancestors or birds descend from animals like it is debated even among mainstream scientists; the stop sticks to what the bones show. No public-domain primary source on Velociraptor could be checked word for word, so there is no Primary source box; the 1924 paper is free at the AMNH digital library for older students who want it.

PRACTICE

1. **EASY** Give Velociraptor's length, hip height and mass.
2. **MEDIUM** Why were the "Velociraptors" of the 1990 novel and 1993 film so much bigger than the real animal?
3. **MEDIUM** What are quill knobs, and what do they prove about Velociraptor?
4. **CHALLENGE** A Velociraptor is 1.8 m long and weighs 15 kg. If Deinonychus (3.4 m) had exactly the same shape, what would it weigh? Show your work.
5. **CHALLENGE** The Fighting Dinosaurs fossil is sometimes used to say "Velociraptor hunted Protoceratops." List what the fossil directly shows, and then one interpretation that goes beyond it.
6. **EASY** Who found the first Velociraptor skull, where, and in what year? Who named it?

Make it a game • Source Check. A parent reads ten short claims about Velociraptor, some true and some taken from popular myths ("It was as tall as a man," "It had

feathers,” “It could open doors,” “It weighed about as much as a turkey,” and so on). For each, players must answer “true,” “false” or “no evidence,” and name the fossil or study that decides it. A point for each right answer with a reason.

Scripture. “He that is first in his own cause seemeth just; but his neighbour cometh and searcheth him.” (Proverbs 18:17, KJV)

The first story we hear often sounds right until someone tests it. A careful thinker checks claims, even exciting ones, against the evidence.

Practice: answers

1. About 1.5–2 m long (half of it tail), about 0.5 m at the hip, and about 15 kg.
2. Crichton followed Gregory Paul’s 1988 proposal to put the larger *Deinonychus* into the genus *Velociraptor*, and the film enlarged them further. Most paleontologists did not accept that lumping, so the name went with the wrong size.
3. Bumps on the forearm bone where large wing feathers are anchored in birds. Their presence on a *Velociraptor* ulna shows it had large vaned feathers on its arms, even though no feather impressions were preserved.
4. Length ratio = $3.4 \div 1.8 \approx 1.89$. Mass ratio = $1.89^3 \approx 6.7$. $15 \text{ kg} \times 6.7 \approx 100 \text{ kg}$. Published estimates (around 70 kg or more) are in the same range; differences come from body shape and from how mass is estimated.
5. Directly shows: a *Velociraptor* and a *Protoceratops* buried together, the raptor’s sickle claw at the other’s throat area, and the *Protoceratops*’s beak clamped on the raptor’s right arm. Beyond the fossil: that *Velociraptor* regularly hunted *Protoceratops*, or that it started the fight, or how the claw was used in general. One fossil shows one event.
6. Peter Kaisen of the American Museum’s Central Asiatic Expeditions, at the Flaming Cliffs in Mongolia, in 1923. Henry Fairfield Osborn named it in 1924.

1.6 ANKYLOSAURUS

OBJECTIVES

- Describe the armor and tail club of Ankylosaurus and explain how they were built.
- Weigh the evidence for whether the tail club was used against predators, rivals or both.
- Explain why a well-known dinosaur can be reconstructed from only a few incomplete specimens, and what that requires of honest scientists and artists.

Warm-up. Lay a few overlapping coins or bottle caps on the back of your hand and try to bend your wrist. Now glue or tape them to a stiff card and try again. Small pieces of armor let you move; fused armor does not. Ankylosaurus had both kinds.

Video slot. Video coming. Ankylosaurus armor and tail club; the nodosaur Borealopelta at the Royal Tyrrell Museum; Zuul crurivastator at the Royal Ontario Museum. Search approved channels (Royal Tyrrell Museum, Royal Ontario Museum, American Museum of Natural History, Natural History Museum London; for creation-friendly framing, Answers in Genesis or the Institute for Creation Research once vetted); preview first.

KEY TERMS

ankylosaur

A member of the armored, four-legged plant-eating dinosaurs. Ankylosaurids had tail clubs; nodosaurids had shoulder spikes and no club.

osteoderm

A bone formed inside the skin. An ankylosaur's armor is made of hundreds of osteoderms of different sizes.

tail club

A heavy knob of fused osteoderms at the end of an ankylosaurid's tail, swung by a stiffened "handle" of interlocking tail vertebrae.

ossified tendon

A tendon that has turned to bone, stiffening part of the skeleton, as in an ankylosaur's tail handle.

melanin

The pigment that colors skin, hair and feathers. Traces of it in fossils can show an animal's color pattern.

reconstruction

A scientist's or artist's best picture of a whole animal, built from the bones that survive plus comparison with relatives.

CORE IDEAS

A fused lizard with a big belly. In 1906 Barnum Brown found part of a skeleton in the Hell Creek rocks of Montana (Trail B tells his story) and in 1908 named it *Ankylosaurus magniventris*: “fused lizard” with a “great belly.” In 1910 his crew in Alberta found a second specimen with the first known Ankylosaurus tail club. After more than a century, Ankylosaurus is still known from only a handful of specimens: skulls, a tail club, scattered armor and parts of the body. Every full drawing of it is a reconstruction based on these bones and on better-known relatives such as *Euoplocephalus*.

The biggest tank. Ankylosaurus was the largest ankylosaur known. A 2017 study by Victoria Arbour and Jordan Mallon estimated it at about 6 to 8 m (20–26 ft) long and roughly 5 to 8 metric tons. The largest skull is about 64 cm long and wider than it is long, about 75 cm across, with triangular horns at the back corners. The body was very broad and low, carried on short, strong legs. The skull itself is covered in fused bony tiles, and the nasal passages loop inside it in a way that may have warmed and moistened air or helped make sound.

How the armor was built. The back was covered by osteoderms: large oval plates with low keels in rows across the back, small round bony pebbles filling the spaces between them, and bony rings or half-rings around the neck. Each osteoderm grew inside the skin, so the armor could flex with the body. Thin sections show that many osteoderms had a dense outer layer over a lighter interior, crossed by fibers of collagen like the fibers in reinforced material, so they were tough without being as heavy as solid bone. In life they were covered by horny sheaths, like the scales of a crocodile or turtle shell.

The club. The tail club was made of two large osteoderms on the sides and smaller ones at the tip, fused into a knob that in Ankylosaurus was nearly 60 cm (2 ft) wide in the one known club. The last part of the tail was a stiff “handle”: the vertebrae interlocked in long V-shapes and were wrapped in bony tendons, so the base of the tail did the swinging and the end worked like a mace. In 2009 Victoria Arbour modeled clubs of different sizes and estimated that large ones could strike hard enough to break bone, while small ones probably could not.

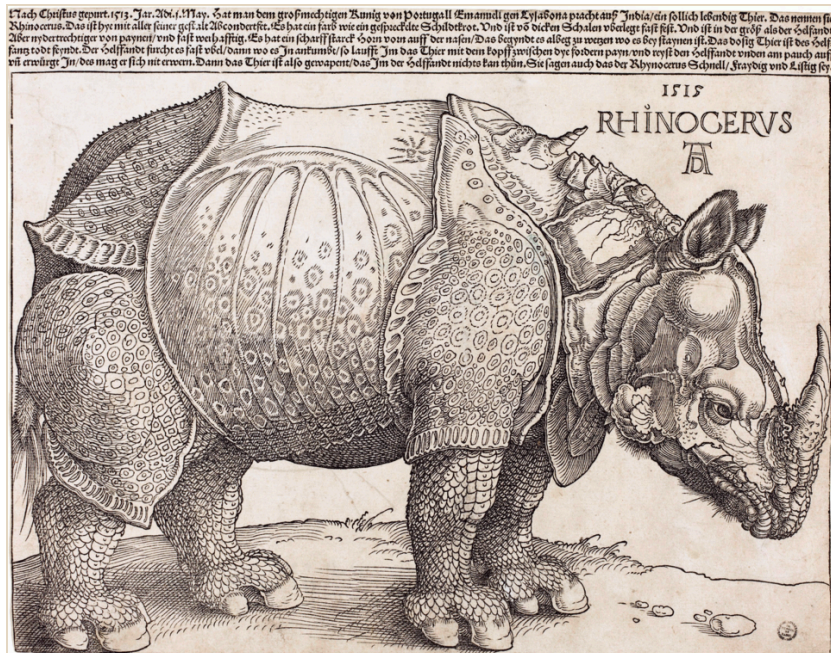
Who was it hitting? A club seems built for fighting off a tyrannosaur. But tail clubs swing at about leg height, and in 2017 a beautifully preserved ankylosaur from Montana, nicknamed *Zuul crurivastator* (“shin destroyer”), showed something unexpected. In 2022 Arbour and colleagues reported that several of the big spikes along its sides were broken and had healed, in the places a rival ankylosaur’s swinging club would strike. They concluded that ankylosaurs clubbed each other, perhaps over territory or mates, the way deer use antlers. Many researchers think the club served both purposes. The evidence for rival fights is direct; for predator defense it is likely but indirect.

A nodosaur with its skin on. In 2011 a heavy-equipment operator named Shawn Funk struck stone in an oil-sand mine in northern Alberta. It turned out to be an armored dinosaur, a nodosaur called *Borealopelta*, preserved in three dimensions with its armor still in place and the horny sheaths on its spikes. Chemical traces of the pigment melanin showed a

reddish-brown back and lighter belly, a pattern called countershading, which suggests that even a five-meter armored animal needed to hide from predators. Its stomach contents were mostly ferns. It lay on its back in rock that holds sea creatures, so it was carried out to sea and buried; young-earth Christians read such burials as part of the Flood, and others read them as a carcass washed off a coast.

Building from little. Ankylosaurus shows both the power and the limits of reconstruction. With a few skulls and a club, scientists can say a great deal by comparing it carefully with its relatives. But the exact shape of the body, the arrangement of every plate and the color are inferences, and good books say so. A Christian student can hold reconstructions with an open hand: confident where the bones are clear, humble where they are not, and grateful for a Creator whose works are worth this kind of care (Psalm 18:2 calls Him a “fortress” and a “buckler,” a word picture any ankylosaur might understand).

PICTURE STUDY



The Rhinoceros, Albrecht Dürer, 1515 · Woodcut · Prints in many collections, including the British Museum, London, and the National Gallery of Art, Washington
Wikimedia Commons · Public domain

In 1515 an Indian rhinoceros was shipped to Lisbon, the first seen alive in Europe in more than a thousand years. Dürer, in Germany, never saw it. He worked from a letter and a sketch sent by someone who had, and made this famous print. For nearly three centuries most Europeans pictured rhinos this way. It is a perfect warning for anyone reconstructing an armored animal they cannot see.

Look closely

- Find the parts that look like metal armor: plates, rivets, seams. A real rhino has thick folds of skin there.

- Find the small twisted horn on the back of the neck. Real rhinos do not have it.
- Look at what Dürer got right: the single horn on the nose, the heavy body, the general shape.

Talk about it

1. Dürer was a careful artist working with incomplete information. Which of his mistakes came from the description he was given, and which from his own guesses?
2. What parts of an Ankylosaurus reconstruction are like Dürer's guesses, and how can a scientist avoid adding a "horn on the back"?

HANDS-ON: BUILD AN ARMOR PANEL AND TEST THE FLEX

Make two armor panels, one with separate osteoderms set in a flexible skin and one fused like a club, and test which protects and which moves.

You will need

- Air-dry or oven-bake clay (or bottle caps and buttons)
- Two pieces of felt or an old T-shirt, each about 20 × 20 cm
- Craft glue
- A small rubber ball and a ruler

Steps

1. Shape about twelve oval osteoderms (3–4 cm, with a low ridge) and twenty small round "pebbles" from clay. Let them dry or bake them with an adult.
2. Glue them in rows on the first piece of felt: large ovals in rows across, pebbles between. Leave tiny gaps.
3. On the second piece, glue the same pieces edge to edge so they form one stiff plate.
4. Test flexibility: wrap each panel around your forearm. Which bends? Test protection: drop the ball from 50 cm onto each and see whether it strikes felt or armor.
5. Write a short report: why did God's design for Ankylosaurus use flexible armor on the back and fused armor in the club?

Check your work

- My flexible panel has large osteoderms and small pebbles in rows.
- I tested both panels for flexibility and protection.
- I explained the difference between the back armor and the club.

FIELD NOTEBOOK

1. Draw an Ankylosaurus from above. Use solid lines for parts known from fossils of Ankylosaurus itself (skull, club, some armor) and dotted lines for parts reconstructed from relatives. Add a scale bar.
2. Draw the tail club from above and the stiff handle of interlocking vertebrae.

3. **Narration (the parent keeps this).** Write one paragraph answering: What was the Ankylosaurus tail club for? Use the Zuul evidence and at least one other fact from this stop.

Did you know? Even ankylosaur eyelids could be armored: some had a bony plate in the upper eyelid. Zuul's skeleton came out of the ground with its tail club and much of its skin and armor still in place, one of the most complete ankylosaurs ever found. Borealopelta's species name, *markmittelli*, honors Mark Mitchell, the Royal Tyrrell Museum technician who spent more than 7,000 hours preparing it.

Primary source. *Charles H. Sternberg, Hunting Dinosaurs in the Bad Lands of the Red Deer River, Alberta, Canada (1917), Preface, summarizing what the Sternberg family had found for the Geological Survey of Canada. Project Gutenberg eBook #77814.*

We have found many new genera of the duck-billed dinosaurs, those wonderful swimmers of the old lakes and bayous of the Cretaceous period, three new genera of horned dinosaurs, learning more about them than was ever known before, finding that instead of being covered with bony plates as has been supposed they had thin skins with small scales like mosaic-work; then, stranger still, the huge plated dinosaurs completely enveloped in an armor of bony plates, some large, and others small like chained armor, allowing motion to the body.

Go deeper. Royal Tyrrell Museum, "Borealopelta" and the nodosaur pages (tyrrellmuseum.com). Royal Ontario Museum, "Zuul" (rom.on.ca). Victoria Arbour and Jordan Mallon, "Unusual cranial and postcranial anatomy in the archetypal ankylosaur *Ankylosaurus magniventris*," *FACETS* 2017 (free online; advanced). Second video topic: "How the Borealopelta nodosaur was prepared."

Goes deeper in. Life Science, high-school Biology, the units on skin, bone and tissues and on animal defenses (coming soon); and Art, the unit on drawing from life versus drawing from description.

For families. Facts: Brown 1908; Arbour and Mallon 2017 (size, skull, club width); Arbour 2009 (club impact modeling); Arbour and Evans 2017 (Zuul); Arbour et al., *Biology Letters* 2022 (flank injuries); Brown et al., *Current Biology* 2017 (Borealopelta color) and 2020 (gut contents). The Sternberg excerpt was checked word for word against Project Gutenberg eBook #77814; note that his picture of duck-bills as swimmers in lakes is no longer held, which the practice uses. The Dürer woodcut is public domain; check that the Commons copy is the 1515 woodcut, not a later copy. The Borealopelta burial sentence names the young-earth and mainstream readings briefly and fairly; no date is given.

PRACTICE

1. **EASY** What does *Ankylosaurus magniventris* mean?

2. **MEDIUM** Describe how the tail club and its handle were built.
3. **MEDIUM** What does the Zuul specimen show about how ankylosaurs used their clubs?
4. **CHALLENGE** **Primary source.** Sternberg describes the armor as “some large, and others small like chained armor, allowing motion to the body.” Match this to the modern description of osteoderms in this stop. Then find one claim in the same sentence that scientists no longer accept, and say what replaced it.
5. **CHALLENGE** A paleontologist has an Ankylosaurus skull 64 cm long and a club nearly 60 cm wide, but no complete body. Explain how she could estimate the animal’s total length, and name one assumption that could make the estimate wrong.
6. **EASY** What is countershading, and which armored dinosaur shows it?

Make it a game · Dürer’s Challenge. One player looks at a picture of an unusual animal (a pangolin, armadillo or horned lizard) that the others cannot see, and writes a description of no more than 40 words. The others draw the animal from the description alone. Reveal the picture and compare. Which details came through, and which did the artists invent? Switch roles.

Scripture. “The LORD is my rock, and my fortress, and my deliverer; my God, my strength, in whom I will trust; my buckler, and the horn of my salvation, and my high tower.” (Psalm 18:2, KJV)

A buckler is a small shield. David, who knew battle well, piles up pictures of protection: rock, fortress, shield, horn and tower. An armored animal is protected by bone; the believer is protected by the faithful God.

Practice: answers

1. “Fused lizard” with a “great belly.”
2. The club was a knob of large and small osteoderms fused together. The handle was the end of the tail, where the vertebrae interlocked in long V-shapes and were stiffened by bony (ossified) tendons, so the tail swung from its base like a mace.
3. Several flank spikes were broken and healed in places a rival’s club would hit, so ankylosaurs probably clubbed each other (in contests over territory or mates), not only predators.
4. His “large” plates are the big keeled oval osteoderms; the “small like chained armor” pieces are the little round pebbles between them, set in skin so the body could bend, just as he says. The rejected claim is that duck-billed dinosaurs were “wonderful swimmers of the old lakes and bayous.” Their strong legs, hoof-like toes and trackways now show they lived and fed mainly on land, though they may have waded or swum at times (their skin does have small scales, as he says).
5. Measure the same skull and club in a better-known relative with a complete skeleton (such as *Euoplocephalus*), find the ratio of skull length to body length, and scale up: if the relative’s body is about 10–12 times its skull length, *Ankylosaurus* would be about 6.4–7.7 m. Assumption: that *Ankylosaurus* had the same body proportions as its relative. If it had a relatively larger head (and the skull is unusual), the estimate would be too long.

6. A darker back and lighter belly, which helps an animal blend in. The nodosaur *Borealopelta* from Alberta shows it in traces of the pigment melanin.

1.7 SPINOSAURUS

OBJECTIVES

- Tell the history of Spinosaurus: Stromer’s discovery, the loss of the original bones in 1944 and the new finds in Morocco.
- Lay out the current debate over whether Spinosaurus swam, dove or waded, and the evidence each side uses.
- Test buoyancy with a model and explain how bone density bears on the debate.

Warm-up. Stand against a wall and have someone mark 1.65 m (5 ft 5 in). That is the height of the tallest spine Stromer measured from the back of one Spinosaurus, a single bone. Write down two things you think such a tall “sail” might have been for.

Video slot. Video coming. Spinosaurus: Ernst Stromer’s lost fossils, Nizar Ibrahim’s Moroccan finds, the tail discovery and the swimming-or-wading debate. Search approved channels (National Geographic, Natural History Museum London, Field Museum, University of Chicago Fossil Lab; for creation-friendly framing, Answers in Genesis or the Institute for Creation Research once vetted); preview first.

KEY TERMS

spinosaurid

A member of the family of large theropods with long, narrow, crocodile-like snouts and cone-shaped teeth, such as Spinosaurus and Baryonyx.

neural spine

The upward projection on top of each vertebra. In Spinosaurus they were very tall and supported a sail.

neotype

A new specimen chosen to carry a species name when the original type specimen has been lost or destroyed.

bone density

How solid a bone is. Dense, heavy bones help animals such as penguins and hippos stay under water.

buoyancy

The upward push of water on an object. An object floats if it weighs less than the water it pushes aside.

Kem Kem beds

Red sandstone layers along the Morocco–Algeria border, full of fish, crocodile and dinosaur fossils, especially teeth.

CORE IDEAS

A sail from the desert. In 1912 the fossil collector Richard Markgraf dug bones from the rocks of the Bahariya Oasis in the Egyptian desert and sent them to the German paleontologist Ernst Stromer in Munich. Among them was part of a long lower jaw with straight, cone-shaped teeth, and vertebrae with spines up to 1.65 m tall. In 1915 Stromer named the animal *Spinosaurus aegyptiacus*, “Egyptian spine lizard.” He drew and photographed the bones carefully and published them with detailed plates.

Lost in the war. Stromer opposed the National Socialist government, and he urged the director of the Bavarian state collection to move the fossils to safety. The director refused. On the night of April 24–25, 1944, Allied bombers struck Munich and the museum burned; the *Spinosaurus* bones were destroyed. Stromer, who lost two of his three sons in the war, lived until 1952. For sixty years the animal was known almost only from his drawings and descriptions, and every picture of it was largely guesswork.

The new *Spinosaurus*. In 2008 the young paleontologist Nizar Ibrahim was shown some unusual bones by a fossil digger in the Moroccan town of Erfoud. Years later, after a long search, he found the man again and was led to the place in the Kem Kem beds where they had been dug. In 2014 Ibrahim and colleagues named that partial skeleton the neotype. It had short hind legs, dense limb bones, flat-bottomed foot claws and nostrils set far back on the snout. In 2020 the same team reported a tail with tall, thin spines and long chevron bones forming a deep, flexible fin, and called *Spinosaurus* a dinosaur that swam after its prey with its tail like a crocodile or newt.

The debate. Not everyone agreed. In 2021 David Hone and Thomas Holtz argued that the tail fin was too weak to power real swimming and that *Spinosaurus* waded in shallows like a giant heron. In 2022 Matteo Fabbri and colleagues measured bone density in hundreds of animals and found *Spinosaurus* and its relative *Baryonyx* had dense bones like penguins and hippos, which dive, and argued that *Spinosaurus* hunted under water. Later that year Paul Sereno’s team built a digital model and concluded that *Spinosaurus* would float tipped over in deep water because of the sail, could not dive easily, and walked on two legs as a wading “semi-aquatic” hunter. Others questioned the density sample. All sides agree it lived by water and ate fish; how it caught them is not settled.

What it ate. The long snout and cone teeth are good for gripping slippery prey, and the Kem Kem rocks are full of large fish such as the sawfish-like *Onchopristis* and coelacanths several meters long. Direct evidence comes from *Spinosaurus*’s English cousin *Baryonyx*: its skeleton, found in 1983, held fish scales and the bones of a young plant-eating dinosaur in its stomach area. So spinosaurids ate fish and also took land animals when they could.

The numbers, honestly. *Spinosaurus* was probably the longest meat-eating dinosaur, about 14 m (46 ft) by many estimates, longer than *T. rex*. Mass estimates range widely, from about 7 to more than 15 metric tons, because the body shape is disputed and much of the skeleton is still missing. The sail’s purpose is also debated: display to rivals and mates is the most common view, while some have suggested heat control or a fatty hump. Add the problems of

the Moroccan fossil trade, where bones are sometimes bought rather than dug by scientists and occasionally pieced together from more than one animal, and Spinosaurus becomes a lesson in patience. Scientists are still collecting, measuring and arguing in print.

Seeing in part. Spinosaurus has been reinvented three times in a century: a sail-backed giant from Stromer's plates, a long-legged land predator in early reconstructions, and the low, finned, water-loving hunter of today's debate. Paul wrote that "now we see through a glass, darkly" (1 Corinthians 13:12). That verse is about knowing God, but it describes every honest science well: our knowledge of creation is real but partial, and humility about the part we do not yet see is a virtue, not a weakness.

PICTURE STUDY

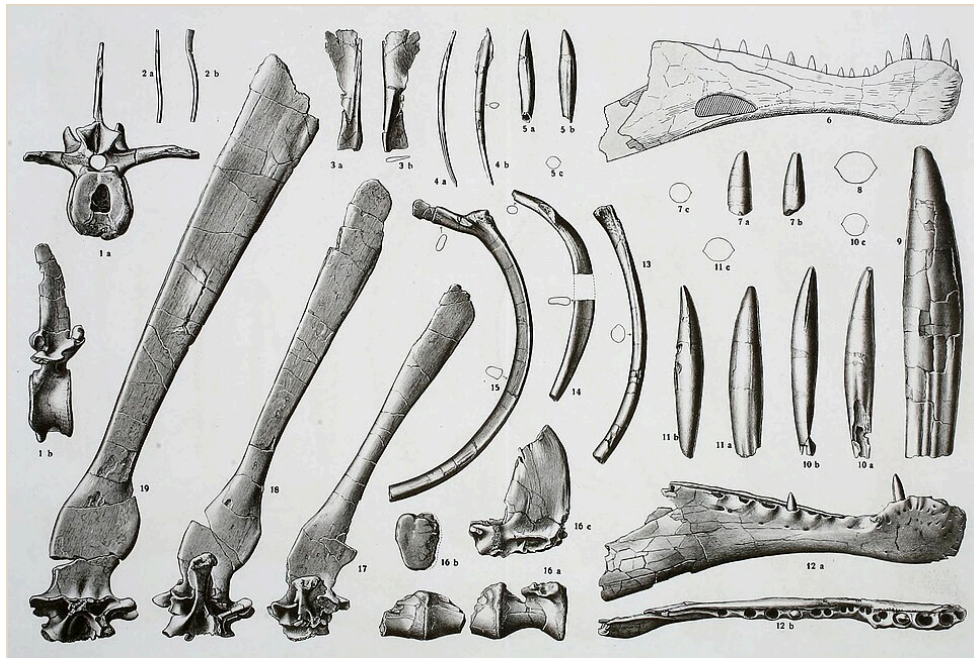


Plate of the Spinosaurus aegyptiacus type specimen, from Stromer's 1915 description, Ernst Stromer (plates prepared for his monograph), 1915 · Printed scientific plate · From Stromer's paper in the Abhandlungen der Königlich Bayerischen Akademie der Wissenschaften (Munich, 1915); the bones themselves were destroyed in 1944

Wikimedia Commons · Public domain

This plate is one of the few records left of the original Spinosaurus. Stromer could not have known that his careful drawings would outlast the bones. Scientists today still compare new finds with these pictures.

Look closely

- Find the tallest spine. Using the 1.65 m figure, estimate the scale of the plate.
- Find the jaw. What shape are the tooth sockets?
- Look for broken edges and missing parts. How did Stromer show what was really there?

Talk about it

1. Why are careful drawings and photographs part of good science, even when the fossil itself is safe in a museum?
2. If you could only save one bone from this plate, which would tell scientists the most, and why?

Safety first. Do the buoyancy test in a bathtub, sink or large tub on a towel. Wipe up spills, and never leave small children alone with a tub of water.

HANDS-ON: SINK, FLOAT OR TIP? A BUOYANCY MODEL

Fabbri argued that heavy bones helped Spinosaurus dive; Sereno argued that the sail made it tip over. Test both ideas with a simple model.

You will need

- A clean 1.5 L plastic bottle with cap (the body and lungs)
- Metal washers or coins (dense bone) and a kitchen scale
- A strip of stiff card or a plastic lid, about 10 × 20 cm (the sail)
- Strong tape and a bathtub or large tub of water

Steps

1. Weigh the empty bottle. Predict how much mass you must add for it to hover in the water, neither sinking nor floating (1 L of water has a mass of 1 kg).
2. Tape washers along the underside of the bottle a few at a time until it just hovers. Record the total mass. Compare with your prediction.
3. Now remove a few washers so it floats, and tape the card “sail” upright along the top. Push it gently under and release. Does it float upright, roll to one side or sink?
4. Move the washers higher or lower on the bottle and test again. Which arrangement is most stable?
5. Write three sentences: what dense “bones” did, what the sail did, and which scientist’s argument your model supports more. Name one way your model is unlike a real animal.

Check your work

- I predicted and then measured the mass needed to hover.
- I tested the model with and without the sail.
- I explained what my model can and cannot show.

FIELD NOTEBOOK

1. Draw three Spinosaurus silhouettes in a row: as Stromer’s bones suggested (1915), as a long-legged land hunter (1990s pictures), and as the low, short-legged, finned animal of the 2014–2020 finds. Write the year under each.
2. Make a table of the swim / dive / wade debate with the scientist, the year and the main evidence for each view.

3. **Narration (the parent keeps this).** Write one paragraph telling the story of the Spinosaurus bones from Bahariya to Munich to their loss in 1944, and why that loss still matters to scientists today.

Did you know? Stromer also named other giants from Bahariya, including the meat-eater *Carcharodontosaurus* and the sauropod *Aegyptosaurus*; all were lost in the same raid. In 2000 an American team returned to Bahariya, guided in part by Stromer's notes, and found a new giant sauropod, named *Paralititan* in 2001. Spinosaurus teeth are among the most common fossils sold in rock shops, because they turn up by the thousands in the Kem Kem beds.

 **What the sign says / What we observe / How Christians read it.**  **What the sign says:** "Spinosaurus lived about 100 to 95 million years ago in a land of great rivers in North Africa." **What we observe:** the Kem Kem beds are sandstones laid down by flowing water, packed with fish, crocodile, pterosaur and dinosaur teeth and bones, often broken and mixed together. The date comes from comparing these layers with others elsewhere and from radioactive dating of rocks in those other places, which assumes steady decay rates, known starting amounts and closed systems. **How Christians read it:** many young-earth Christians read such water-laid layers packed with mixed animals as deposits of the Flood, laid down rapidly, and treat "Cretaceous" as a name for rock layers. Other Christians accept the long ages. All can agree on the observation: abundant water-dwelling and land-dwelling animals buried together in river sands.

Go deeper. William Nothdurft with Josh Smith, *The Lost Dinosaurs of Egypt* (Random House, 2002), the story of Stromer and the 2000s return to Bahariya. National Geographic, "Spinosaurus" articles (2014 and 2020). University of Chicago Fossil Lab, Paul Sereno's Spinosaurus pages (fossilab.uchicago.edu). Second video topic: "How bone density shows whether an animal dives."

Goes deeper in. Earth Science, the units on water and rock layers and on the Flood (coming soon); Life Science, high-school Biology, the unit on adaptations to water; and History, the Second World War (the loss of museum collections).

For families. Facts: Stromer 1915; destruction in the Munich raid of April 24–25, 1944; Ibrahim et al., *Science* 2014 (neotype) and *Nature* 2020 (tail); Hone and Holtz, *Palaeontologia Electronica* 2021; Fabbri et al., *Nature* 2022; Sereno et al., *eLife* 2022. Length and mass figures are given as ranges because published estimates differ widely. Some researchers have questioned whether the 2014 neotype is a single individual; the stop mentions the problem of the fossil trade without accusing anyone. The war is mentioned plainly without detail. No public-domain English primary source could be checked word for word (Stromer wrote in German), so there is no Primary source box. 1 Corinthians 13:12 is applied by analogy; its first meaning is our present, partial knowledge of God.

PRACTICE

1. **EASY** Who named Spinosaurus, from where, and in what year? What happened to the original bones?
2. **EASY** What is a neotype, and why did Spinosaurus need one?
3. **MEDIUM** Give the main argument of each: Ibrahim (2020), Hone and Holtz (2021), Fabbri (2022), Sereno (2022).
4. **CHALLENGE** A sealed 1.5 L bottle has a mass of 0.05 kg. How much mass must you add for it to hover in fresh water (1 L = 1 kg)? If each washer is 20 g, how many washers is that?
5. **CHALLENGE** Explain why bone density alone cannot settle whether Spinosaurus dove. Name two other things a scientist would want to know.
6. **MEDIUM** What evidence from a close relative shows that spinosaurids ate fish, and what else did that relative eat?

Make it a game · Rebuild from the Plates. A parent hides a picture of a whole animal (a crocodile, heron or newt) and shows the players only three “bones”: small cropped parts of the picture. Each player sketches the whole animal from those three parts, then the next part is revealed and they may revise. The player closest after three reveals wins. Talk about how Spinosaurus has been redrawn as new bones appeared.

Scripture. “For now we see through a glass, darkly; but then face to face: now I know in part; but then shall I know even as also I am known.” (1 Corinthians 13:12, KJV)

Paul is writing about how we know God now and how we shall know Him fully. His words also fit the study of creation: we know in part, we keep learning, and we can be both confident and humble.

Practice: answers

1. Ernst Stromer, from the Bahariya Oasis in Egypt, in 1915. They were destroyed when Munich was bombed on the night of April 24–25, 1944.
2. A new specimen chosen to carry a species name when the original type is lost. The original Spinosaurus bones were destroyed in 1944, so a Moroccan skeleton was named the neotype in 2014.
3. Ibrahim: the finned tail shows it swam after prey. Hone and Holtz: the tail was too weak for real swimming; it waded like a heron. Fabbri: dense bones like penguins and hippos show it hunted under water. Sereno: a digital model floats tipped over and cannot dive easily; it was a two-legged wader.
4. It displaces 1.5 kg of water, so the total mass must be 1.5 kg: $1.5 - 0.05 = 1.45$ kg to add. $1,450 \text{ g} \div 20 \text{ g} \approx 72.5$, so about 72–73 washers (the bottle’s own plastic and the tape also take up a little volume, so the real number may differ slightly).
5. Dense bones help an animal stay under water, but some waders and shallow-water animals also have dense bones, and density can depend on the bones sampled and the animal’s age. A scientist would want (any two): the shape and strength of the tail, the body’s balance and

center of mass in water (the sail), the shape of the feet and limbs, the position of the nostrils and eyes, and direct evidence of diet or behavior.

6. Baryonyx, found in England in 1983, had fish scales in its stomach area, and also the bones of a young plant-eating dinosaur.

1.8 PARASAUROLOPHUS AND ITS CREST

OBJECTIVES

- Describe the hollow crest of Parasaurolophus and trace the air passage through it.
- Evaluate the many hypotheses proposed for the crest and explain why the sound-and-display idea is favored.
- Build a resonating tube and connect tube length to pitch.

Warm-up. Blow across the top of an empty bottle until it hums. Now add a little water and blow again. Did the note go up or down? Parasaurolophus carried a long hollow tube on its head, and that simple experiment is a clue to what it was for.

Video slot. Video coming. Parasaurolophus crest and the computer-simulated sound from Sandia National Laboratories and the New Mexico Museum of Natural History; the baby Parasaurolophus “Joe” from Utah. Search approved channels (Royal Ontario Museum, Raymond M. Alf Museum of Paleontology, Field Museum, Smithsonian National Museum of Natural History; for creation-friendly framing, Answers in Genesis or the Institute for Creation Research once vetted); preview first.

KEY TERMS

hadrosaur

A member of the “duck-billed” dinosaurs: large plant-eaters with a broad, toothless beak in front and hundreds of grinding teeth behind.

lambeosaurine

The group of hadrosaurs with hollow head crests, such as Parasaurolophus, Corythosaurus and Lambeosaurus.

premaxilla

The front bone of the upper jaw. In Parasaurolophus it and the nasal bone stretch back to form most of the crest.

resonance

The way a hollow space strengthens certain notes. Longer tubes resonate at lower notes.

frequency

How many sound vibrations happen each second, measured in hertz (Hz). Low frequencies are deep sounds.

CT scan

A series of X-ray images that a computer stacks into a 3-D picture of the inside of an object, such as a fossil skull.

CORE IDEAS

Found on the Red Deer River. In 1920 a field party from the University of Toronto dug a skull and much of a skeleton from the badlands near Sand Creek on the Red Deer River in Alberta. In 1922 William Parks named it *Parasaurolophus walkeri*, “near crested lizard,” because it seemed related to the crested *Saurolophus*, and honored Sir Byron Edmund Walker, chairman of the Royal Ontario Museum’s trustees. *Parasaurolophus* was a large hadrosaur, perhaps 9 to 10 m (30–33 ft) long and around 2.5 metric tons, with a duck-like beak and dental batteries of hundreds of teeth for grinding plants. It is rarer than many of its relatives: only a handful of good skulls are known, from Alberta, New Mexico and Utah.

A tube, not a horn. The crest is a long, curved tube sweeping back from the top of the head, about a meter long in the Alberta skull. It is not solid. The premaxilla and nasal bones grow far back and wrap around air passages. Air entering the nostrils traveled up through the crest to its tip, turned, and came back down to the throat, so the passage was several times longer than the crest itself. In some species the tubes divide and loop. A small notch on the back of the neck in the Alberta skeleton once suggested a ligament or skin flap joining the crest to the neck.

A century of guesses. Scientists proposed at least a dozen uses. A snorkel? There is no hole at the tip, so it could not draw air from above water. An air tank for diving? The volume was far too small. A weapon? The bone is thin and hollow. A branch deflector for pushing through forest, a salt gland, an organ that enlarged the sense of smell: each was tried, and each failed against the anatomy. As early as 1931 Carl Wiman suggested the crest worked as a resonator for sound.

Testing the sound idea. In 1981 David Weishampel modeled the crest as a bent pipe, like a crumhorn or bassoon, and calculated it would make deep, low-frequency sounds that could carry far. Studies of the inner ear in hadrosaur braincases later showed it was suited to hearing low notes. In 1995 a well-preserved *Parasaurolophus* skull was found in New Mexico, and in 1997 scientists at Sandia National Laboratories and the New Mexico Museum of Natural History CT-scanned it, mapped the passages and used a computer to simulate air flowing through them. The result was a low, rumbling call. The simulated sound is a reasonable estimate, not a recording; soft tissues such as the larynx, which do not fossilize, would have changed the real voice.

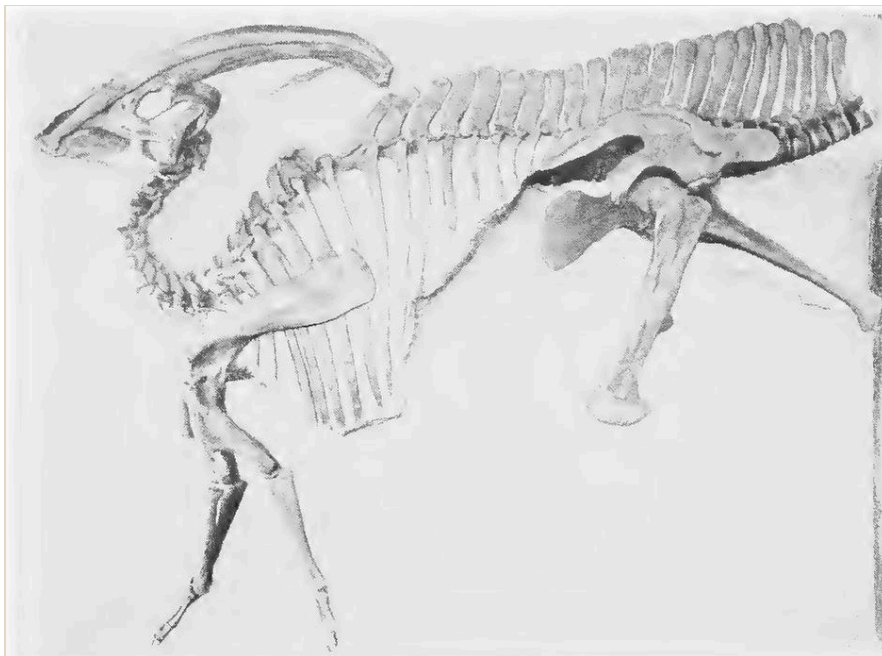
Sound and sight. Most paleontologists today think the crest served two purposes at once. It made a resonating call that let animals keep in touch across distance and perhaps tell their own kind from others, and it was a visual signal of species, age and perhaps maturity, like the antlers of an elk. The two ideas fit together: closely related lambeosaurines living in the same land had crests of very different shapes, which would help them recognize each other by look and by voice.

A baby with a bump. In 2009 Kevin Terris, then a high-school student volunteering with the Raymond M. Alf Museum of Paleontology in California, spotted bone in a cliff in southern Utah. It was the most complete *Parasaurolophus* skeleton known, a baby less than a year old,

nicknamed “Joe.” Andrew Farke’s team (2013) CT-scanned the skull and found the crest was only a small bump, but already hollow. Crest growth started early and sped up later. That fits a crest used for signals: a baby’s high-pitched call through a short tube would sound very different from an adult’s deep note through a long one. The same pattern explains why some short-crested skulls once given their own species names may simply be younger animals.

A voice in creation. We will never hear a living *Parasaurolophus*, but the shape of its skull is enough to let us imagine its voice with real evidence behind the guess. Scripture pictures all of creation praising its Maker, and the last verse of the Psalms calls on “every thing that hath breath.” A hadrosaur breathing through a meter of hollow bone was, in its own way, a creature built to sound.

PICTURE STUDY



Mounted skeleton of Parasaurolophus walkeri (Plate II), William A. Parks, 1922 · Printed scientific plate (drawing of the mounted skeleton, about 1/24 natural size) · From Parks, “Parasaurolophus walkeri, a new genus and species of trachodont dinosaur,” University of Toronto Studies, Geological Series (1922); the skeleton is at the Royal Ontario Museum, Toronto
Wikimedia Commons · Public domain

This plate from Parks’s original 1922 description shows the skeleton as the Royal Ontario Museum mounted it. The caption notes which parts were restored, a good habit every museum should keep.

Look closely

- Follow the crest from the beak to its tip. Where does it start, and how far back does it reach compared with the neck?
- Find the long spines on the back vertebrae and the bony rods along the back and tail. What would they do to the animal’s flexibility?

- Compare the front and hind legs. Did this animal walk on two legs, four, or both?

Talk about it

1. The scale is about 1/24. If the crest measures 4 cm on the printed plate, how long was it in life?
2. Why might Parks have marked which parts were restored instead of drawing the whole skeleton as if it were complete?

HANDS-ON: MAKE A HADROSAUR HORN

Build a resonating tube, test how its length changes the pitch, and compare your results with the long passages of the *Parasaurolophus* crest.

You will need

- Three cardboard or PVC tubes of different lengths (for example 30 cm, 60 cm and 120 cm), or flexible tubing from a hardware store
- A kazoo or a party-horn mouthpiece, or just your buzzing lips
- Tape
- A free tuner or frequency app on a parent's phone (optional)

Steps

1. Fit the mouthpiece to the shortest tube and make a steady buzz. Record the pitch (by ear or with the app).
2. Repeat with each longer tube. Keep the buzz as steady as you can.
3. Bend the longest tube into a U-shape and tape it so it doubles back on itself, like the air passage inside the crest. Does bending change the note, or only the length?
4. Make a table and a simple graph of tube length against pitch.
5. Write: If an adult *Parasaurolophus* air passage was several times longer than a baby's, how would their calls compare?

Check your work

- I tested at least three lengths and recorded the pitch of each.
- I tested a bent tube and compared it with a straight one.
- I explained what my results suggest about adult and baby calls.

FIELD NOTEBOOK

1. Draw the *Parasaurolophus* skull from the side and trace the air passage in color from the nostril up to the crest tip and back down to the throat.
2. List at least five hypotheses for the crest. Beside each, write the anatomical fact that supports or rules it out.
3. **Narration (the parent keeps this).** Write one paragraph explaining what the *Parasaurolophus* crest was most likely for. Include the CT-scan evidence and the baby

“Joe.”

Did you know? Kevin Terris was only a teenager when he found “Joe,” and the skeleton’s official specimen number belongs to the Raymond M. Alf Museum, a museum on the campus of a high school in Claremont, California. Joe’s skin impressions were also preserved in places. Weishampel’s modeling compared the crest to the crumhorn, a Renaissance wind instrument with a curved tube.

Primary source. *Charles H. Sternberg, Hunting Dinosaurs in the Bad Lands of the Red Deer River, Alberta, Canada (1917), the closing lines of his Preface, written as a letter, about the work of his family for the Geological Survey of Canada. Project Gutenberg eBook #77814.*

We have already mounted the first duck-billed dinosaur in Canada, it is thirty-two feet long. We secured eight skeletons of a new form with a hooded head.

Go deeper. Raymond M. Alf Museum of Paleontology, “Joe” the baby *Parasaurolophus* (alfmuseum.org), with the free 3-D scans. Royal Ontario Museum, *Parasaurolophus walkeri* (rom.on.ca). David Weishampel, “Acoustic analyses of potential vocalization in lambeosaurine dinosaurs,” *Paleobiology* 1981 (advanced). Second video topic: “How a crumhorn or bassoon makes its sound.”

Goes deeper in. Life Science, high-school Biology, the units on breathing and on hearing (coming soon); and Arithmetic, graphs and scale (using the 1/24 plate).

For families. Facts: Parks 1922 (ROM 768, found 1920 near Sand Creek); Wiman 1931; Weishampel, *Paleobiology* 1981; the New Mexico skull (1995) and the Sandia National Laboratories simulation (reported 1997–1998); Evans, Ridgely and Witmer 2009 on hadrosaur brains and ears; Farke et al., *PeerJ* 2013 (Joe). Size figures are rounded estimates. The Sternberg excerpt was checked word for word against Project Gutenberg eBook #77814. His “hooded” animal is not *Parasaurolophus* (which was not found until 1920); it was most likely a crested relative such as *Corythosaurus*, and the stop treats it only as an early report of crested duck-bills from the same river. No millions-of-years date is given in this stop.

PRACTICE

1. **EASY** Which bones form most of the *Parasaurolophus* crest, and what is inside it?
2. **MEDIUM** Give two hypotheses for the crest that were ruled out and the fact that ruled out each.
3. **MEDIUM** What did the CT scan and computer simulation of the New Mexico skull produce, and what is one limit of that result?
4. **CHALLENGE** A tube closed at one end resonates most strongly at a wavelength four times its length. Sound travels about 343 m/s. Find the frequency (speed ÷ wavelength) for an air passage 1 m long and for one 3 m long. Which is deeper?

5. **CHALLENGE Primary source.** Sternberg reports “eight skeletons of a new form with a hooded head.” Explain why finding many skeletons of one crested kind is more useful for testing crest hypotheses than finding one perfect skeleton.
6. **EASY** Who found the baby *Parasaurolophus* “Joe,” where, and what did its skull show?

Make it a game · Call Across the Valley. Outdoors, players split into two “herds” at opposite ends of a yard or field. Each herd agrees on a secret call pattern (for example, long-short-long) using a cardboard tube. One herd calls; the other must answer with the same pattern. Then add a third herd with a different-length tube. Can each herd tell its own call from the others by pitch alone?

Scripture. “Let every thing that hath breath praise the LORD. Praise ye the LORD.” (Psalm 150:6, KJV)

The Psalms end by calling on every breathing creature to praise God. A hadrosaur sounding its call through a hollow crest is a picture of that verse: breath given by God and returned in sound.

Practice: answers

1. The premaxilla and the nasal bone. Inside are hollow air passages that run from the nostrils up to the crest tip and back to the throat.
2. Any two: snorkel (no opening at the tip); air tank for diving (far too small a volume); weapon (bone too thin and hollow); salt gland or smell organ (no evidence of the needed tissues; the passages are simple tubes).
3. A low, deep rumbling sound. It is a model, not a recording: soft tissues like the larynx and the exact shape of the airways in life are unknown, so the real voice may have differed.
4. 1 m tube: wavelength 4 m; $343 \div 4 \approx 86$ Hz. 3 m tube: wavelength 12 m; $343 \div 12 \approx 29$ Hz. The 3 m passage gives the deeper (lower) sound, near the bottom of human hearing.
5. Many skeletons let scientists compare crests across ages and individuals. If crests grow in a pattern, differ between adults, or appear early in babies, that tests ideas such as display, recognition or sound. One skeleton, however perfect, shows only one animal at one age and cannot reveal growth or variation.
6. Kevin Terris, a high-school student, in southern Utah in 2009. Its crest was only a small bump but was already hollow, showing the crest began growing very early.

1.9 PACHYCEPHALOSAURUS

OBJECTIVES

- Describe the domed skull of Pachycephalosaurus and explain why the rest of its body is less well known.
- Weigh the evidence for and against head-butting and reach a reasoned conclusion.
- Calculate the energy of a charge and compare it with that of a bighorn ram.

Warm-up. Knock gently on your own forehead, then on a wooden table. Your skull bone there is less than 1 cm thick. The dome on top of a big Pachycephalosaurus skull was more than 20 times thicker. Guess what such a head might have been for before you read on.

Video slot. Video coming. Pachycephalosaurus dome and the head-butting debate; bighorn sheep clashing in the Rocky Mountains. Search approved channels (Museum of the Rockies, Smithsonian National Museum of Natural History, National Park Service (bighorn sheep), U.S. Fish and Wildlife Service; for creation-friendly framing, Answers in Genesis or the Institute for Creation Research once vetted); preview first.

KEY TERMS

pachycephalosaur

A member of the “thick-headed” plant-eating dinosaurs that walked on two legs, many with a thickened, domed skull roof.

frontoparietal dome

The thick, rounded mass of bone on top of a pachycephalosaur skull, formed from the fused frontal and parietal bones.

lesion

An area of damaged or diseased bone, such as a healed wound or infection, that can be seen in a fossil.

finite element analysis

A computer method that divides a structure into many small parts to calculate how it bends or breaks under force.

kinetic energy

The energy of a moving object, equal to $\frac{1}{2} \times \text{mass} \times \text{speed}^2$; it is measured in joules (J).

CORE IDEAS

A head with no body. Pachycephalosaurus was known for years only by its thick skull roofs, which weather out of the rock like stones. In 1931 Charles Gilmore described one such dome and placed it in *Troodon*, a genus known only from teeth. Then in 1940 a Montana rancher, William Winkley, found a nearly complete skull near Ekalaka. In 1943 Barnum Brown and

Erich Schlaikjer named *Pachycephalosaurus*, “thick-headed lizard.” Even now, no complete skeleton has been described. The body in museum pictures is borrowed from smaller relatives such as *Stegoceras* and *Homalocephale*, which are known from more bones.

The skull. Pachycephalosaurus was the largest of its kind: perhaps 4.5 m (15 ft) long and a few hundred kilograms, roughly the weight of a horse. The skull is about 60 cm (2 ft) long, and the dome at its top is up to about 20–25 cm (8–10 in) thick, the thickest skull roof of any known dinosaur. The dome is ringed with knobs, and short bony spikes stand on the snout and along the back of the skull. The teeth are small and leaf-shaped with saw-edged rims, and those at the front are more pointed. It probably ate mostly plants, perhaps also seeds, fruit or insects; with no stomach contents known, the diet is an inference from the teeth.

The battering-ram idea. In the 1950s and 1970s scientists such as Edwin Colbert and Peter Galton pictured male pachycephalosaurs charging and crashing heads, like bighorn rams in the Rockies. The neck and back had features that seemed to fit: the backbones were stiffened by tight joints and bony tendons, and the head and neck could be lined up straight. It made a vivid picture and appeared in nearly every dinosaur book.

The objections. Then came doubts. A rounded dome meeting another rounded dome would tend to glance off, which could wrench the neck instead of driving straight. In 2004 Mark Goodwin and Jack Horner cut thin sections of domes and found that young domes were spongy, full of blood vessels and growing fast, not built like solid armor; they argued the domes were for display, signaling age and kind. They also showed that two spiky, flat-headed skulls from the same rocks, once given their own names (*Dracorex* and *Stygimoloch*), may simply be young Pachycephalosaurus: as the animal grew, the spikes shrank and the dome rose.

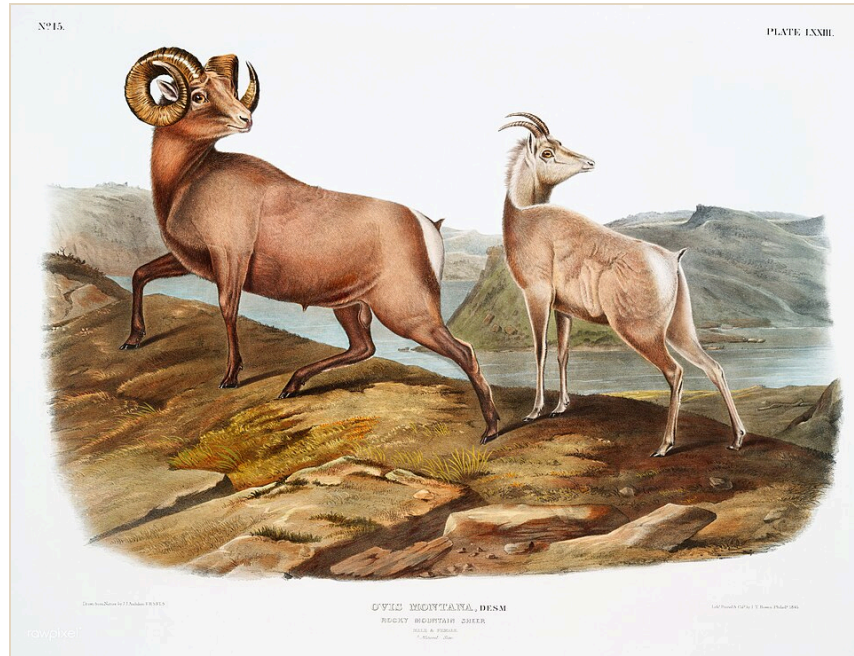
The evidence returns. Newer tests have swung many researchers back. In 2008 Eric Snively and Adam Cox used finite element analysis on dome shapes and found they could take hard blows without breaking, especially with the dense outer layer of adult domes. In 2011 Snively and Jessica Theodor CT-scanned domes and compared them with the skulls of head-butting animals such as musk oxen and duikers; the internal structure was similar. In 2013 Joseph Peterson, Collin Dischler and Nicholas Longrich examined pachycephalosaur skull roofs from many species and found healed lesions on about 22 percent of the domed ones, mostly on top of the dome where blows would land, while flat-headed specimens showed few. They concluded that domed pachycephalosaurs did fight with their heads.

Head-on or side-on? Fighting does not have to mean high-speed, head-to-head collisions. Some researchers have suggested the dinosaurs butted each other’s flanks, as some living antelope and giraffes do, or shoved head to head at lower speeds. The wounds fit several kinds of combat. The present balance of evidence is that Pachycephalosaurus used its dome in contests with its own kind, and also that the dome, growing with age, signaled maturity. Both display and combat can be true at once, as they are for the bighorn ram.

Lifter of the head. Pachycephalosaurus is a reminder that the most striking thing about an animal is not always the best known; we know its head far better than its body. David, fleeing his own son, wrote that the LORD was “a shield for me; my glory, and the lifter up of mine

head” (Psalm 3:3). A creature with a God-given shield on its head is a picture worth remembering: our real protection is not thick bone but the faithful care of God.

PICTURE STUDY



Rocky Mountain Sheep, from The Viviparous Quadrupeds of North America, John Woodhouse Audubon (for John James Audubon and John Bachman), 1845 · Hand-colored lithograph · From The Viviparous Quadrupeds of North America (1845–1848); copies in many libraries and museums
Wikimedia Commons · CC BY 2.0

After painting the birds of America, John James Audubon set out with the Lutheran pastor and naturalist John Bachman to picture every North American mammal. Audubon’s son John Woodhouse Audubon painted many of the plates, including this one. Bighorn rams are the living animals most often compared with *Pachycephalosaurus*.

Look closely

- Look at the ram’s horns: their shape, thickness and the flat front surface where two rams would meet.
- Look at the neck and shoulders. How are they built to take a shock?
- Look at the setting. What does it tell you about where bighorns live?

Talk about it

1. A ram’s horns meet with broad, rough surfaces. How is a pachycephalosaur dome different, and why does that matter in the head-butting debate?
2. What can a living animal teach us about an extinct one, and where can the comparison mislead us?

HANDS-ON: DOMES AND GLANCING BLOWS

Test the objection that two domes would slide off each other, using a simple pendulum.

You will need

- Two oranges (domes) and two small boxes or thick books (flat surfaces)
- String, strong tape and a doorway or a broom handle across two chairs
- A ruler or a protractor and a pencil

Steps

1. Hang one orange on a string so it swings freely. Set a second orange on a table at the bottom of the swing as the “rival.”
2. Pull the hanging orange back 30 cm and release so it strikes the rival dead center. Mark where the rival goes.
3. Move the rival 1 cm to one side and repeat, then 2 cm. Record whether the blow lands squarely or glances off and which way the rival moves.
4. Repeat the whole test with the two flat boxes.
5. Write three sentences: Which shape needs better aim? What would the dinosaurs have needed (aim, neck strength, slower speed) to butt domes safely? Does your result rule out head-butting or only fast head-on collisions?

Check your work

- I tested at least three aiming offsets for both shapes.
- I recorded where each rival moved.
- I wrote what my test shows and what it does not.

FIELD NOTEBOOK

1. Draw a Pachycephalosaurus skull from the side and from above, with the dome, knobs and snout spikes labeled and the dome’s thickness written in.
2. Draw a three-step growth series: a spiky flat-headed young animal, a half-grown animal with a small dome, and an adult with a high dome and short knobs.
3. **Narration (the parent keeps this).** Write one paragraph answering: Did Pachycephalosaurus butt heads? Give the strongest evidence on each side and your conclusion.

Did you know? The 1940 Pachycephalosaurus skull was found near Ekalaka, Montana, a town whose small Carter County Museum later became known for its dinosaur collections. Bighorn rams clash horns at running speed, and the sound can be heard far across a canyon; their horns alone can weigh as much as all the bones in their body. Pachycephalosaurus lived in the same Hell Creek and Lance rock layers as T. rex and Triceratops.

Go deeper. Museum of the Rockies, Bozeman (museumoftherockies.org), and the Burpee Museum of Natural History, Rockford, Illinois, for pachycephalosaur displays. Peterson, Dischler and Longrich, “Distributions of Cranial Pathologies Provide Evidence for Head-Butting in Dome-Headed Dinosaurs,” *PLoS ONE* 2013 (free online; advanced but readable). National Park Service pages on bighorn sheep (nps.gov). Second video topic: “How bighorn sheep and musk oxen survive head-butting.”

Goes deeper in. Life Science, high-school Biology, the units on bone and growth and on animal behavior (coming soon); Arithmetic, formulas and energy; and Gardening & Animals (sheep and goats).

For families. Facts: Gilmore 1931; Brown and Schlaikjer 1943 (the 1940 Winkley skull, AMNH 1696); Goodwin and Horner 2004; Horner and Goodwin 2009 (growth series; not all researchers accept that the spiky skulls are juveniles); Snively and Cox 2008; Snively and Theodor 2011; Peterson, Dischler and Longrich 2013 (about 22 percent of domes with lesions). Size figures and dome thickness are rounded; published estimates vary. No public-domain primary source on *Pachycephalosaurus* could be checked word for word, so there is no Primary source box. The names *Dracorex* and *Stygimoloch* come from fiction and mythology; the stop gives the names without the stories. No millions-of-years date is given in this stop.

PRACTICE

1. **EASY** What does *Pachycephalosaurus* mean, and why is most of its body unknown?
2. **MEDIUM** Give two objections to the head-butting idea and the evidence behind each.
3. **MEDIUM** What did Peterson, Dischler and Longrich (2013) find, and why does where the lesions were matter?
4. **CHALLENGE** Find the kinetic energy ($\frac{1}{2} \times \text{mass} \times \text{speed}^2$) of (a) a 400 kg *Pachycephalosaurus* charging at 5 m/s and (b) a 120 kg bighorn ram charging at 9 m/s. Which carries more energy?
5. **CHALLENGE** If a study examined 100 domed skulls and 22 had lesions, and 40 flat-headed skulls of which 1 had a lesion, compare the two rates. What alternative explanation would a careful scientist need to rule out before concluding the lesions came from fighting?
6. **EASY** Who found the best *Pachycephalosaurus* skull, where and when, and who named the dinosaur?

Make it a game • Evidence Tug-of-War. Lay a rope on the ground with a center mark. Two teams, “Head-butting” and “Display only,” take turns naming a real piece of evidence from this stop. A parent judges each one: a strong piece moves the rope two steps toward the team’s side, a weak one moves it one, and a wrong fact moves it back. After ten turns, see where the rope lies, and discuss whether both teams might be partly right.

Scripture. “But thou, O LORD, art a shield for me; my glory, and the lifter up of mine head.” (Psalm 3:3, KJV)

David wrote this psalm when he fled from his son Absalom. Surrounded by enemies, he trusted God as his shield and the One who would lift his head again. God, not our own strength, is our true defense.

Practice: answers

1. “Thick-headed lizard.” Its thick skull roofs survive well, but no complete skeleton has been described; the body is reconstructed from smaller relatives.
2. (1) Two rounded domes would glance off each other and could injure the neck. (2) Goodwin and Horner found young domes were spongy and fast-growing, which suggested display rather than armor.
3. About 22 percent of domed skulls had healed lesions, mostly on top of the dome, while flat-headed skulls had few. Damage clustered where blows would land fits combat, not random disease.
4. (a) $\frac{1}{2} \times 400 \times 5^2 = 200 \times 25 = 5,000 \text{ J}$. (b) $\frac{1}{2} \times 120 \times 9^2 = 60 \times 81 = 4,860 \text{ J}$. They are nearly equal; the heavier dinosaur needs only a slow trot to match a ram at full speed.
5. Domed: $22 \div 100 = 22 \text{ percent}$. Flat: $1 \div 40 = 2.5 \text{ percent}$, so domed skulls are almost nine times more likely to show lesions. The scientist must rule out disease or infection that targets thick bone, damage after death (during burial or weathering), and the fact that domed skulls are older animals who had more years to be injured.
6. William Winkley, a rancher, near Ekalaka, Montana, in 1940. Barnum Brown and Erich Schlaikjer named it in 1943.

1.10 ARGENTINOSAURUS, ONE OF THE BIGGEST

OBJECTIVES

- Tell how Argentinosaurus was found and what bones are actually known.
- Explain how scientists estimate the size of a giant from a few bones, and why “the biggest dinosaur” is a claim to handle with care.
- Use measurements and the square-cube law to compare Argentinosaurus with other giants and with familiar objects.

Warm-up. Look up the weight of your family car (it is usually printed inside the driver’s door or in the owner’s manual). Most estimates say Argentinosaurus weighed as much as forty to fifty cars. Write down how you would weigh an animal that big if it were alive, and then how you would do it with only a few bones.

Video slot. Video coming. Argentinosaurus and Patagotitan, the titanosaurs of Patagonia; how scientists estimate the weight of giant sauropods; the Argentinosaurus skeleton at Fernbank Museum. Search approved channels (Fernbank Museum of Natural History, American Museum of Natural History (the Titanosaur), Field Museum (Máximo the titanosaur), Natural History Museum London; for creation-friendly framing, Answers in Genesis or the Institute for Creation Research once vetted); preview first.

KEY TERMS

titanosaur

A member of a widespread group of sauropods that includes the largest known land animals, such as Argentinosaurus and Patagotitan.

fibula

The thinner of the two bones of the lower leg.

dorsal vertebra

A backbone from the trunk, between the neck and the hips.

allometry

The study of how body proportions change with size; for example, leg bones get thicker faster than they get longer as animals get heavier.

fragmentary

Known from only a few pieces of the skeleton, so much of the animal must be estimated.

margin of error

The range within which the true value probably lies. A careful estimate gives a range, not just one number.

CORE IDEAS

Petrified wood? In 1987 Guillermo Heredia, a rancher near the town of Plaza Huincul in Neuquén Province, Argentina, found what he took to be a log of petrified wood. It was a leg bone about 1.5 m (5 ft) long, first identified as a shin bone and later as a fibula. In 1989 the Argentine paleontologist José Bonaparte led a dig at the spot and recovered several enormous back vertebrae, part of the hips, rib pieces and, later, part of a thighbone. In 1993 Bonaparte and Rodolfo Coria named the animal *Argentinosaurus huinculensis*, “Argentine lizard from Huincul.” The original bones are in the Carmen Funes Municipal Museum in Plaza Huincul.

Just a few bones. *Argentinosaurus* is fragmentary. No skull, no neck, no tail and almost no limbs have been found. One back vertebra is about 1.6 m (5 ft 3 in) tall, as tall as many adults. Every picture of the whole animal, and every mounted skeleton, including the full-sized cast at Fernbank Museum in Atlanta, is a reconstruction built by scaling up better-known relatives to match these few bones.

How big? Most estimates put *Argentinosaurus* at about 30 to 35 m (100–115 ft) long and roughly 65 to 80 metric tons, though published figures range from around 50 to more than 90 tons. The range comes from method. One approach measures the circumference of the limb bones, which in living four-legged animals grows in step with body weight; but *Argentinosaurus* has only a partial thighbone, so that circumference must itself be estimated. Another builds a three-dimensional model of the whole body, scaled from a better-known titanosaur, and multiplies its volume by an assumed density; but that depends on how big the gut was, how much of the neck and body was filled with air sacs, and which relative is used. Different reasonable choices give different answers.

Rivals for the title. Several titanosaurs compete with *Argentinosaurus*. *Patagotitan mayorum*, found on a ranch in Chubut Province, dug up from 2012 and named in 2017, is known from parts of at least six individuals, which makes it far better known; it was first estimated at about 69 tons and later somewhat less. Other “biggest” candidates are known from a single bone or from bones that have since been lost, and their sizes are much less certain. So the honest statement is not “*Argentinosaurus* was the biggest dinosaur” but “*Argentinosaurus* is one of the largest land animals known, and among the best-supported candidates for the largest.” The largest blue whales are heavier still, but the water carries their weight.

Building to carry weight. The square-cube law is a giant’s main problem: if every length doubles, weight goes up eight times but the cross-section of the leg bones only four times. Titanosaurs answer with columns. Their legs stood straight under the body like pillars, their limb bones are thick for their length, and footprints and foot bones show a padded, elephant-like foot. The vertebrae are hollowed by air spaces, so the huge trunk was lighter than it looks. In 2013 William Sellers and colleagues built a computer model of *Argentinosaurus* and let it “learn” to walk; its best speed was about 2 m/s (about 7 km/h, 4.5 mph), a brisk human walking pace. A giant need not hurry when almost nothing could attack an adult.

From egg to giant. Titanosaurs laid eggs only about the size of a grapefruit. At a famous Patagonian nesting ground called Auca Mahuevo, discovered in 1997, thousands of titanosaur eggs lie in layers, and some hold embryos with skin impressions. A hatchling weighing a few kilograms would have had to grow by tens of thousands of times to reach adult size, which bone-tissue studies of sauropods suggest happened rapidly. Whether those eggs belonged to *Argentinosaurus* itself is not known.

Weighed in a balance. Scientists estimate *Argentinosaurus* with tape measures, computer models and careful ranges, and still disagree by tens of tons. Isaiah asks who has “weighed the mountains in scales, and the hills in a balance.” The answer is the LORD, who knows the exact measure of every creature He made. Our estimates are honest work; His knowledge is complete.

PICTURE STUDY



Brontosaurus and Diplodocus, Charles R. Knight, 1897 · Painting (made under the direction of the American Museum of Natural History) · American Museum of Natural History, New York; later printed in the New-York Tribune (1919)

Wikimedia Commons · Public domain

When Knight painted this in 1897, many scientists thought sauropods were too heavy to walk well on land and must have lived in water, which would bear their weight. Knight painted that idea. *Argentinosaurus*, two or more times heavier than *Brontosaurus*, makes the question sharper: how did the largest of all sauropods carry itself on dry ground?

Look closely

- Find the *Brontosaurus* in the water and the *Diplodocus* on land. How did Knight show the difference in their weight?
- Look at the legs. Are they straight columns under the body, or bent?

- Look at the tails. Where are they, and what would that mean for trackways?

Talk about it

1. What evidence has since shown that sauropods lived on land (think of footprints, feet and lungs from Stop A4)?
2. Why would a heavy animal be pictured in water, and what is the flaw in that reasoning?

HANDS-ON: MEASURE A GIANT

Lay out Argentinosaurus at full size outdoors and compare it, length and weight, with things you know.

You will need

- A ball of string at least 40 m long, and a tape measure
- Eight stakes, flags or stones
- A field, park or long driveway
- A calculator

Steps

1. Measure and mark 35 m of string in a straight line. Put flags at 0 m (snout) and 35 m (tail tip).
2. Mark the length of a school bus (about 12 m), a large blue whale (about 30 m) and SUE the T. rex (12.3 m from Stop A1) along the same line with other flags.
3. Mark the hips about 15–17 m from the tail tip, and stand someone there. Mark a 1.6 m height on a wall or post for the tallest back vertebra.
4. Calculate how many 1.5-ton cars equal 70 tons, and how many 15 kg Velociraptors (Stop A5) equal one Argentinosaurus.
5. Write a short “museum sign” of 60 words for Argentinosaurus that gives a range instead of a single number and says how much of the skeleton is known.

Check your work

- My string is 35 m long with at least three comparisons marked.
- I worked out the car and Velociraptor comparisons.
- My museum sign gives a range and says the animal is known from only a few bones.

FIELD NOTEBOOK

1. Draw a silhouette of Argentinosaurus. Shade the parts actually known from fossils (a few back vertebrae, part of the hips, ribs, a fibula and part of a femur) and leave the rest as an outline. Add a person to scale.
2. Draw a bar chart comparing the mass estimates of Argentinosaurus, Brontosaurus (from the primary source), T. rex and an African elephant.

3. **Narration (the parent keeps this).** Write one paragraph answering: Was Argentinosaurus the biggest dinosaur? Explain what is known, how its size is estimated, and what an honest answer must say.

Did you know? Argentina is one of the richest countries in the world for giant dinosaur fossils: Argentinosaurus, Patagotitan, the meat-eater *Giganotosaurus* and many others come from Patagonia. A cast of Patagotitan stands in the American Museum of Natural History in New York, and another, nicknamed “Máximo,” in the main hall of the Field Museum in Chicago.

 **What the sign says / What we observe / How Christians read it.**  **What the sign says:** “Argentinosaurus lived about 96 to 94 million years ago, in the middle of the Cretaceous Period.” **What we observe:** the bones lie in the Huincul Formation of Neuquén, layers of sandstone and mudstone laid down by rivers, with other dinosaurs and plant remains. The date comes from radioactive minerals in volcanic material in this and nearby layers and from comparison with dated rocks elsewhere, assuming constant decay rates, known starting amounts and no gain or loss of atoms. **How Christians read it:** many young-earth Christians read such water-laid layers with giant animals as deposits of the Flood, and “Cretaceous” as the name of a group of layers, not an age. Other Christians accept the long ages. What all can observe: very large bones buried in river-laid rock in a particular order of layers.

Primary source. *W. D. Matthew, Dinosaurs, with Special Reference to the American Museum Collections (1915), describing the museum’s mounted sauropod. Project Gutenberg eBook #19302.*

The Brontosaurus skeleton, the principal feature of the hall, is sixty-six feet eight inches long. (The weight of the animal when alive is estimated by W.K. Gregory at 38 tons). About one-third of the skeleton including the skull is restored in plaster modelled or cast from other incomplete skeletons.

Go deeper. Fernbank Museum of Natural History, Atlanta, “Giants of the Mesozoic” (fernbankmuseum.org). American Museum of Natural History, “The Titanosaur” (amnh.org). William Sellers et al., “March of the Titans: The Locomotor Capabilities of Sauropod Dinosaurs,” *PLoS ONE* 2013 (free online). Luis Chiappe and Lowell Dingus, *Walking on Eggs* (Scribner, 2001), the Auca Mahuevo story. Second video topic: “How scientists weigh a dinosaur.”

Goes deeper in. Arithmetic, ratios, the square-cube law and estimation (coming soon); Life Science, high-school Biology, the unit on size and design in animals; and Geography (Argentina and Patagonia).

For families. Facts: Heredia’s find (1987), Bonaparte’s excavation (1989), Bonaparte and Coria 1993. Size: commonly 30–35 m and 65–80 t, with published estimates from about 50 to over 90 t (e.g., Mazzetta et al. 2004; Sellers et al. 2013; Benson et al. 2014).

Patagotitan: Carballido et al., *Proc. R. Soc. B* 2017. Auca Mahuevo: Chiappe et al., *Nature* 1998. The primary source was checked word for word against Project Gutenberg eBook #19302. Gregory's "38 tons" is probably short tons (about 34 metric tons); modern estimates for Brontosaurus are mostly lower. "Brontosaurus" was long treated as a synonym of Apatosaurus and was restored as its own genus in 2015 (Tschopp, Mateus and Benson). The ⌚ box gives the museum date as an interpretation.

PRACTICE

1. **EASY** Who first found Argentinosaurus bones, what did he think they were, and who named the animal?
2. **MEDIUM** Which parts of Argentinosaurus are known, and which are missing?
3. **MEDIUM** Why is "Argentinosaurus was the biggest dinosaur" an overstatement?
4. **CHALLENGE** **Primary source.** Matthew reports Gregory's estimate of 38 tons for Brontosaurus and says one-third of the skeleton was restored. If 38 short tons is about 34.5 metric tons, how many times heavier is a 70-ton Argentinosaurus? Then explain why both numbers deserve caution.
5. **CHALLENGE** Using the square-cube law: suppose a well-known titanosaur relative is 20 m long and weighs 20 tons. If Argentinosaurus had the same shape and was 33 m long, what would it weigh? What does the leg-bone cross-section grow by?
6. **MEDIUM** Sellers's computer model gave Argentinosaurus a best speed of about 2 m/s. Convert this to km/h, and find how long the animal would take to walk 1 km.

Make it a game • Biggest Claim Showdown. Write on cards ten "biggest" claims from books, signs or websites ("the biggest dinosaur ever," "as long as three buses," "weighed 100 tons"). Players take turns drawing a card and rating it: "well supported," "stretched," or "unknown," and must say what evidence would be needed to support it. The best-reasoned rating in each round wins the card; most cards wins.

Scripture. "Who hath measured the waters in the hollow of his hand, and meted out heaven with the span, and comprehended the dust of the earth in a measure, and weighed the mountains in scales, and the hills in a balance?" (Isaiah 40:12, KJV)

Isaiah's question has one answer: the LORD. We estimate the size of the greatest land animals with careful ranges; God holds the oceans in His hand and knows the exact weight of every creature He has made.

Practice: answers

1. Guillermo Heredia, a rancher near Plaza Huincul, Argentina, in 1987. He thought the first bone was petrified wood. José Bonaparte and Rodolfo Coria named it in 1993.
2. Known: several back (dorsal) vertebrae, part of the hips (sacrum), rib pieces, a fibula and part of a femur. Missing: the skull, neck, tail and nearly all the limbs.
3. It is known from only a few bones, so its size is a wide estimate; other giants such as Patagotitan overlap with it; and some other candidates are known from too little to compare.

The careful claim is that it is one of the largest known land animals.

4. $70 \div 34.5 \approx 2.0$, so about twice as heavy. Caution: the Brontosaurus mount was one-third plaster, built from other skeletons, and 1905 methods (scale models) depended on guesses about flesh and density; Argentinosaurus is known from even fewer bones, and its estimate ranges from about 50 to over 90 tons.
5. Length ratio $33 \div 20 = 1.65$. Mass ratio $1.65^3 \approx 4.49$, so about $20 \times 4.49 \approx 90$ tons. Leg-bone cross-section grows by $1.65^2 \approx 2.72$. Weight grows much faster than bone area, which is why giants need relatively thicker, column-like legs (and why the same-shape assumption probably overestimates).
6. $2 \text{ m/s} \times 3,600 \text{ s/h} = 7,200 \text{ m/h} = 7.2 \text{ km/h}$. $1,000 \text{ m} \div 2 \text{ m/s} = 500 \text{ s}$, about 8 minutes 20 seconds.

TRAIL 1 BADGE QUIZZES

The badge quizzes are optional. Students answer in writing, in complete sentences, with numbers where asked; a calculator is allowed. Four good answers out of five earn each badge. Badges and the certificate are earned by doing the stops, not by scores; use the quizzes to find what to review.

Badge quiz 1 (Stops 1–5)

1. Name the single fossil that best shows T. rex attacked living animals, and explain why it is strong evidence.
2. Explain the Triceratops–Torosaurus debate in two or three sentences.
3. Give one piece of evidence for each: the Stegosaurus plates were for heat control; the plates were for display; the tail spikes were weapons.
4. Why is the famous Berlin skeleton usually called Giraffatitan rather than Brachiosaurus today?
5. Give Velociraptor’s real length and mass, and the evidence that it had feathers.

Badge quiz 2 (Stops 6–10)

6. What does the Zuul specimen suggest about how ankylosaurs used their tail clubs?
7. Why does Spinosaurus have a neotype, and what are the two main sides of the current debate about its life?
8. What is inside the Parasaurolophus crest, and what is the leading explanation for it?
9. What did the 2013 study of pachycephalosaur skulls find, and what does it suggest?
10. Write an honest one-sentence museum sign about the size of Argentinosaurus.
11. A museum sign says “Tyrannosaurus rex lived 66 million years ago.” Separate what is observed from what is interpreted.
12. Use the square-cube law: if an animal’s length doubles and its shape stays the same, what happens to its mass and to the cross-section of its leg bones? Why does that matter for giants?

TRAIL CERTIFICATE: MY DINOSAUR EXPERT FIELD NOTEBOOK AND TRAIL A CERTIFICATE

Gather the notebook pages from all ten stops into one booklet with a cover: “Dinosaur Expert Field Notebook: Meet the Dinosaurs,” your name and the dates you started and finished.

Include all ten narration paragraphs, which the parent has kept, and at least three project records with your measurements, tables or graphs (for example the chalk T. rex, the heat-fin test, the blood-column calculation, the buoyancy test or the 35 m Argentinosaurus).

Add a final page: a rewritten museum sign for any one dinosaur on this trail, about 100 words, that gives sizes as ranges, names one open question and labels any date as an interpretation.

When the booklet is done, a parent reviews it with the rubric and signs the Trail A certificate.

- **Ten stops:** Each stop has a dated page with a labeled drawing or diagram and a narration paragraph of at least five sentences.
- **Numbers and method:** Project records show real measurements or calculations with units and say what the method can and cannot show.
- **Evidence and reasoning:** Narrations state a clear claim, support it with specific fossil evidence and fairly describe the other side of each debate.
- **Observation and interpretation:** The museum sign and notebook keep observations apart from interpretations, label dates as interpretations and treat other views without mockery.

Answer key

1. The duck-billed dinosaur tail vertebra with a T. rex tooth crown in it and healed bone around it. Bone heals only in a living animal, so it was bitten alive and escaped.
2. Scannella and Horner (2010) proposed that Torosaurus, with its longer, holed frill, is simply the fully grown Triceratops, since skulls change a great deal with age. Others (Longrich and Field 2012) answered that some Torosaurus skulls look young and some Triceratops skulls look old, so they were separate. It is not settled.
3. Heat: Farlow's 1976 wind-tunnel test showed staggered plates shed heat well, and the plates have blood-vessel grooves. Display: Main's 2005 bone study showed the grooves fed plate growth and the plates are thin and showy. Weapons: about one spike in ten has a healed broken tip, and an Allosaurus vertebra has a spike-shaped hole.
4. The name Brachiosaurus is tied to Riggs's Colorado type specimen. When Michael Taylor (2009) compared the bones in detail, the African skeleton differed in its backbones, hips and limb proportions enough to deserve its own genus, Giraffatitan (first proposed by Gregory Paul in 1988).
5. About 1.5–2 m long (half tail) and about 15 kg. Quill knobs on its forearm bone (Turner, Makovicky and Norell 2007) show where large feathers were anchored, as in birds.
6. Its flank spikes were broken and healed where a rival's swinging club would strike, so ankylosaurs probably clubbed each other, not only predators.
7. The original bones were destroyed in the bombing of Munich in April 1944, so a Moroccan skeleton was named the neotype in 2014. One side (Ibrahim, Fabbri) argues it swam or dove after prey, citing the finned tail and dense bones; the other (Hone and Holtz, Sereno) argues it waded in shallows, citing a weak tail and a body that would tip over in deep water.
8. Hollow air passages running from the nostrils up to the crest tip and back. The leading view is that it worked as a resonator for low-pitched calls and as a visual signal of species and age.
9. About 22 percent of domed skulls had healed lesions, mostly on top of the dome, while flat-headed skulls had few. It suggests the domed animals fought with their heads.
10. Sample: "Known from only a few huge bones, Argentinosaurus was probably about 30–35 m long and 65–80 tons, one of the largest land animals ever found." (Any answer that gives a range and notes the incomplete skeleton.)
11. Observed: T. rex bones lie in particular rock layers (such as the Hell Creek Formation) near volcanic ash beds, in a known order of layers. Interpreted: the date in years, which depends

on assumptions about constant decay rates, starting amounts and closed systems. Young-earth Christians read the same layers as laid down quickly in the Flood.

12. Mass goes up 8 times (2^3); leg-bone cross-section only 4 times (2^2). Weight outgrows bone strength, so giants need relatively thicker, column-like legs, as titanosaurs had.

DINOSAURS TRAIL B: DINOSAUR HUNTERS

The second trail of the Dinosaurs track follows the people who found the dinosaurs and how their knowledge grew. It begins with Mary Anning on the cliffs of Lyme Regis (1811), then William Buckland's *Megalosaurus* (1824), Gideon and Mary Ann Mantell's *Iguanodon*, Richard Owen's new word "Dinosauria" (1842), and Benjamin Waterhouse Hawkins' life-size Crystal Palace models (1854). It crosses to America for the Bone Wars of Cope and Marsh and Barnum Brown's first *Tyrannosaurus rex* (1902), goes to the Gobi with Roy Chapman Andrews (1923), and ends with SUE the *T. rex* (1990) and Mary Schweitzer's soft tissue (2005). The thread running through all ten stops is how observations are made, interpreted, tested and corrected.

This is the  **Expert** level, for ages 14 and up. Each stop takes 35–50 minutes and includes a longer reading with numbers and honest complexity, five or six key terms, a picture study, a hands-on project, a written narration the parent keeps, six practice questions (two of them "challenge" problems), and, where one exists, a primary source copied exactly from a public-domain text: Owen's 1854 Crystal Palace guide, Charles Sternberg's 1909 memoir, W. D. Matthew's 1915 museum booklet and Andrews' 1921 travel book among them. The track is creation-friendly. Period names such as Jurassic and Cretaceous are taught as museum vocabulary, and stops where a date in millions of years comes up (B9 and B10) include the  box: *What the sign says / What we observe / How Christians read it*.

Five stops earn the **Dinosaur Hunter badge, part 1**; ten earn part 2 and the **Trail B certificate**. Two optional badge quizzes at the end check the main facts and reasoning of each half of the trail. The certificate is earned by completing the stops and the portfolio, not by quiz scores.

BEFORE YOU BEGIN

- Read a few paragraphs of nineteenth-century English (long sentences, older spelling) with a parent's help, and write a clear paragraph in your own words.
- Know what a fossil is and how layers of rock are described, and know the creation account of Genesis 1 (Trail A or the Earth Science course is helpful but not required).

MASTERY CHECKLIST

- ☐ I can put the ten discoveries of this trail in order with their dates and tell what each hunter found.
- ☐ I can explain, with an example from at least three stops, how a reconstruction changed when new evidence came (the *Iguanodon* horn, the *T. rex* pose, the *Oviraptor* "egg thief").
- ☐ I can read a nineteenth-century primary source and separate its facts, its opinions and what it leaves out.

- ☐ I can describe the Bone Wars and the SUE case fairly, naming real wrongs plainly and judging people by the standards of their own day.
- ☐ I can separate observation from interpretation on a museum sign and state the young-earth and mainstream readings of the soft-tissue finding accurately and respectfully.

GO DEEPER: BOOKS, MUSEUM PAGES AND RESOURCES

- **Project Gutenberg: the trail's primary sources** (<https://www.gutenberg.org>): Free full texts: Richard Owen, *Geology and Inhabitants of the Ancient World* (1854, #62414); H. N. Hutchinson, *Extinct Monsters* (1892, #42584); Charles H. Sternberg, *The Life of a Fossil Hunter* (1909, #57178); W. D. Matthew, *Dinosaurs* (1915, #19302); Roy Chapman Andrews, *Across Mongolian Plains* (1921, #29024).
- **Natural History Museum, London** (<https://www.nhm.ac.uk>): Pages on Mary Anning, Mantell's Iguanodon teeth and Richard Owen, and the history of the museum Owen founded.
- **Friends of Crystal Palace Dinosaurs** (<https://www.cpdinosaurs.org>): Photographs and history of Hawkins' 1854 models, which still stand in Crystal Palace Park, London (Stop B5).
- **Field Museum, Chicago: SUE the T. rex** (<https://www.fieldmuseum.org>): SUE's story, injuries and the 2018 remount (Stop B9); also Charles R. Knight's murals (Stop B7).
- **Biodiversity Heritage Library** (<https://www.biodiversitylibrary.org>): Free scans of original papers and plates: Buckland 1824, Mantell 1822 and 1825, Owen 1842, Osborn 1905.

2.1 MARY ANNING (1811)

OBJECTIVES

- Explain how the Anning family’s finds at Lyme Regis, beginning with the ichthyosaur of 1811–1812, helped convince scientists that whole kinds of animals had died out.
- Describe how a fossil dealer without schooling or money became a trusted expert, and why her name was often left out of the papers built on her specimens.
- Read a nineteenth-century source critically: what it praises, what it leaves out and what its author could have known.

Warm-up. Look at the label on any museum object, online or in person. Whose name is on it: the person who found it, the person who described it, or the person who paid for it? Keep that question in mind. In Mary Anning’s day, the answer was usually not the finder.

Video slot. Video coming. Mary Anning, Lyme Regis and the first ichthyosaur and plesiosaur skeletons; the Jurassic Coast cliffs. Search approved channels (Natural History Museum London, Lyme Regis Museum, Smithsonian); preview first.

KEY TERMS

ichthyosaur

A dolphin-shaped sea reptile (“fish lizard”) with paddles and huge eyes; not a dinosaur. The Annings found the first skeleton to reach scientists in London.

plesiosaur

A sea reptile with four long flippers, a small head and, in many kinds, a very long neck. Mary Anning found the first nearly complete one in 1823.

Blue Lias

The layered grey limestone and shale of the cliffs around Lyme Regis, rich in ammonites and marine reptiles. Museums label it “Early Jurassic.”

coprolite

Fossilized dung. Anning noticed that certain stones inside ichthyosaur skeletons held fish bones and scales; William Buckland named them in 1829.

extinction

The dying out of a whole kind of animal or plant. Around 1800 many people doubted it could happen; fossils like Anning’s helped settle the question.

fossilist

An old word for a person who collected, cleaned and sold fossils, often for a living.

CORE IDEAS

A family in debt. Mary Anning was born in 1799 in Lyme Regis, a small seaside town on the south coast of England. Her father, Richard, was a cabinetmaker who searched the cliffs for

“curiosities” to sell to summer visitors. When he died in 1810 he left his wife and two surviving children, Mary and her older brother Joseph, in debt. Ten children were born to the family; only those two lived to grow up. Selling fossils was not a hobby for the Annings. It was how they paid for bread.

The “crocodile” of 1811. In 1811 Joseph found a long skull, about four feet in length, weathering out of the cliff. About a year later Mary, then twelve or thirteen, found the rest of the skeleton. The family sold it for about £23 to Henry Hoste Henley, the lord of the manor. It was shown in William Bullock’s museum in London and bought by the British Museum in 1819. Scientists argued over it for years. Sir Everard Home, who described it from 1814 on, could not decide whether it was a fish, a crocodile or something in between. In 1819 it was given the name *Ichthyosaurus*, “fish lizard.” It was neither a fish nor a lizard, and it was not a dinosaur, but it was plainly an animal no one had ever seen alive.

Dangerous work, careful hands. The cliffs of Blue Lias slump and slide in winter storms, and that is when new fossils appear. Anning walked the shore after storms, often alone, racing the tide. In 1833 a landslip that she barely escaped killed her dog, Tray. Finding a skeleton was only the start. She cut it out of the rock in sections, carried it home, cleaned each bone with fine tools and set it in plaster or a frame for sale. She had only a little schooling, but she taught herself. She copied scientific papers by hand, drawing the plates, and dissected fish and cuttlefish to compare their anatomy with her fossils. Visitors were surprised to find that this poor shopkeeper knew more anatomy than many gentlemen.

The plesiosaur and the doubters. In December 1823 she found a nearly complete skeleton of a new kind of sea reptile with a tiny head and an extraordinarily long neck. William Conybeare and Henry De la Beche had named *Plesiosaurus* from scattered bones in 1821; now there was a whole animal. The great French anatomist Georges Cuvier at first suspected a fake, a head joined to the wrong body, because the neck had far more vertebrae than any known reptile. After a meeting of the Geological Society of London examined it in 1824, Cuvier accepted it. Anning herself could not attend; the Society did not admit women. She went on to find the first British pterosaur (1828), recognized coprolites, and noticed ink sacs preserved in fossil squid-like belemnites.

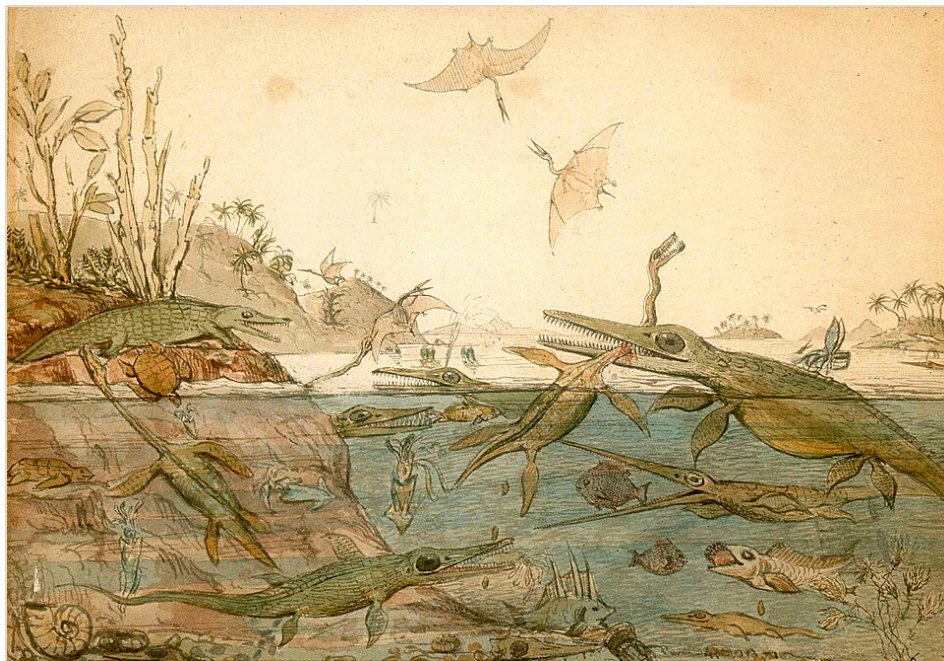
Credit and charity. Gentlemen geologists, among them Buckland, Conybeare and Henry De la Beche, bought her specimens, walked the shore with her and wrote papers based on her finds, usually without naming her. In that day collectors and dealers were rarely named in scientific papers, and a tradeswoman was even less likely to be. That was the custom of the time, and it was still a loss to the truth: the record of who found what became blurry. Others helped generously. In 1820 the collector Thomas Birch sold his own collection and gave the proceeds, about £400, to the family. De la Beche had his 1830 picture *Duria Antiquior* printed and sold for her benefit, and in 1838 Buckland arranged a yearly payment for her from the British Association for the Advancement of Science.

Faith and a memorial. The Annings worshipped at the Independent (Congregational) chapel in Lyme; later in life Mary joined the Church of England. She died of breast cancer in 1847, aged forty-seven. De la Beche honored her in his presidential address to the Geological

Society, an unusual tribute for someone who was not a member, and the Society paid for a stained-glass window in her memory in St Michael's Church, Lyme Regis.

Why she belongs on a dinosaur trail. Anning never found a dinosaur. But by the time Buckland named the first one in 1824 (Stop B2), her sea reptiles had already done two things. They showed, beyond reasonable doubt, that God's world once held large creatures that no longer live, and they trained a whole circle of geologists to rebuild unknown animals from bones. Museum signs at Lyme today call the Blue Lias "Early Jurassic" and attach a date to it. Here the period name is museum vocabulary. Many creation geologists read thick, fossil-packed marine beds like these as laid down rapidly by the Flood; mainstream geologists read them as slow deposits over long ages. Both readings start from the same observed bones and layers.

PICTURE STUDY



Duria Antiquior, a More Ancient Dorset, Henry De la Beche (lithograph by George Scharf), 1830 · Watercolor, printed as a hand-colored lithograph · Original watercolor at the National Museum Wales; prints in several museums
Wikimedia Commons · Public domain

Henry De la Beche had collected with Mary Anning since they were young. In 1830 he painted the animals found at Lyme as if a window had opened onto the ancient sea, one of the first pictures ever made of a scene from the fossil world. Prints were sold to raise money for Anning.

Look closely

- Find an ichthyosaur and a plesiosaur. Which body parts did De la Beche know from Anning's skeletons, and which did he have to imagine?
- Look near the surface and in the air. What other animals has he added?

- Notice how much fighting and eating there is. What do you think De la Beche wanted viewers to feel?

Talk about it

1. De la Beche drew coprolites into the picture, as dung falling from an animal. Why would a scientist bother to include that detail?
2. Every reconstruction mixes observation and guesswork. If you painted this scene today, what would you change, and how would you know?

HANDS-ON: SPECIMEN, LABEL AND CREDIT

A fossil without a record is only a pretty stone. Make a plaster cast of a shell or bone, then write the kind of full museum record that Anning's finds often lacked.

You will need

- Modeling clay or salt dough
- A shell, chicken bone (boiled clean) or plastic toy skeleton
- Plaster of Paris and a paper cup
- An index card and a fine pen
- The primary source in the asides

Steps

1. Press the object into a flattened lump of clay to make a mold. Lift it out carefully.
2. Mix plaster to the thickness of pancake batter and pour it into the mold. Let it set at least one hour, then peel away the clay.
3. Write a specimen label: name of the object, where it was found (your "locality"), the layer or setting, date, finder, preparer (who cleaned it), and who first described it.
4. Read the primary source. Underline every word that praises Anning, and circle any facts it gives about her (dates, finds, payment). How many specific facts does it give?
5. Write two sentences on your card's back: what a future historian could learn from your label that they could not learn from Hutchinson's paragraph.

Check your work

- My cast shows clear detail.
- My label names finder, preparer and describer separately.
- I can explain why the 1892 source is useful but thin as evidence.

FIELD NOTEBOOK

1. Make a timeline from 1799 to 1847 with at least six events from Anning's life and finds.
2. Draw an ichthyosaur and a plesiosaur side by side. Label paddles, eye, neck and tail, and write one difference under each.

3. **Narration.** Write one paragraph telling how the 1811–1812 ichthyosaur went from a cliff in Dorset to the British Museum, and what scientists argued about once it got there. A parent keeps this page.

Did you know? The Lyme Regis Museum stands on the site of the Anning family’s home and shop. A bronze statue of Mary Anning with her hammer and her dog was unveiled on the Lyme Regis seafront in 2022, paid for by a public campaign begun by a schoolgirl. The cliffs where she worked are part of the Jurassic Coast, a World Heritage Site.

Primary source. *H. N. Hutchinson, Extinct Monsters (London, 1892), Chapter III, “The Great Fish-Lizards.” Project Gutenberg eBook #42584.*

The labours of the learned men of the day were greatly assisted by the exertions of Miss Anning, an enthusiastic collector of fossils. This lady, devoting herself to science, explored the frowning and precipitous cliffs in the neighbourhood of Lyme-Regis, when the furious spring-tide combined with the tempest to overthrow them, and rescued from destruction by the sea, sometimes at the peril of her life, the few specimens which originated all the facts and speculations of those persons whose names will ever be remembered with gratitude by geologists.

Go deeper. Shelley Emling, *The Fossil Hunter: Dinosaurs, Evolution, and the Woman Whose Discoveries Changed the World* (2009). Deborah Cadbury, *The Dinosaur Hunters* (2000), opening chapters. Natural History Museum, London: “Mary Anning” pages and the ichthyosaur gallery. Lyme Regis Museum website. Second video: the Jurassic Coast and how winter landslips expose fossils.

Goes deeper in. Earth Science, the fossils and rock-layers units (coming soon); and History, the early nineteenth century (Britain in the age of George III and George IV).

For families. Dates: Joseph Anning’s skull, 1811; the body, 1812 (some accounts say 1811–1812 for both). The sale price to Henley is usually given as £23. Conybeare named *Plesiosaurus* with De la Beche in 1821 from fragments; the 1823 skeleton was presented in 1824. The ichthyosaur is now placed in *Temnodontosaurus*. Hutchinson is not an eyewitness; his praise reads like an earlier tribute and gives few checkable facts, which is the point of the source exercise. The widely repeated tongue-twister “She sells seashells” is often linked to Anning, but no evidence ties it to her, so it is left out. Anning’s cancer is stated plainly and not dwelt upon.

PRACTICE

1. **EASY** Who found the ichthyosaur skull in 1811, and who found the rest of the skeleton?
2. **EASY** Name two kinds of animals Mary Anning found, other than ichthyosaurs.
3. **MEDIUM** Why did Cuvier at first doubt the 1823 plesiosaur, and what changed his mind?

4. **MEDIUM** Give two reasons Anning's name was often missing from papers about her specimens, stated in the terms of her own day.
5. **CHALLENGE** Use the primary source. List what it tells you as checkable fact and what is praise or opinion. Then name two facts about Anning, from this stop, that a careful historian would want but the passage omits.
6. **CHALLENGE** The 1812 ichthyosaur sold for about £23 and was resold to the British Museum in 1819 for about £47. Birch's gift to the family in 1820 was about £400. How many times the first sale price was Birch's gift, and what does that suggest about the family's position?

Make it a game · Beat the Tide. Hide ten "fossils" (shells, buttons or folded paper bones) along a hallway or yard "beach." Set a timer for 60 seconds: that is the tide. Players must find and bring back as many as they can before the tide comes in, then lay them out and label each with finder and place. A fossil with no label does not count.

Scripture. "Or speak to the earth, and it shall teach thee: and the fishes of the sea shall declare unto thee." (Job 12:8, KJV)

Job says the creatures and the earth itself testify to God's hand. Mary Anning spent her life listening to the earth at Lyme, and the sea creatures she uncovered still teach anyone willing to look carefully.

Practice: answers

1. Joseph Anning found the skull in 1811; his sister Mary found the body about a year later.
2. Any two: a nearly complete plesiosaur (1823), the first British pterosaur (1828), fish, belemnites with ink sacs; she also recognized coprolites.
3. Its neck had far more vertebrae than any known reptile, so he suspected a head attached to the wrong body. After the skeleton was examined at the Geological Society in 1824 and found genuine, he accepted it.
4. Collectors and dealers were rarely named in scientific papers; she was a tradeswoman selling specimens, not a member of the learned societies (which did not admit women); the person who bought and described a specimen was treated as its scientific owner.
5. Checkable: she collected fossils, worked the cliffs near Lyme Regis, worked during storms and spring tides, sometimes at risk, and her specimens were used by learned men. Praise or opinion: "enthusiastic," "devoting herself to science," the claim that her few specimens "originated all the facts." Omitted (any two): her first name, dates, specific finds (ichthyosaur 1811-12, plesiosaur 1823, pterosaur 1828), that she sold fossils for a living, her brother Joseph's part, the names of the scientists who used her work.
6. $400 \div 23 \approx 17$ times. Even a spectacular skeleton brought little money compared with the family's needs; the Annings depended on a steady stream of sales and on the generosity of friends. The resale for roughly double the first price also shows that dealers and middlemen, not finders, often gained most.

2.2 WILLIAM BUCKLAND NAMES MEGALOSAURUS (1824)

OBJECTIVES

- Tell how a jaw and scattered bones from the Stonesfield quarries became the first dinosaur given a scientific name, and why it took years.
- Explain how Buckland reasoned from a few bones to a whole animal, and why his size estimate was too large.
- Describe fairly how Buckland's views on the Flood changed, and how Christians then and now read the rock record differently.

Warm-up. Have someone hand you three bones from a chicken dinner (cleaned) without telling you which parts they are. Can you tell how big the bird was? What else would you need to know? Buckland had a jaw, a thigh bone and a few other pieces of an animal nobody had ever seen.

Video slot. Video coming. Megalosaurus, William Buckland and the Oxford University Museum of Natural History; the Stonesfield slate. Search approved channels (Oxford University Museum of Natural History, Natural History Museum London); preview first.

KEY TERMS

Megalosaurus

"Great lizard," the first dinosaur to be given a scientific name, in Buckland's paper read on 20 February 1824. A two-legged meat-eater about 6 meters (20 feet) long by today's estimates.

Stonesfield slate

Thin limestone beds mined near Oxford for roofing "slates." Quarrymen sold the fossils they found to collectors.

comparative anatomy

The study of how the bodies of different animals compare, used to identify an unknown bone by matching it with known ones.

serrated

Edged with tiny saw-like teeth, as on a steak knife; a mark of a meat-eater's tooth.

diluvial

Having to do with the Flood (Latin *diluvium*). Early geologists called certain gravels and cave deposits "diluvium."

type specimen

The particular bone or skeleton to which a scientific name is tied, so later scientists can check what the name means.

CORE IDEAS

Bones in the roofing stone. For centuries the villagers of Stonesfield, about twelve miles from Oxford, dug thin limestone beds, left them out for winter frosts to split, and sold the pieces as roofing slates. Now and then a quarryman's pick struck bone. Over the early 1800s a set of large bones from these pits reached the University of Oxford: part of a lower jaw with blade-like teeth, vertebrae, pieces of the hip, a shoulder blade and leg bones. They were not all from one animal, and they were not found together. Strange large bones had come out of Oxfordshire before. In 1677 Robert Plot published a drawing of the knob-end of a huge thigh bone and suggested it came from a giant man. It was very likely a dinosaur bone, but it is now lost.

The reverend professor. William Buckland (1784–1856) was a clergyman of the Church of England and Oxford's first reader in geology, famous for lively lectures in which he waved bones and imitated animals. He studied the Stonesfield bones for years. The great French anatomist Georges Cuvier examined them on a visit to Oxford in 1818 and agreed they belonged to a giant reptile. Buckland's friend James Parkinson printed the name *Megalosaurus* in 1822 without describing the animal. Finally, on 20 February 1824, Buckland read his "Notice on the Megalosaurus or great Fossil Lizard of Stonesfield" to the Geological Society of London. With that paper, a dinosaur had a scientific name for the first time, though the word "dinosaur" did not yet exist (Stop B4).

Reasoning from a jaw. The jaw was the key. Its teeth sat in sockets, like a crocodile's, but were flattened, curved backward and finely serrated on their edges. They kept growing in, new teeth rising beneath old ones. A tooth like that cuts flesh; it does not grind plants. Buckland compared each bone with crocodiles and monitor lizards and concluded he had a huge, flesh-eating, land-dwelling reptile. As Owen later put it, quoting him, the teeth combined the features of "the knife, the sabre, and the saw."

How big? Here Buckland went wrong, and how he went wrong is instructive. He scaled the bones as if the animal were built like a giant lizard, low-slung with a long body and tail. That gave a length of more than 40 feet and the bulk of a large elephant. Owen later trimmed the estimate, and the Crystal Palace model of 1854 was built at 37 feet (Stop B5). Today, with better skeletons of related animals, *Megalosaurus* is thought to have been a two-legged predator about 6 meters (20 feet) long, weighing perhaps a ton. Buckland's observations were sound; his interpretation rested on an assumption, that the unknown animal was proportioned like a living lizard, and the assumption was wrong.

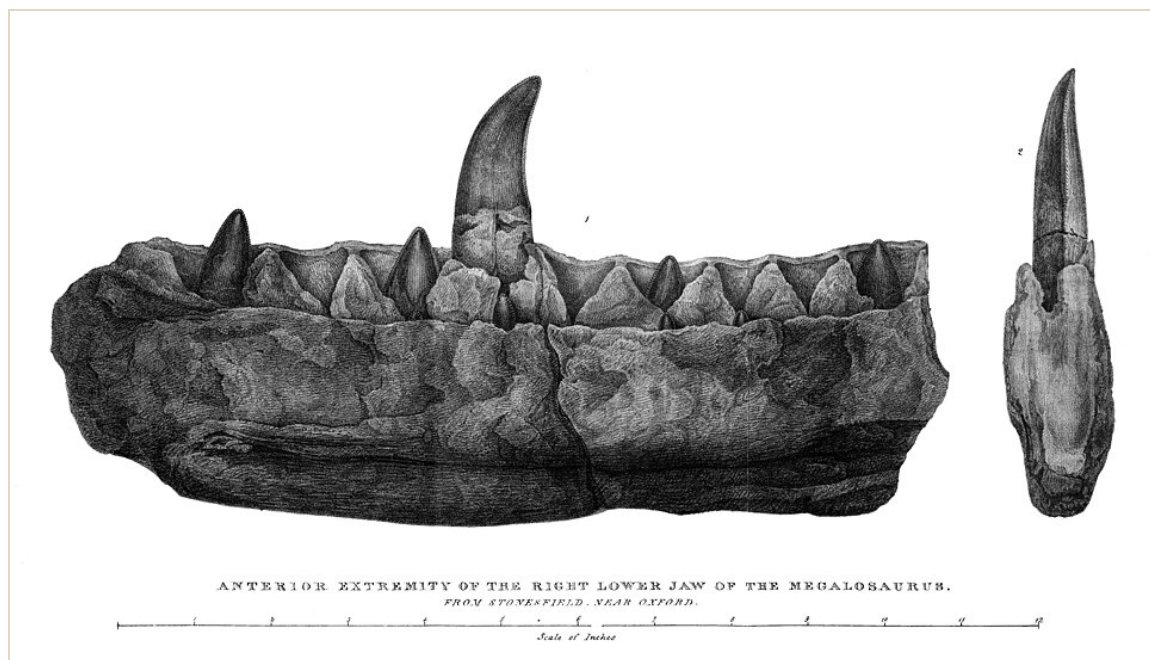
Buckland and the Flood. Buckland believed geology and Scripture would agree. In 1821–1823 he studied Kirkdale Cave in Yorkshire, full of hyena bones and gnawed bones of elephants and hippos, and argued in *Reliquiae Diluvianae* (1823) that the cave had been a hyena den sealed by Noah's Flood. By 1836, in his Bridgewater Treatise, he had changed his mind: he no longer thought the gravels and caves were Flood deposits, and he placed the fossil-bearing rocks in long ages before Adam, between the first two verses of Genesis. Other Christians of his day, sometimes called the "scriptural geologists," rejected that view and kept a young earth. Many creation geologists today argue that Buckland looked for the Flood

in the wrong place, in the thin surface gravels, rather than in the thick, fossil-filled rock layers themselves, such as the Stonesfield beds, which they read as laid down during the Flood year. Museums call the Stonesfield slate “Middle Jurassic,” a piece of museum vocabulary taught here without its attached date.

A name that stuck, mostly. Buckland gave only the genus. The species name, *Megalosaurus bucklandii*, came from Gideon Mantell in 1827. For a century afterward almost any large meat-eating dinosaur tooth from anywhere was called “*Megalosaurus*,” and the name became a wastebasket. Modern paleontologists have trimmed it back to the Stonesfield-type material. The original jaw, now designated the type specimen, is still displayed at the Oxford University Museum of Natural History.

Why it matters. The *Megalosaurus* paper showed that comparative anatomy could reliably say what kind of animal a few bones came from: a meat-eating reptile living on land. It also showed the limits of the method: what you assume about the missing parts shapes the picture you draw. Both lessons run through the rest of this trail.

PICTURE STUDY



The lower jaw of Megalosaurus, plate from Buckland's "Notice on the Megalosaurus", Drawn for William Buckland (often credited to Mary Morland), 1824 · Lithograph · Transactions of the Geological Society of London, 2nd series, vol. 1; the jaw itself is at the Oxford University Museum of Natural History
Wikimedia Commons · Public domain

This is the drawing scientists all over Europe saw when they first read about *Megalosaurus*. A careful plate let readers check Buckland's reasoning without traveling to Oxford.

Look closely

- Count the teeth in the jaw. Do they look the same size, or are some smaller ones coming in?

- Look closely at a single tooth. Find the curve and the edges.
- Notice what the artist leaves out: there is no imagined skin, color or setting. Why?

Talk about it

1. Compare this plate with De la Beche's *Duria Antiquior* (Stop B1). Which is more useful to a scientist, and which to the public?
2. From the jaw alone, what can you be sure of about *Megalosaurus*, and what can you only guess?

HANDS-ON: FROM BONES TO BODY: TESTING BUCKLAND'S ASSUMPTION

Reconstruct an animal from a few "bones" using two different assumptions about its build, and see how much the answer changes.

You will need

- Graph paper and a ruler
- Calculator
- The primary source in the asides

Steps

1. Read the primary source. Write down, word for word, the two things Buckland says made him confident about the limbs.
2. Assume a thigh bone 0.8 m long (close to a large *Megalosaurus* femur).
3. Model 1, Buckland's lizard: suppose the whole animal is about 15 times the length of its thigh bone. Calculate the length and draw it to scale (1 square = 0.5 m) as a sprawling lizard.
4. Model 2, an upright two-legged predator: suppose it is about 7.5 times the thigh-bone length. Calculate and draw it beside the first.
5. Write a short paragraph: which numbers came from observation and which from assumption? Which model matches today's estimate of about 6 m?

Check your work

- I calculated both lengths (12 m and 6 m).
- Both drawings are to the same scale and labeled.
- I can say which part of Buckland's reasoning was observation and which was assumption.

FIELD NOTEBOOK

1. Draw one *Megalosaurus* tooth, large, from the side. Label the crown, the backward curve and the serrated edges, and write what each tells about diet.
2. Make a three-column table, "Plot 1677 / Buckland 1824 / today," and write what each thought the big Oxfordshire bones were.

3. **Narration.** Write one paragraph explaining how Buckland identified Megalosaurus as a meat-eating land reptile and why his size estimate was wrong. A parent keeps this page.

Did you know? Charles Dickens opened his novel *Bleak House* (1852–53) by imagining a Megalosaurus waddling up a muddy London street, only a generation after Buckland named it. Buckland himself was known for trying to taste as many kinds of animal as he could, and kept a pet bear at Oxford for a time. His son Frank continued the tradition.

Primary source. Richard Owen, *Geology and Inhabitants of the Ancient World* (London: Crystal Palace Library, 1854), the guide to Hawkins' models, quoting Buckland. Project Gutenberg eBook #62414.

The Megalosaurus, as its name implies (compounded by its discoverer, Dr. Buckland, from the Greek *megas*, great, and *sauros*, lizard), was a lizard-like reptile of great size, 'of which,' writes Dr. Buckland, 'although no skeleton has yet been found entire, so many perfect bones and teeth have been discovered in the same quarries, that we are nearly as well acquainted with the form and dimensions of the limbs as if they had been found together in a single block of stone.'

The fossils which brought to light the former existence of this most formidable reptile, were discovered in 1823, in the oolitic slate of Stonesfield, near Oxford, and were described by Dr. Buckland, in the volume of the 'Geological Transactions' for the year 1824.

Go deeper. Deborah Cadbury, *The Dinosaur Hunters* (2000; U.S. title *Terrible Lizard*). Christopher McGowan, *The Dragon Seekers* (2001). Oxford University Museum of Natural History: pages on Megalosaurus and William Buckland. Second video: Kirkdale Cave and Buckland's hyena den.

Goes deeper in. Earth Science, the fossils and Flood-geology units (coming soon); and Life Science, the skeleton (comparing bones).

For families. Buckland's paper was read 20 February 1824 and printed in *Transactions of the Geological Society of London*, 2nd series, vol. 1. Owen's 1854 guide says the fossils were "discovered in 1823"; in fact the bones had been collected over several years before then, a small discrepancy worth noticing with students. Parkinson's 1822 use of the name is usually treated as a name without a description. Plot's 1677 bone was later labeled *Scrotum humanum* by Richard Brookes (1763) because of its shape; that name is not used. The drawing of the jaw is often credited to Mary Morland, who married Buckland in 1825 and drew for him and for Cuvier; the attribution is hedged. Modern length (about 6 m) follows Benson's revision of the genus (2010). Buckland's "gap" reading of Genesis is presented as his position, alongside the young-earth reading the course teaches.

PRACTICE

1. **EASY** What does Megalosaurus mean, and in what year was it named?
2. **EASY** Where were the Megalosaurus bones found, and how did they reach scientists?
3. **MEDIUM** Which features of the teeth told Buckland that Megalosaurus ate meat?
4. **MEDIUM** How did Buckland's view of the Flood change between 1823 and 1836?
5. **CHALLENGE** In the primary source, Buckland says that so many bones came from the same quarries that he knew the limbs "as if they had been found together in a single block of stone." Give one reason that confidence was justified and one reason it was risky.
6. **CHALLENGE** Buckland estimated more than 40 feet; the 1854 model is 37 feet; today's estimate is about 6 meters. Convert 6 m to feet ($1 \text{ m} \approx 3.28 \text{ ft}$) and find by what percentage the 40-foot estimate was too large.

Make it a game · Name That Bone. One player draws a single bone or tooth from a familiar animal (a dog's fang, a bird's wishbone, a cow's molar). Others guess the animal and what it ate, and must give one reason from the shape. A correct animal with a correct reason scores two points; a correct guess with no reason scores one.

Scripture. "The works of the LORD are great, sought out of all them that have pleasure therein." (Psalm 111:2, KJV)

These words, in Latin, are carved over the old door of the Cavendish Laboratory in Cambridge. Buckland sought out God's works with delight. His successes and his mistakes both show that seeking is slow, careful work and that conclusions must keep being tested.

Practice: answers

1. "Great lizard"; named by William Buckland in a paper read in February 1824.
2. In the Stonesfield slate quarries near Oxford; quarrymen found them while digging roofing stone and sold them to collectors and the university.
3. They were flattened blades, curved backward, with finely serrated cutting edges, set in sockets and replaced from below: tools for slicing flesh, not grinding plants.
4. In 1823 (*Reliquiae Diluvianae*) he argued that cave deposits and gravels like Kirkdale were left by Noah's Flood. By 1836 (*Bridgewater Treatise*) he no longer read them as Flood deposits and placed the fossil-bearing rocks in long ages before Adam.
5. Justified: many repeated, well-preserved bones of the same shape from one locality let him compare and average them, and comparative anatomy can match bones reliably. Risky: the bones were not found together and might come from different individuals, sizes or even different kinds of animal; and the overall build still had to be assumed, which led to his oversized, lizard-like estimate.
6. $6 \times 3.28 \approx 19.7 \text{ ft}$, about 20 ft. $(40 - 20) \div 20 = 1.0$, so the estimate was about 100% too large: roughly double the modern figure.

2.3 GIDEON AND MARY ANN MANTELL'S IGUANODON

OBJECTIVES

- Tell the story of the Iguanodon teeth from the Sussex quarries to the Royal Society paper of 1825, including the doubts of the experts.
- Trace how the picture of Iguanodon changed with new evidence: the 1834 Maidstone slab and the 1878 Bernissart skeletons.
- Analyze Cuvier's 1824 letter as an example of scientific reasoning: evidence, hypothesis and a testable prediction.

Warm-up. Look at your own front teeth and back teeth in a mirror. One set cuts and one set grinds. If someone found only one of your molars a thousand years from now, what could they say about what you ate? The Mantells began with a handful of worn teeth.

Video slot. Video coming. Gideon Mantell, Mary Ann Mantell and the discovery of Iguanodon; the Iguanodons of Bernissart in Brussels. Search approved channels (Natural History Museum London, Royal Belgian Institute of Natural Sciences, Sussex museums); preview first.

KEY TERMS

Iguanodon

"Iguana tooth," a large plant-eating dinosaur named by Gideon Mantell in 1825, the second dinosaur to be named.

Wealden

The layers of sandstone and clay under the Weald of Sussex, Kent and Surrey, where Iguanodon was found. Museums label them "Early Cretaceous."

herbivore

An animal that eats plants. Cuvier's key insight was that the teeth came from a plant-eating reptile.

hypothesis

A proposed explanation that can be tested by further evidence.

thumb spike

The cone-shaped bone first thought to be a nose horn; the Bernissart skeletons showed it sat on the hand.

reconstruction

A drawing, model or mounted skeleton showing what an extinct animal is thought to have looked like; always partly interpretation.

CORE IDEAS

A doctor and an engraver. Gideon Mantell (1790–1852) was a busy country surgeon in Lewes, Sussex, who delivered babies, set bones and spent his few spare hours, often late at night, on fossils. In 1816 he married Mary Ann Woodhouse, who shared the work. When he published *The Fossils of the South Downs* in 1822, the dozens of careful plates were engraved by Mary Ann herself. That was skilled, exacting work, and it made the book useful to every geologist who read it.

The teeth. Around the spring of 1822, large, worn, ridged teeth came to light in the quarries of the Tilgate Forest district near Cuckfield. The famous story, told by Owen in 1854 and by Mantell late in life, is that Mary Ann spotted the first one in a heap of stone while her husband visited a patient. Historians have noted that Mantell’s own earlier notes do not mention it that way and that quarrymen also sold him teeth, so the details are uncertain. What is certain is that the Mantells together collected the teeth, and Gideon saw that they were unlike anything he knew. The teeth were flattened, with ridged and notched edges, and were worn flat on top, as though by grinding plants. But plant-eating reptiles were not thought to exist.

The experts say no. In 1822 Mantell showed the teeth at the Geological Society of London. Buckland, Conybeare and others thought they were fish teeth or mammal teeth from a later layer. In 1823 the geologist Charles Lyell carried one to Paris, where Cuvier at first called it the incisor of a rhinoceros. Mantell kept collecting. Then Cuvier looked again, with more specimens, and in 1824 wrote the remarkable letter quoted in the primary source: the teeth were reptilian, and the animal must have been a *herbivorous* reptile. That same year, at the Hunterian Museum in London, the assistant curator Samuel Stutchbury showed Mantell the skeleton of a modern iguana. Its small teeth matched the fossils in form, though the fossils were about twenty times larger.

Naming the animal. Mantell wanted to call it *Iguanasauros*; William Conybeare suggested *Iguanodon*, “iguana tooth,” and Mantell took the advice. His paper was read before the Royal Society in February 1825. Scaling up an iguana gave a giant many times longer than any living lizard. Like Buckland, Mantell had assumed the unknown animal was built like the living animal it resembled most. Mantell went on to name *Hylaeosaurus* (1833), an armored dinosaur and the third of Owen’s original three dinosaurs.

The Maidstone slab and the horn. In 1834 a quarry owner at Maidstone, Kent, William Bensted, found many bones of one animal together in a block of stone. Mantell’s friends raised £25 to buy it for him; he joked that it was his “Mantel-piece.” From it he sketched a new reconstruction, and he put a cone-shaped bone on the animal’s nose as a horn. Owen and Hawkins kept that horn on the 1854 Crystal Palace model, though Owen called it “more than doubtful” (Stop B5). The answer came in 1878, when coal miners at Bernissart in Belgium broke into a clay-filled fissure more than 300 meters down and found dozens of *Iguanodon* skeletons, many nearly complete. Louis Dollo’s study showed that the “horn” was a thumb spike. Dollo mounted the skeletons standing upright like kangaroos; restudy in the

1980s showed they mostly walked on all fours and held the tail out level. Each picture was an honest attempt from the evidence then in hand.

A costly passion. Fossils took more than Mantell had to give. He moved to Brighton to be nearer wealthy patrons, built a public museum in his house and fell into debt. In 1838 he sold his collection to the British Museum for £4,000. The marriage broke down, and in 1839 Mary Ann left. In 1841 a carriage accident injured his spine and left him in pain for the rest of his life. He kept working, and the Royal Society awarded him its Royal Medal in 1849 for his Iguanodon studies. He died in 1852. Richard Owen, his rival, opposed several of his papers, and an unkind unsigned obituary is usually attributed to Owen (Stop B4).

What the story teaches. The Iguanodon story shows science working well over decades: a careful observer collects, experts doubt, more evidence arrives, and a hypothesis is confirmed and then corrected. Mantell's and Cuvier's reasoning from the teeth held up. The details of the body did not, until whole skeletons were found. Notice too that the work was shared: a surgeon, his wife, quarrymen, a curator's assistant, a French anatomist and Belgian miners all had a part.

PICTURE STUDY

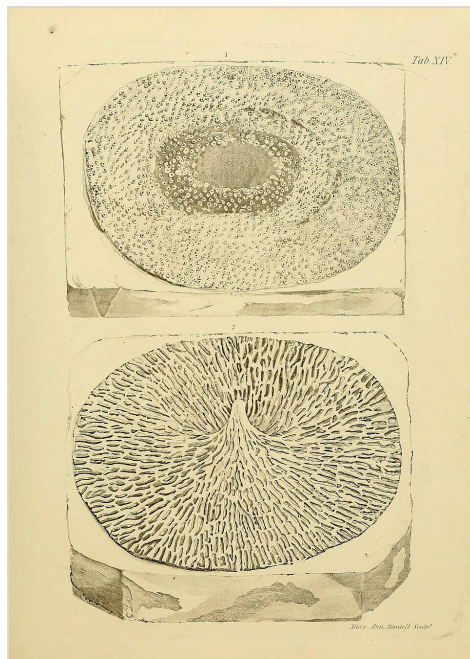


Plate from The Fossils of the South Downs, Engraved by Mary Ann Mantell for Gideon Mantell, 1822 · Engraving · Gideon Mantell, *The Fossils of the South Downs, or Illustrations of the Geology of Sussex* (London, 1822); copies in the Biodiversity Heritage Library
Wikimedia Commons · Public domain

Mary Ann Mantell engraved the plates for her husband's first book. Engraving meant cutting every line, backward, into a metal plate so it could be inked and printed. Her accuracy let readers in London and Paris identify fossils they had never seen in person.

Look closely

- Pick one fossil and count how many kinds of line (dots, hatching, outlines) are used to show its shape.
- Find the numbers. What are they for?
- Notice the light. From which side does it fall on every object, and why would an engraver keep it the same?

Talk about it

1. Why would a scientific engraver avoid adding anything that is not in the specimen?
2. How does an accurate picture let other scientists test the author's claims?

HANDS-ON: CUVIER'S LETTER: EVIDENCE, HYPOTHESIS, PREDICTION

Cuvier's 1824 letter is a small model of good scientific reasoning. Take it apart, then test your own tooth hypothesis.

You will need

- The primary source in the asides
- Three colored pencils
- Teeth to compare: pictures or real ones (dog or cat, cow or horse, a shark tooth, a fish)
- Notebook

Steps

1. Read Cuvier's letter aloud. In one color underline the observations about the teeth. In another underline the hypothesis. In a third underline the prediction.
2. Write in your own words the analogy Cuvier draws from living mammals. Is it a proof or a reason to expect something?
3. Find what actually happened: which later finds "confirmed" and which "confuted" parts of the idea? (Use the core ideas: 1834 and 1878.)
4. Now examine the teeth you gathered. For each, write one observation (shape, edges, wear) and a hypothesis about diet.
5. Write a prediction for one of them that a further find could test, as Cuvier did.

Check your work

- I marked observation, hypothesis and prediction in three colors.
- I can say which part of Cuvier's idea was confirmed and how.
- I wrote my own testable prediction.

FIELD NOTEBOOK

1. Draw three reconstructions in a row: Mantell's 1834 idea (horn on the nose, lizard-like), Dollo's upright 1880s mount, and today's four-legged Iguanodon. Label the thumb spike in each.
2. Make a "who did what" chart for the Iguanodon story with at least six people.

3. **Narration.** Write one paragraph telling how the Iguanodon teeth went from being called fish or rhinoceros teeth to being recognized as a plant-eating reptile's. A parent keeps this page.

Did you know? The coat of arms of the town of Maidstone, Kent, has included an Iguanodon since 1949, honoring the 1834 slab. In Brussels, the Royal Belgian Institute of Natural Sciences displays the Bernissart Iguanodons in a tall glass hall, some still standing upright as they were first mounted and others lying as they were found.

Primary source. *Richard Owen, Geology and Inhabitants of the Ancient World (London: Crystal Palace Library, 1854), the section on the Iguanodon, quoting Mantell and Cuvier's 1824 letter. Project Gutenberg eBook #62414.*

One afternoon, in the spring of 1822, an accomplished lady, the wife of a medical practitioner, at Lewes, in Sussex, walking along the picturesque paths of Tilgate Forest, discovered some objects in the coarse conglomerate rock of the quarries of that locality, which, from their peculiar form and substance, she thought would be interesting to her husband, whose attention had been directed, during his professional drives, to the geology and fossils of his neighbourhood.

"As these teeth," writes the doctor, "were distinct from any that had previously come under my notice, I felt anxious to submit them to the examination of persons whose knowledge and means of observation were more extensive than my own."

"These teeth are certainly unknown to me; they are not from a carnivorous animal, and yet I believe that they belong, from their slight degree of complexity, the notching of their margins, and the thin coat of enamel that covers them, to the order of reptiles. May we not here have a new animal!—a herbivorous reptile? And, just as at the present time with regard to mammals (land-quadrupeds with warm blood), it is amongst the herbivorous that we find the largest species, so also with the reptiles at the remote period when they were the sole terrestrial animals, might not the largest amongst them have been nourished by vegetables? Some of the great bones which you possess may belong to this animal, which, up to the present time, is unique in its kind. Time will confirm or confute this idea, since it is impossible but that one day a part of the skeleton, united to portions of jaws with the teeth, will be discovered.'

"The name Iguanodon, derived from the form of the teeth, (and which I have adopted at the suggestion of the Rev. W. Conybeare,) will not, it is presumed, be deemed objectionable."

Go deeper. Dennis R. Dean, *Gideon Mantell and the Discovery of Dinosaurs* (1999). Deborah Cadbury, *The Dinosaur Hunters* (2000). Natural History Museum, London: pages on Mantell's Iguanodon teeth. Royal Belgian Institute of Natural Sciences: the Bernissart

Iguanodons. Second video: the Bernissart mine discovery and how the skeletons were removed.

Goes deeper in. Life Science, teeth and diet (coming soon); Earth Science, the fossils unit; and Art, scientific illustration and engraving.

For families. The teeth came from the Whiteman's Green area near Cuckfield, in the Tilgate Forest district. Whether Mary Ann Mantell found the very first tooth is debated (Dean 1999 discusses the evidence); the stop says so. The Royal Society paper is Mantell, "Notice on the Iguanodon," *Philosophical Transactions* 115 (1825). Cuvier's first identification as a rhinoceros incisor and his later revision are both in the record. Owen's guide omits the Mantells' names in its first sentence, as was a common polite style; students can discuss it. The Bernissart find was in 1878; numbers given range from about 30 to 38 individuals. In 2000 the official type species of Iguanodon was changed to *I. bernissartensis* because Mantell's original teeth are not distinctive enough; some researchers also assign the Maidstone slab to a related genus. The Mantells' separation is stated plainly as fact and not elaborated.

PRACTICE

1. **EASY** What does Iguanodon mean, and who suggested the name?
2. **EASY** What did Mary Ann Mantell contribute to her husband's first book?
3. **MEDIUM** What did the experts first say the teeth were, and why was a plant-eating reptile hard for them to accept?
4. **MEDIUM** What did the 1878 Bernissart discovery show about Mantell's "horn"?
5. **CHALLENGE** In the primary source, identify Cuvier's three observations, his hypothesis, the analogy he uses to support it, and his prediction. Was the prediction fulfilled?
6. **CHALLENGE** A large modern green iguana is about 1.5 m long. If the fossil teeth were about 20 times larger than an iguana's and you scaled the whole animal by the same factor, how long would Iguanodon be? Compare with today's estimate of about 10 m and explain the error.

Make it a game · Horn or Thumb?. Lay out 8–10 paper "bones" for a made-up animal with one odd piece (a cone). Each player assembles the animal and must place the cone somewhere and defend it. Then the leader reveals a "new find" card (for example, a hand with the cone attached), and players must revise. A player who revises gracefully with a reason scores a point.

Scripture. "Give her of the fruit of her hands; and let her own works praise her in the gates." (Proverbs 31:31, KJV)

Mary Ann Mantell's careful engravings are still in libraries two centuries later. Honest history gives each worker the credit their hands have earned.

Practice: answers

1. "Iguana tooth"; suggested by the Rev. William Conybeare and adopted by Gideon Mantell (1825).
2. She engraved the plates for *The Fossils of the South Downs* (1822); she also helped collect fossils.
3. Fish teeth or mammal teeth from a later layer; Cuvier first said a rhinoceros incisor. No large plant-eating reptile was known, and the teeth were worn by grinding, as in mammals.
4. With dozens of nearly complete skeletons, Dollo could see the cone-shaped bone was on the hand: it was a thumb spike, not a nose horn.
5. Observations: slight complexity of the teeth, notched margins, thin enamel (also: not from a carnivore). Hypothesis: a new herbivorous reptile. Analogy: among living land mammals the largest species are plant-eaters, so the largest reptiles of that time may have been too. Prediction: a skeleton with jaws and teeth together would one day be found to confirm or refute the idea. Fulfilled: the Maidstone slab (1834) and especially the Bernissart skeletons (1878) joined teeth, jaws and skeleton and confirmed a large plant-eating reptile.
6. $1.5 \times 20 = 30$ m (about 100 ft). That is three times too long. Teeth do not scale with body length the same way in different animals, and *Iguanodon* was not built like an iguana; it had large teeth for its size and a shorter body and tail than a lizard scaled up.

2.4 RICHARD OWEN COINS “DINOSAURIA” (1842)

OBJECTIVES

- Explain what Owen meant by “Dinosauria,” which three animals he grouped, and the features he used to define the group.
- Describe Owen’s larger purpose, especially his argument against the idea that living things steadily progress on their own.
- Weigh Owen’s brilliance as an anatomist against his treatment of rivals, judging him fairly by the standards of his own day.

Warm-up. Write down a definition of “dinosaur” in one sentence without looking anything up. Then ask: does your definition include crocodiles? Pterosaurs? Plesiosaurs? Birds? In 1842 one man had to write the first definition.

Video slot. Video coming. Richard Owen, the word “dinosaur,” and the founding of the Natural History Museum in London. Search approved channels (Natural History Museum London, Royal College of Surgeons Hunterian Museum); preview first.

KEY TERMS

Dinosauria

The group named by Richard Owen in his report published in 1842, from Greek *deinos* (terribly great, fearful) and *sauros* (lizard).

sacrum

The bones of the backbone joined to the hip. Owen noted that his dinosaurs had five vertebrae fused into a strong sacrum.

diagnosis

In naming, the list of features that sets a group apart from all others.

transmutation

The early 1800s word for the idea that one kind of living thing changes into another over time (later, evolution). Owen used his dinosaurs to argue against the popular version of it.

archetype

Owen’s word for an ideal plan, which he held was in the mind of the Creator, underlying the skeletons of all backboned animals.

Hunterian Museum

The anatomy museum of the Royal College of Surgeons in London, where Owen worked for more than twenty years.

CORE IDEAS

The anatomist. Richard Owen (1804–1892) was born in Lancaster, trained as a surgeon and became the conservator, then professor, at the Hunterian Museum in London. He dissected

almost everything that died at the London Zoo and could identify an animal from a fragment. In 1839 he was handed a six-inch piece of bone from New Zealand and announced that it came from a giant bird, larger than an ostrich, then unknown to science. Within a few years crates of moa bones arrived and proved him right. Charles Darwin chose Owen to describe the fossil mammals from the voyage of the *Beagle*. By 1840 he was often called the British Cuvier.

A report on fossil reptiles. The British Association for the Advancement of Science asked Owen to review every fossil reptile known from Britain. He presented the second part of his report at the Association's meeting in Plymouth in the summer of 1841, and it was printed in April 1842. In the printed version he grouped together three animals: Buckland's *Megalosaurus* (Stop B2), Mantell's *Iguanodon* (Stop B3) and Mantell's armored *Hylaeosaurus*, and named them a new order, the *Dinosauria*. Historians note that newspaper reports of the 1841 lecture do not use the word, so Owen probably added it while writing up the report. That is why the date is given as 1842.

What made a dinosaur. Owen did not group them simply because they were big. He listed shared features. Their hip had five vertebrae fused into a strong sacrum, where most reptiles have two. Their ribs were double-headed. Most important, their legs were held upright under the body, like an elephant's or a rhinoceros's, rather than sprawling out to the sides like a lizard's. These were heavy land animals, built, as he put it in 1854, "for more efficient progression upon dry land." He drew them as huge, four-legged, almost mammal-like reptiles. That was a big correction of Buckland's and Mantell's giant lizards, though, as later finds showed, many dinosaurs walked on two legs.

Owen's purpose. Owen had an argument to make. Some radical thinkers in the 1830s, following Jean-Baptiste Lamarck, taught that living things climb steadily upward by their own natural drive, from simple to complex, with no need of a Creator. Owen pointed out that his dinosaurs, which came early in the fossil record, were in many ways more advanced in build than the reptiles living today. Reptiles, he argued, had not climbed; if anything they had declined. Owen believed the patterns in skeletons reflected a plan, an "archetype" in the mind of God, and his dinosaurs were part of his case. Later, he opposed Darwin's theory of natural selection as well, though he came to accept some kind of lawful development of species.

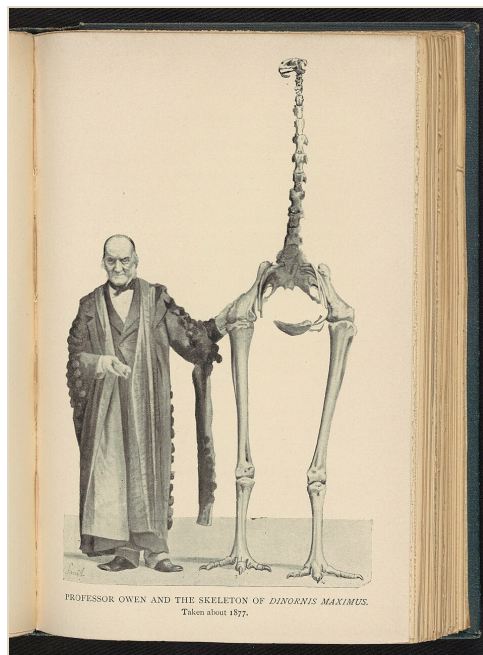
Builder of a cathedral. In 1856 Owen became superintendent of the natural history collections of the British Museum. He argued for years that God's creatures deserved a great building of their own, open to ordinary people. The result was the Natural History Museum in South Kensington, opened in 1881, with carvings of plants and animals over every arch. Owen also advised Hawkins on the Crystal Palace dinosaurs (Stop B5) and in 1863 described the first *Archaeopteryx* skeleton to reach Britain. He was knighted in 1884.

Honest complexity: the rival. Owen was brilliant and could be ruthless. He rarely gave credit to others when he could take it, and he quarreled with many contemporaries. Gideon Mantell, older and in poor health, believed that Owen worked against his papers at the Royal Society and took credit for discoveries about *Iguanodon* and other animals that Mantell had

made first. Other colleagues complained of the same thing, and over the years several learned societies grew tired of his quarrels. Judged by the standards of his own day, not ours, this was still wrong: gentlemen of science were expected to acknowledge the work of others, and Owen often did not. His science and his character have to be weighed separately.

Was Owen's definition right? Owen's three animals still belong to Dinosauria, and the word has spread to every language. His group, though, has been redrawn many times. Scientists now define dinosaurs by features of the hip socket and limbs and by family relationships, and today's diagnosis is longer and more technical. Pterosaurs, ichthyosaurs and plesiosaurs, often called dinosaurs in casual speech, are not. Most paleontologists today also class birds within the dinosaur group, a claim Christians evaluate in Trail C. The lesson of Owen's definition is that a scientific name is a tool: it names what has been observed and is refined as more is observed.

PICTURE STUDY



Richard Owen with the skeleton of a giant moa, Unknown photographer, about 1877–1879 · Albumen photograph · Natural History Museum archives, London (often reproduced)
Wikimedia Commons · Public domain

Late in life Owen posed beside a mounted moa, the bird he had predicted from one fragment of bone in 1839. In his hand is a bone, a reminder of how the story began.

Look closely

- Compare Owen's height with the moa's. How much taller is the bird?
- Find the bone in Owen's hand. Why might he have chosen to hold it?
- Look at the bird's legs and feet. What do they tell you about how it moved?

Talk about it

1. Why would Owen want to be remembered with the moa rather than with a dinosaur?
2. The moa prediction was confirmed by complete skeletons. What would count as confirmation of a reconstruction of an extinct animal?

HANDS-ON: WRITE A DIAGNOSIS

A good scientific group is defined by shared features, not just by size or how impressive something looks. Practice Owen's method on familiar animals, then test his 1842 definition.

You will need

- Pictures or toy models of 8–10 animals: lizard, crocodile, turtle, elephant, horse, chicken, ostrich, and toy dinosaurs
- Index cards
- The primary source in the asides

Steps

1. Sort the animals by how their legs meet the body: sprawling to the sides, or upright underneath.
2. On a card, write a three-feature diagnosis for a group you invent (for example, "upright legs, beak, lays hard-shelled eggs"). Which animals fit?
3. Read the primary source. What features does Owen say fitted Dinosauria for life on land? Which three animals does he name in this guide (one by name earlier, two in this sentence)?
4. Write a one-sentence diagnosis of Dinosauria in Owen's 1842 terms: five fused hip vertebrae, upright limbs, great size, land living.
5. Test it: would it include a crocodile? A plesiosaur? A small two-legged dinosaur like *Compsognathus*? Write what this shows about Owen's definition.

Check your work

- I sorted by legs, not by size.
- I wrote a diagnosis in Owen's terms.
- I found at least one case where Owen's definition needed improving.

FIELD NOTEBOOK

1. Draw the front view of two animals: a lizard with sprawling legs and an elephant with legs underneath. Under them, draw Owen's *Megalosaurus* the way he imagined it. Label the posture.
2. Write the Greek roots of three dinosaur names from this trail and what they mean.
3. **Narration.** Write one paragraph explaining what Owen meant by Dinosauria and why he used it to argue against the idea that animals climb upward by themselves. A parent keeps this page.

Did you know? Owen's word is usually translated "terrible lizard," but Owen's own explanation in 1854 was "terribly great." The Greek *deinos* can mean fearful, awe-inspiring or wondrous. A statue of Owen once stood at the top of the main staircase of the Natural History Museum; in 2008 a statue of Darwin took that place, and Owen's was moved to a less central spot in the building.

Primary source. Richard Owen, *Geology and Inhabitants of the Ancient World* (London: Crystal Palace Library, 1854), the entry for the *Megalosaurus* model. Project Gutenberg eBook #62414.

The restoration of the animal has been accordingly effected, agreeably with the proportions of the known parts of the skeleton, and in harmony with the general characters of the order of reptiles to which the *Megalosaurus* belonged. This order—the Dinosauria (Gr. *deinos*, terribly great *sauros*, a lizard)—is that to which the two foregoing huge reptiles of the Wealden series belong, viz., the *Iguanodon* and *Hylæosaurus*, and is characterised by the modifications already mentioned, that fitted them for more efficient progression upon dry land.

Go deeper. Nicolaas Rupke, *Richard Owen: Biology without Darwin* (revised edition, 2009). Deborah Cadbury, *The Dinosaur Hunters* (2000), on Owen and Mantell. Natural History Museum, London: history of the Waterhouse building and Hintze Hall. Second video: how Owen identified the moa from one bone.

Goes deeper in. Life Science, classification and the skeleton (coming soon); History, Victorian Britain; and Earth Science, the fossils unit.

For families. Owen's report: "Report on British Fossil Reptiles, Part II," *Report of the Eleventh Meeting of the British Association for the Advancement of Science* (published April 1842). Hugh Torrens (1992) showed the word was probably added after the 1841 lecture. Owen's anti-Lamarckian purpose is argued by Adrian Desmond and others and widely accepted. The moa fragment (1839) and confirmation (1843) are well documented. His conflicts with Mantell, Huxley and others are documented by Rupke and Cadbury; the stop states them plainly without slogans. The 2008 statue change is described only in general terms because accounts of where Owen's statue now stands vary. Whether birds are dinosaurs is left to Trail C.

PRACTICE

1. **EASY** What three animals did Owen place in his new group Dinosauria?
2. **EASY** Give the Greek roots of "dinosaur" and Owen's own translation.
3. **MEDIUM** Name two anatomical features Owen used to define Dinosauria.
4. **MEDIUM** Why is the word usually dated 1842 rather than 1841?
5. **CHALLENGE** Explain how Owen used his dinosaurs to argue against Lamarck-style transmutation. Is the argument decisive? Give one strength and one weakness.

6. **CHALLENGE** Using the primary source, name the observed basis and the interpretive basis for Hawkins' Megalosaurus model.

Make it a game • Define It. One player secretly picks a group (birds, things with wheels, mammals). They give one diagnostic feature at a time. Others name an example that fits. If someone names an example that fits the features but is not in the group, the definer must add a feature. Fewest features to a perfect definition wins.

Scripture. "O LORD, how manifold are thy works! in wisdom hast thou made them all: the earth is full of thy riches." (Psalm 104:24, KJV)

Owen spent his life naming and ordering the "manifold works" of God. Classification is a way of noticing the wisdom and order in creation, and it is humble work, always open to correction.

Practice: answers

1. Megalosaurus, Iguanodon and Hylaeosaurus.
2. *Deinos* and *sauros*; Owen translated it "terribly great lizard" (often given as "terrible lizard").
3. Any two: five vertebrae fused in the sacrum; upright limbs under the body like large mammals; double-headed ribs; adaptations for heavy walking on land.
4. Owen gave the lecture in 1841, but reports of the lecture do not use the word; it appears in the printed report published in April 1842, so he probably added it then.
5. Owen argued that early dinosaurs were more advanced in build (mammal-like posture, strong sacrum) than living reptiles, so reptiles had not steadily progressed upward; they had, if anything, declined. Strength: it uses observed anatomy to test a claim of constant upward progress, and the evidence did not fit. Weakness: it answers only one version of change over time; a theory in which change is branching rather than always upward (as Darwin later proposed) is not touched by it.
6. Observed: "the proportions of the known parts of the skeleton." Interpretive: "in harmony with the general characters of the order of reptiles" to which it belonged, meaning missing parts were filled in from what Owen believed all dinosaurs were like (heavy, four-legged). Where that belief was wrong, as with Megalosaurus walking on two legs, the model was wrong.

2.5 HAWKINS' CRYSTAL PALACE DINOSAURS (1854)

OBJECTIVES

- Describe how Benjamin Waterhouse Hawkins and Richard Owen built the first life-size dinosaur models and what they were made of.
- Sort what the models got right and wrong, and explain why each mistake was reasonable from the evidence of 1854.
- Analyze a public science display as both teaching and persuasion, including the assumptions built into it.

Warm-up. Think of the last museum diorama, movie or toy that showed a dinosaur. Did it have feathers, scales, a color pattern, a pose, a sound? Which of those details do you think came from bones, and which from an artist?

Video slot. Video coming. The Crystal Palace dinosaurs of Benjamin Waterhouse Hawkins in Crystal Palace Park, London; their restoration. Search approved channels (Friends of Crystal Palace Dinosaurs, Natural History Museum London, Historic England); preview first.

KEY TERMS

Crystal Palace

A huge glass and iron hall built for the Great Exhibition of 1851 in Hyde Park, then rebuilt larger at Sydenham in south London, reopening in 1854.

armature

The inner framework that holds up a sculpture. Hawkins used iron, brick and tile inside his models.

restoration

In Victorian usage, a reconstruction of an extinct animal as it looked alive.

geological island

The islands in the park's lake where the models were grouped in the order of the rock layers in which their fossils were found.

mounted skeleton

Real or cast bones fixed on a frame in a lifelike pose. Hawkins built the world's first mounted dinosaur skeleton, *Hadrosaurus*, in Philadelphia in 1868.

listed

In Britain, protected by law as a building or monument of special historic interest. The Crystal Palace dinosaurs are listed at the highest grade, Grade I.

CORE IDEAS

A palace and a park. The Great Exhibition of 1851 filled a palace of glass in London's Hyde Park with the products of industry from around the world. When it closed, a company bought the building, moved it to Sydenham Hill in south London and rebuilt it even larger, surrounded by a park of fountains and gardens. The company wanted the park to teach as well as delight. In 1852 it commissioned Benjamin Waterhouse Hawkins (1807–1894), a sculptor and natural-history artist, to build life-size models of extinct animals, with Richard Owen (Stop B4) as scientific adviser. No one had ever tried this before.

How they were built. Hawkins set up a workshop in the park. For each animal he and Owen studied the bones, worked out proportions and made a small clay model. Then Hawkins enlarged it to full size. The big models were not solid stone. Each had a skeleton of iron rods and columns, a core of brick and tiles, and an outer skin of cement modeled into scales, wrinkles and claws. A single Iguanodon used hundreds of bricks and tiles and many casks of cement. In all there were about thirty-three models: ichthyosaurs and plesiosaurs from Mary Anning's coast, pterosaurs, the three dinosaurs Owen had grouped as Dinosauria, a mosasaur, and mammals such as the giant ground sloth *Megatherium* and the Irish elk. They were placed on islands in the lake roughly in the order of the rock layers in which their fossils had been found, and the lake rose and fell so that the sea reptiles appeared to swim.

Dinner in a dinosaur. To win publicity, Hawkins held a dinner on New Year's Eve, 1853, inside the mold of one of the Iguanodon models. About twenty guests, scientists and backers, sat at a table in the body of the animal, with Owen at the head. The *Illustrated London News* printed an engraving of the scene, and the public was hooked. When Queen Victoria opened the new Crystal Palace on 10 June 1854, the models were among its most popular sights. Owen wrote the official guide, *Geology and Inhabitants of the Ancient World*, and Hawkins sold small sets of models and wall charts to schools.

Right and wrong. Some of the models hold up well. The ichthyosaurs, plesiosaurs and the giant sloth were based on nearly complete skeletons and still look much as scientists picture them, though the ichthyosaurs are shown hauled out on the shore like seals, which they almost certainly never did. The dinosaurs were another matter. Only scattered bones were known, and Owen believed dinosaurs were heavy, four-legged, mammal-like reptiles. So the Megalosaurus stands on four legs like a scaly bear, and the Iguanodons look like enormous rhinoceroses with a horn on the nose. Owen himself was cautious in print: in the guide he wrote that the horn was "more than doubtful." Later finds proved the horn was a thumb spike (Stop B3) and that Megalosaurus walked on two legs. These were not careless mistakes; they were reasonable interpretations from limited evidence, displayed in concrete for all to see.

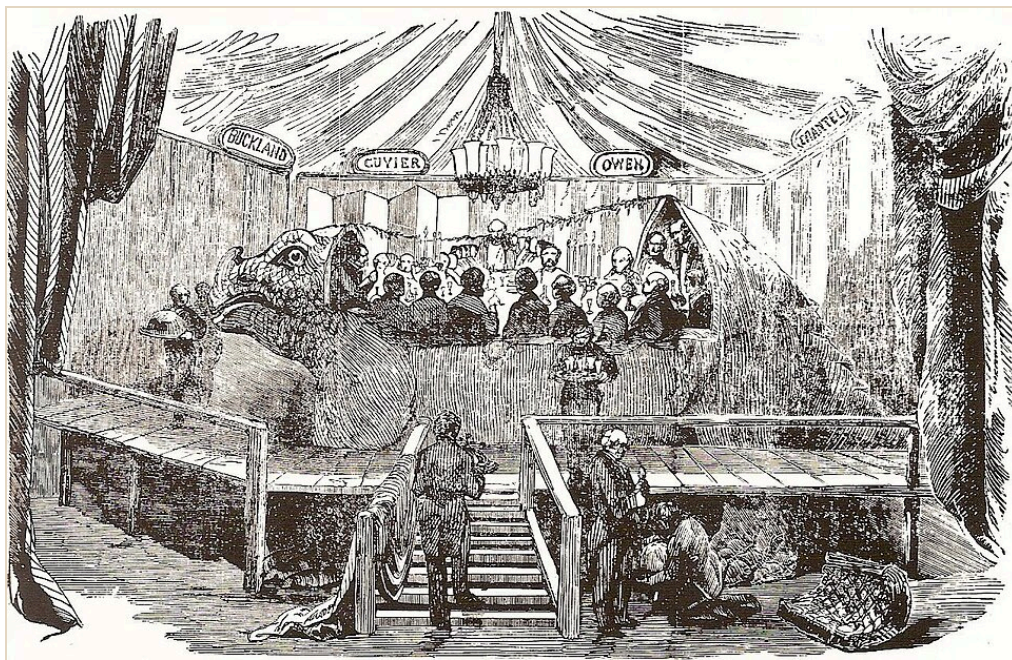
What a display teaches. A model in a park teaches more than its anatomy. The arrangement on the islands, in the order of the rock layers, taught visitors to think of the past as a series of distinct "ages," each with its own creatures. Owen's guide described these animals as having lived "long ages prior to the creation of man." That phrase was an interpretation, not something the bones themselves showed. A careful visitor then, and now,

can enjoy a display and still ask: which parts are observed, and which parts are the designer's view of history? Creation-friendly readers today interpret the same fossils as creatures made during the creation week and buried mostly in the Flood.

Hawkins in America. In 1868 Hawkins went to the United States. At the Academy of Natural Sciences in Philadelphia, working with the anatomist Joseph Leidy, he mounted the bones of *Hadrosaurus foulkii*, found in New Jersey in 1858, standing on its hind legs. It was the first mounted dinosaur skeleton anywhere, and visitor numbers soared. Hawkins was then hired to build a "Paleozoic Museum" of models in New York's Central Park. In 1870-71 the city government, controlled by the corrupt Tammany Hall political machine of William "Boss" Tweed, cancelled the project, and in May 1871 men sent by the park administration smashed the models in Hawkins' workshop. Pieces are said to have been buried in the park, but they have never been found.

Still standing. The Crystal Palace itself burned down in 1936. The models survived, faded and sometimes neglected, in what is now Crystal Palace Park. They were restored in 2002 and listed Grade I in 2007, and a volunteer society now cares for them. They are a monument to the moment when, for the first time, ordinary people could stand face to face with the creatures that scientists had pieced together from bones.

PICTURE STUDY



Dinner in the Iguanodon Model at the Crystal Palace, Sydenham, Unknown engraver for the Illustrated London News, 1854 (published 7 January 1854) · Wood engraving · The Illustrated London News; prints in many libraries
Wikimedia Commons · Public domain

This picture told readers all over Britain that something extraordinary was happening at Sydenham. It is part news report and part advertisement.

Look closely

- Find the shape of the model around the diners. Where is the head? Where is the back?
- Find the waiters. How can you tell them apart from the guests?
- Count the diners you can see. How do they seem to feel about where they are sitting?

Talk about it

1. Why would a dinner inside a model sell tickets better than a scientific paper?
2. This picture shows the inside of a dinosaur, but not the real inside. What does it actually show?

HANDS-ON: BUILD A MODEL, MARK THE EVIDENCE

Sculpt a small dinosaur the way Hawkins did, over an armature, and then make honest labels that show which parts came from bones and which from interpretation.

You will need

- Aluminum foil and pipe cleaners or soft wire (armature)
- Air-dry clay or salt dough
- Two colors of paint or two colors of small sticky dots
- A card for a museum label
- The primary source in the asides

Steps

1. Choose one dinosaur from this trail: Megalosaurus or Iguanodon.
2. Twist a wire skeleton (backbone, legs, tail) and pad it with crumpled foil. This is your armature.
3. Cover it with clay. Pose it the way scientists today think it stood.
4. When dry, mark parts known from bones with one color and parts that are interpretation (skin texture, color, soft tissue, posture details) with the other.
5. Write a museum label in two short paragraphs: “What the bones show” and “What the artist has supplied.” Read Owen’s horn sentence and use it as a model of honest labeling.

Check your work

- My model has an armature inside, as Hawkins’ did.
- I color-coded evidence and interpretation.
- My label separates what is observed from what is supplied.

FIELD NOTEBOOK

1. Draw the Crystal Palace Iguanodon (horn on nose, four legs) and, beside it, a modern Iguanodon. Draw arrows to three differences and write what new evidence caused each

change.

2. List the main groups of models on the islands (sea reptiles, pterosaurs, dinosaurs, mammals) in the order they were placed.
3. **Narration.** Write one paragraph describing how Hawkins built his models and what they got right and wrong. A parent keeps this page.

Did you know? Hawkins planned more models, including animals from America, but the company stopped paying him in 1855, so several molds were never cast. In Philadelphia, his 1868 Hadrosaurus drew so many visitors that the Academy of Natural Sciences began charging admission to thin the crowds. A children's picture book, *The Dinosaurs of Waterhouse Hawkins* by Barbara Kerley, illustrated by Brian Selznick, won a Caldecott Honor in 2002 and is good for younger siblings.

Primary source. Richard Owen, *Geology and Inhabitants of the Ancient World* (London: Crystal Palace Library, 1854), Introduction and the entry for the *Iguanodon* models. Project Gutenberg eBook #62414.

In every stage of this difficult, and by some it may be thought, perhaps, too bold, attempt to reproduce and present to human gaze and contemplation the forms of animal life that have successively flourished during former geological phases of time, and have passed away long ages prior to the creation of man, the writer of the following brief notice of the nature and affinities of the animals so restored feels it a duty, as it is a high gratification to him, to testify to the intelligence, zeal, and peculiar artistic skill by which his ideas and suggestions have been realised and carried out by the talented director of the fossil department, Mr. Waterhouse Hawkins. Without the combination of science, art, and manual skill, happily combined in that gentleman, the present department of the Instructive Illustrations at the Crystal Palace could not have been realised.

The character of the scales is conjectural, and the horn more than doubtful, though attributed to the *Iguanodon* by Dr. Mantell and most geologists.

Go deeper. Steve McCarthy and Mick Gilbert, *The Crystal Palace Dinosaurs* (1994). Friends of Crystal Palace Dinosaurs (cpdinosaurs.org): photographs, history and visiting information. Historic England: the Grade I listing for the models. Academy of Natural Sciences of Drexel University: the *Hadrosaurus foulkii* story. Second video: the 1871 Central Park models and what happened to them.

Goes deeper in. Art, sculpture and modeling (coming soon); History, Victorian Britain and the Great Exhibition; and Earth Science, reading a museum display.

For families. The Sydenham Crystal Palace opened 10 June 1854. Counts of the models vary (about 30–33) depending on whether broken or lost pieces are included. The dinner was on 31 December 1853; the number of guests is usually given as about twenty-one, and Owen sat at the head; the *Illustrated London News* engraving appeared 7 January

1854. Hadrosaurus was found by William Parker Foulke at Haddonfield, New Jersey, in 1858 and mounted by Hawkins in 1868. The destruction of the Central Park workshop in 1871 is documented; the stop names the Tammany machine because it is the historical cause, not as commentary on modern politics. Owen's phrase "long ages prior to the creation of man" is discussed as an interpretation; the course's young-earth reading is given beside it.

PRACTICE

1. **EASY** Who built the Crystal Palace dinosaurs, and who advised him?
2. **EASY** What was inside the big models?
3. **MEDIUM** Give two mistakes in the dinosaur models and the later evidence that corrected each.
4. **MEDIUM** What was the first mounted dinosaur skeleton, and where and when was it mounted?
5. **CHALLENGE** In the primary source, Owen calls the project "too bold" in some people's eyes and says the horn is "more than doubtful." Yet the horn went on the model. Suggest two reasons it was kept, and say whether you think keeping it was honest.
6. **CHALLENGE** Owen's guide gives the Iguanodon model a length of 34 feet 9 inches. Today Iguanodon bernissartensis is estimated at about 10 m. Convert both to meters (1 ft = 0.3048 m) and find the difference. Then explain why a length can be close while the shape is very wrong.

Make it a game • Gallery Guide. One player is the museum guide and describes a toy or picture of a dinosaur to "visitors." Each time the guide states something as fact, visitors may call "Bones or brush?" The guide must say whether it comes from bones (evidence) or the artist's brush (interpretation). Wrong answers swap the guide.

Scripture. "He that is first in his own cause seemeth just; but his neighbour cometh and searcheth him." (Proverbs 18:17, KJV)

The first version of any story sounds convincing until more evidence arrives. Hawkins' models were the first word, set in concrete; Bernissart and later finds "came and searched" them. Wise learners hold first pictures loosely.

Practice: answers

1. Benjamin Waterhouse Hawkins, advised by Richard Owen.
2. An iron framework, brick and tiles, covered with a cement skin shaped into scales and claws.
3. The Iguanodon's nose horn was really a thumb spike (Bernissart skeletons, 1878); Megalosaurus stood on four legs but walked on two (later finds of related, more complete skeletons); the ichthyosaurs are shown basking on land, though they lived wholly in the sea.
4. Hadrosaurus foulkii, mounted by Hawkins with Joseph Leidy at the Academy of Natural Sciences in Philadelphia in 1868.

5. Reasons: Mantell and most geologists still accepted it; there was no better place known for the cone-shaped bone; a model needed some solution, and leaving it off would also be a guess; it was dramatic and the public expected it. Honesty: a reasonable answer is that it was honest because the guide openly told visitors the horn was doubtful; a stronger answer adds that the guide reached fewer people than the model, so the doubt was easily lost, which is a lasting problem with public displays.
6. $34\text{ ft } 9\text{ in} = 34.75\text{ ft} \times 0.3048 \approx 10.6\text{ m}$; difference $\approx 0.6\text{ m}$. The length could be estimated fairly well from the size of bones, but posture, the horn, the bulk and the four-legged stance depended on assumptions about how the bones fitted together, which were wrong.

2.6 THE BONE WARS: COPE AND MARSH

OBJECTIVES

- Tell the main events of the rivalry between Edward Drinker Cope and Othniel Charles Marsh from about 1868 to 1890.
- Weigh the rivalry's results: the dinosaurs discovered and named, and the damage done by haste, secrecy and envy.
- Use a field collector's memoir to see how the Bone Wars depended on hired hunters in the West.

Warm-up. Name a famous rivalry from sports, business or history. Did the competition make both sides better, or did it make them worse? Could it do both at once? Keep your answer and test it against this story.

Video slot. Video coming. The Bone Wars of Edward Drinker Cope and Othniel Charles Marsh; Como Bluff, Wyoming. Search approved channels (Yale Peabody Museum, Academy of Natural Sciences of Drexel University, PBS American Experience “Dinosaur Wars”); preview first.

KEY TERMS

Bone Wars

The bitter competition, roughly 1868–1890s, between paleontologists E. D. Cope of Philadelphia and O. C. Marsh of Yale to find and name new fossil animals in the American West.

priority

The rule that the first published name for an animal is the valid one. Racing to publish first drove much of the Bone Wars.

synonym

A second name given to an animal that already has a name. Haste in the Bone Wars produced many synonyms, such as *Brontosaurus* for *Apatosaurus*.

Morrison Formation

Layers of mudstone and sandstone across the western United States, rich in giant dinosaurs such as *Stegosaurus*, *Allosaurus* and *Apatosaurus*. Museums label it “Late Jurassic.”

quarry

In paleontology, a dig site where many bones are excavated, such as Como Bluff in Wyoming.

envy

Resentment at another's success or gifts, along with a desire to see them lose it. Scripture names it as a root of strife.

CORE IDEAS

Two gifted men. Edward Drinker Cope (1840–1897) grew up in a well-to-do Quaker family in Philadelphia. He had little formal schooling past his teens but a lightning-fast mind; he published his first scientific paper at eighteen and eventually more than 1,200 papers. Othniel Charles Marsh (1831–1899), from a modest farm family in New York State, had a wealthy uncle, the banker George Peabody, who paid for his education and, at Marsh's urging, founded the Peabody Museum at Yale. Marsh became America's first professor of paleontology in 1866. Marsh was slow, methodical and secretive; Cope was quick, brilliant and impulsive. They met in Germany in 1863 and were friendly at first, even naming species after each other.

The first wounds. In 1868 Cope reconstructed a long-necked sea reptile from Kansas, *Elasmosaurus*, and published a picture of it. He had put the head on the wrong end, at the tip of the tail. The anatomist Joseph Leidy pointed out the error in 1870, and Marsh later claimed credit for spotting it. Cope tried to buy back every copy of the journal. Meanwhile, in 1868, Marsh had visited Cope's fossil pits in New Jersey and quietly arranged for the quarry operators to send their finds to him instead. Each man began to see the other as a thief.

The race to the West. After the Civil War, railroads opened the western territories, and the badlands of Kansas, Wyoming, Colorado and Montana were full of bones. Both men led expeditions and, more and more, paid local collectors. In 1877 a schoolteacher named Arthur Lakes found giant bones near Morrison, Colorado, and sent some to each of them; Marsh hired him. The same year two railroad workers wrote to Marsh about bones at Como Bluff, Wyoming, which became one of the richest dinosaur sites in the world. Crews spied on each other, hired away each other's men, and, according to later accounts, smashed bones they could not carry rather than leave them for the rival. Discoveries were rushed into print by telegraph, sometimes with only a few lines of description.

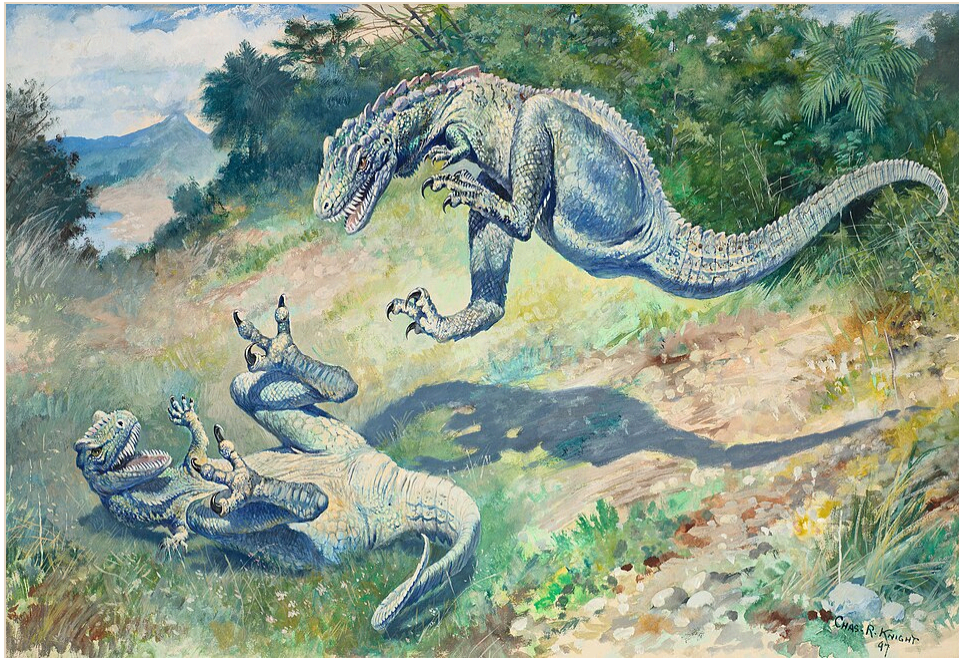
The harvest. The race produced an extraordinary harvest. Marsh named *Stegosaurus*, *Allosaurus*, *Apatosaurus*, *Diplodocus* and *Triceratops*, among many others; Cope named *Camarasaurus*, *Coelophysis* and the sail-backed *Dimetrodon* (not a dinosaur). One common count credits Marsh with about 80 new dinosaur species and Cope with about 56, though many have since been merged or dropped. Haste had a cost. In 1879 Marsh named *Brontosaurus* from a skeleton that turned out to belong to the same kind as his own *Apatosaurus* of 1877; under the rule of priority the earlier name won (1903). In 1887 Marsh described a pair of horn cores as belonging to a giant bison, then realized two years later they came from a horned dinosaur and named *Triceratops*.

War in the newspapers. By the 1880s Marsh was the official paleontologist of the U.S. Geological Survey, with government money and men, while Cope had lost most of his fortune in failed mining investments. On 12 January 1890 the *New York Herald* ran a long article, built on Cope's files, accusing Marsh of plagiarism, incompetence and misuse of public funds. Marsh answered in print, reminding readers of the *Elasmosaurus* with its head on its tail. For weeks the two men traded charges in public. Both reputations suffered, and American science looked petty to the world.

How it ended. In 1892 Congress cut the Survey's budget, and Marsh lost his government post and much of his support; he mortgaged his house and lived on his Yale salary. Cope sold much of his collection to the American Museum of Natural History in New York and died in 1897; Marsh died in 1899. Both left behind enormous collections, but both died far poorer and more bitter than they had been. Later paleontologists spent decades untangling the duplicate names and hasty descriptions.

Judging fairly. It would be easy to call one man the villain. The record shows wrongs on both sides: Marsh's secrecy and his poaching of collectors and quarries, and Cope's impulsiveness and readiness to take his grievances to the press. In their day these were wrongs by the standards of science too: gentlemen were expected to respect another's site and correspondence and to correct errors privately and courteously. Their gifts were real, and so was their sin. James 3:16 describes the pattern exactly: where envy and strife are, there is confusion. The confusion in the scientific record, the many duplicate names, is the measurable result.

PICTURE STUDY



Leaping Laelaps, Charles R. Knight, 1897 · Watercolor (gouache) on paper · American Museum of Natural History, New York

Wikimedia Commons · Public domain

Charles R. Knight painted this with advice from Cope in the last year of Cope's life. The animal was one Cope had named *Laelaps* in 1866 from bones found in New Jersey. Because the name *Laelaps* already belonged to a mite, Marsh renamed it *Dryptosaurus* in 1877, and that is its name today.

Look closely

- Look at the leaping animal's feet and its arms. Which seem to be its main weapons?

- Compare these dinosaurs with Hawkins' heavy Crystal Palace models (Stop B5). How has the idea of a dinosaur changed in 43 years?
- Find the horizon. What does the setting add to the scene?

Talk about it

1. Knight shows a lively, agile animal while most artists of the 1890s showed slow, dragging reptiles. What evidence would Cope have used to justify that?
2. The animal in this picture carries a name Marsh gave it. What does that tell you about the rivalry?

HANDS-ON: A FIELD COLLECTOR'S LEDGER

The Bone Wars were fought by professors in the East, but they were won and lost in the field by hired collectors. Plan a season in the Kansas chalk with Charles Sternberg's budget.

You will need

- The primary source in the asides
- Notebook and calculator
- A map of Kansas (atlas or online)

Steps

1. Read Sternberg's two paragraphs. List everything he asked Cope to pay for.
2. Make a ledger with Sternberg's \$300. Assign rough amounts to each item he names (team of ponies, wagon, camp outfit, cook, driver). Your amounts must add to \$300.
3. Write three rules a professor should give a hired collector to prevent disputes with rival crews (for example, about sites, labeling and letters).
4. Mark western Kansas, Como Bluff (Wyoming) and Morrison (Colorado) on a map.
5. Write a short paragraph: what does Sternberg's letter show about why Cope trusted collectors, and what risks that created?

Check your work

- My ledger adds to \$300 and includes every item Sternberg named.
- I wrote three fair rules for collectors.
- I can explain how hired collectors fueled the Bone Wars.

FIELD NOTEBOOK

1. Make a two-column timeline, "Cope" and "Marsh," from 1863 to 1899, with at least five events in each column.
2. Draw *Elasmosaurus* twice: once as Cope first reconstructed it, and once correctly. Label head, neck and tail.
3. **Narration.** Write one paragraph explaining how the rivalry began and what good and harm came from it. A parent keeps this page.

Did you know? Brontosaurus came back. In 2015 a large study of long-necked dinosaurs argued that the Brontosaurus skeletons differ enough from Apatosaurus to deserve their own genus again. Many paleontologists accept this, though some do not. A widely repeated story says Cope left his skull to science so it could be measured against Marsh's; the story is old, but there is no record that Marsh ever took up the challenge.

Primary source. Charles H. Sternberg, *The Life of a Fossil Hunter* (New York: Henry Holt, 1909), Chapter II, "My First Expedition to the Kansas Chalk, 1876." Project Gutenberg eBook #57178.

I put my soul into the letter I wrote him, for this was my last chance. I told him of my love for science, and of my earnest longing to enter the chalk of western Kansas and make a collection of its wonderful fossils, no matter what it might cost me in discomfort and danger. I said, however, that I was too poor to go at my own expense, and asked him to send me three hundred dollars to buy a team of ponies, a wagon, and a camp outfit, and to hire a cook and driver. I sent no recommendations from well-known men as to my honesty or executive ability, mentioning only my work in the Dakota Group.

I was in a terrible state of suspense when I had despatched the letter, but, fortunately, the Professor responded promptly, and when I opened the envelope, a draft for three hundred dollars fell at my feet. The note which accompanied it said: "I like the style of your letter. Enclose draft. Go to work," or words to the same effect.

Go deeper. Mark Jaffe, *The Gilded Dinosaur* (2000). Url Lanham, *The Bone Hunters* (1973). Charles H. Sternberg, *The Life of a Fossil Hunter* (1909; free on Project Gutenberg). Yale Peabody Museum: O. C. Marsh and the Great Hall. Second video: PBS *American Experience*, "Dinosaur Wars" (2011); preview first.

Goes deeper in. History, the American West after the Civil War (coming soon); Earth Science, the fossils unit; and Small Business & Economics, budgets and contracts (the collector's ledger).

For families. Cope's Elasmosaurus reconstruction dates from 1868-1869; Leidy's correction from 1870. The species counts (Marsh about 80, Cope about 56) are the commonly cited figures and vary by source. The *New York Herald* article (12 January 1890) was written by William Hosea Ballou; Marsh's reply ran in several papers the following week. Stories of bones smashed to deny a rival come from later reminiscences and are hard to verify; the story says "according to later accounts." The Brontosaurus revival is Tschoop, Mateus and Benson, *PeerJ* (2015). Cope's skull story is labeled a legend. Sternberg collected for Cope in Kansas and Montana from 1876. Marsh and Cope are judged by the standards of their own time and by Scripture, not by modern slogans.

PRACTICE

1. **EASY** Which museum did Marsh's uncle found, and in what city did Cope live?
2. **EASY** What mistake did Cope make with *Elasmosaurus*?
3. **MEDIUM** Name three dinosaurs named by Marsh and one by Cope.
4. **MEDIUM** Explain the rule of priority using *Apatosaurus* and *Brontosaurus*.
5. **CHALLENGE** Read the primary source. What does it reveal about how Cope ran his side of the Bone Wars? Give two observations, and one way his method could lead to trouble.
6. **CHALLENGE** If Marsh named about 80 new dinosaur species and Cope about 56, and suppose (as an illustration) that about 40% of the total later proved to be synonyms or invalid, about how many valid species would remain? What does this suggest about racing to publish?

Make it a game • Claim Jumpers. Scatter 20 paper “bones” around a room, each with a letter. Two teams have three minutes to collect bones and spell a dinosaur name from this trail. Rules of honor: no grabbing from another player's hand, and every bone must be logged with the finder's initials. After the round, discuss: did anyone want to break the rules when the clock ran low?

Scripture. “For where envying and strife is, there is confusion and every evil work.”
(James 3:16, KJV)

Cope and Marsh were brilliant, but envy turned their gifts into a war. The confusion they left in the scientific record is a picture of what James describes. Gifts used in humility build; gifts used in envy tear down.

Practice: answers

1. The Peabody Museum at Yale (New Haven, Connecticut); Cope lived in Philadelphia.
2. He put the head at the end of the tail instead of on the long neck.
3. Marsh (any three): *Stegosaurus*, *Allosaurus*, *Apatosaurus*, *Brontosaurus*, *Diplodocus*, *Triceratops*. Cope (any one): *Camarasaurus*, *Coelophysis* (*Dimetrodon* is Cope's but not a dinosaur).
4. The first validly published name wins. Marsh named *Apatosaurus* in 1877 and *Brontosaurus* in 1879; when they were judged to be the same kind (1903), *Apatosaurus*, the earlier name, became the valid one (though since 2015 many again treat *Brontosaurus* as separate).
5. Cope hired collectors he had never met, on the strength of a letter and with no references; he paid quickly and in advance; he cared about enthusiasm and willingness to endure hardship; collectors worked on his money at a distance. Trouble: he had little control over how sites were dug or bones recorded, collectors could be hired away or sell to the rival, and disputes over who owned a site or a find were likely.
6. $80 + 56 = 136$; $40\% \text{ of } 136 \approx 54$; $136 - 54 \approx 82$ valid. A large share of the work had to be undone. Speed won priority but often cost accuracy, and later scientists paid the price in years of revision.

2.7 BARNUM BROWN FINDS T. REX (1902)

OBJECTIVES

- Tell how Barnum Brown found and dug the first Tyrannosaurus rex skeleton in the Hell Creek badlands of Montana and how Henry Fairfield Osborn named it in 1905.
- Explain how a dinosaur goes from rock in the field to a skeleton in a museum: jacketing, transport, preparation and mounting.
- Read a 1915 museum account and match its three skeletons to what is known about each today.

Warm-up. Get a big ball of play dough, hide a small toy inside, and let it harden overnight. Tomorrow, try to get the toy out without scratching it. How long did it take? Barnum Brown's crew spent several summers freeing one skeleton from hard sandstone.

Video slot. Video coming. Barnum Brown and the discovery of Tyrannosaurus rex in Hell Creek, Montana; the American Museum of Natural History T. rex. Search approved channels (American Museum of Natural History, Carnegie Museum of Natural History); preview first.

KEY TERMS

Tyrannosaurus rex

"Tyrant lizard king," the giant two-legged meat-eating dinosaur named by Henry Fairfield Osborn in 1905 from the skeleton Barnum Brown found in 1902.

Hell Creek Formation

Sandstone and mudstone layers in eastern Montana and nearby states, home of T. rex, Triceratops and many other dinosaurs. Museums label it "latest Cretaceous."

badlands

Dry, steep, deeply eroded country with little soil or plant cover, where fossils weather out of the rock.

field jacket

A protective shell of burlap strips soaked in plaster, wrapped around a fossil and the rock holding it before it is moved.

holotype

The one specimen on which a species name is based. The 1902 skeleton is the holotype of Tyrannosaurus rex.

preparator

A museum worker who frees fossil bone from rock with fine tools, glues and patience.

CORE IDEAS

Mr. Bones. Barnum Brown (1873–1963) was born on a farm in Carbondale, Kansas, and named after the showman P. T. Barnum. As a boy he collected fossils from the coal-mine spoil heaps and plowed fields near home. He studied at the University of Kansas and in 1897 was hired by the American Museum of Natural History in New York, where Henry Fairfield Osborn was building a department of vertebrate paleontology to rival the Bone Wars collections of Marsh and Cope (Stop B6). Brown would spend sixty years finding fossils on several continents and became known as “Mr. Bones.”

The 1902 discovery. In 1902 Osborn sent Brown to eastern Montana, a remote stretch of badlands along Hell Creek near the small town of Jordan, days by wagon from the nearest railroad. William Hornaday of the New York Zoological Society had seen fossils there while hunting. Brown soon found the bones of a large meat-eating dinosaur in a hillside of hard sandstone: part of a skull and jaws, vertebrae, the pelvis and leg bones. They were not like anything Marsh or Cope had described. He wrote to Osborn that this was a find of great importance.

Digging it out. Getting the skeleton out took several field seasons, from 1902 to 1905. The bones lay in sandstone so hard that the crew blasted away the overburden with dynamite, then worked close to the bone with picks, chisels and awls. Each section was wrapped in a field jacket of burlap and flour paste or plaster. The blocks, some weighing hundreds of pounds, were hauled by horse-drawn wagon across the prairie to the railroad at Miles City and shipped east. In New York, preparators spent months more cleaning the bones in the museum laboratory.

A name. In October 1905 Osborn published a short paper naming *Tyrannosaurus rex* from the 1902 skeleton. In the same paper he named a second animal, *Dynamosaurus imperiosus*, from a partial skeleton Brown had found in Wyoming in 1900. Within a year Osborn recognized that the two were very likely the same kind. Because *Tyrannosaurus* appeared on an earlier page of the paper, it became the valid name. So, in an important sense, Brown found T. rex first in 1900, though the 1902 skeleton is the one that carries the name.

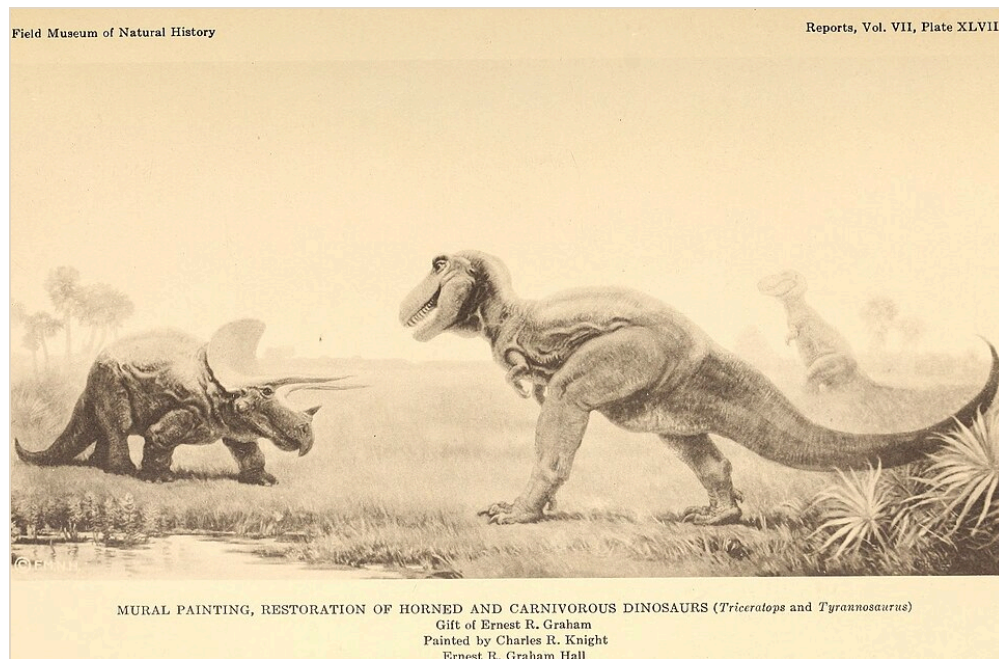
A better skeleton, and a mount. In 1908 Brown found a far more complete skeleton, with a nearly perfect skull, at Big Dry Creek in Montana. In 1915 the museum mounted it, using casts of the 1902 skeleton’s leg bones to fill the gaps, standing upright like a kangaroo with its tail dragging on the floor. For more than seventy years that pose shaped how the world pictured T. rex. Later footprint and skeleton studies led scientists to remount it in 1992–1994 in a level pose, with the body balanced over the hips and the tail held out behind. In 1941, with war in Europe and fear that New York might be bombed, the museum sold the 1902 holotype to the Carnegie Museum in Pittsburgh, where it still stands.

Brown’s way of working. Brown was a fine field man: he read the rock layers carefully, kept notes, wrote steady letters to Osborn, and had a knack for finding bone where others saw only hillside. From 1910 to 1915 he floated down the Red Deer River in Alberta, Canada, on a flatboat, collecting duck-billed and horned dinosaurs, while the Sternberg family (Stop

B6) collected nearby for the Geological Survey of Canada. The two crews competed hard, but, unlike the Bone Wars, they did so mostly with courtesy, and both museums gained great collections. A rivalry does not have to become a war.

Observation and interpretation. Everything about the first T. rex began with careful observation: bones in rock, recorded in place, moved without damage, cleaned and measured. But the pose, the weight, the speed and even the name “king” are interpretations built on those bones. The 1915 upright pose shows how firmly an interpretation, once set in a famous display, can hold for generations, and how willingly good scientists change it when evidence requires.

PICTURE STUDY



Tyrannosaurus and Triceratops (Field Museum mural), Charles R. Knight, about 1927 · Oil on canvas, mural
· Field Museum of Natural History, Chicago
Wikimedia Commons · Public domain

Charles R. Knight painted a series of murals for the Field Museum in Chicago between 1926 and 1930. In this one, the Tyrannosaurus stands much as the American Museum’s 1915 mount stood, upright with its tail on the ground.

Look closely

- Look at the angle of the Tyrannosaurus’s back and tail. Where is the tail?
- Find the Triceratops’s weapons. How does it seem to be defending itself?
- Notice the landscape and the light. What mood has Knight chosen?

Talk about it

1. Knight based his T. rex on the mounted skeleton of his day. If he painted it now, what one change would he most need to make, and why?

2. Both animals were found in the same Hell Creek layers. Does that prove they fought? What would?

HANDS-ON: PLASTER FIELD JACKET

Practice the real field technique that brought the first T. rex out of Montana: expose, map, jacket and flip a “fossil.”

You will need

- A chicken drumstick bone (boiled and cleaned) or a plastic bone
- A shallow box or tub of damp sand mixed with a little clay
- Paper towels or plastic wrap (separator)
- Strips of burlap, cheesecloth or paper towel
- Plaster of Paris and a bowl of water
- Paintbrush, spoon, notebook and graph paper

Steps

1. A partner buries the bone in the damp sand. Excavate the top half with the spoon and brush only; do not pull it out.
2. Map it: on graph paper, draw the bone in place with a north arrow and measurements. Field maps are evidence.
3. Lay damp paper towels over the exposed bone as a separator so the plaster will not stick to it.
4. Dip strips in plaster and lay them over the bone and the sand around it, overlapping, three layers thick. Let it harden 30 minutes.
5. Dig a trench around the jacket, undercut it, and flip it carefully. Then read the primary source and decide which of Matthew’s three skeletons your “find” most resembles.

Check your work

- I mapped the bone before moving it.
- My jacket held the bone and sand together when flipped.
- I can explain why the mapping and jacketing come before removing a fossil.

FIELD NOTEBOOK

1. Draw the 1915 upright T. rex mount and the modern level pose side by side. Mark the hips and draw a line showing where the weight balances in each.
2. Make a field-season page: date, place, layer, what was found, how it was moved.
3. **Narration.** Write one paragraph telling how the first T. rex skeleton went from a Montana hillside to a name in a scientific paper. A parent keeps this page.

Did you know? Barnum Brown also found and named *Ankylosaurus* (1908) and *Corythosaurus* (1914). He worked for oil companies between museum trips, reading rock

layers for them as he did for fossils, and traveled to India, Greece, Burma and elsewhere. The Carnegie Museum in Pittsburgh paid \$7,000 for the T. rex holotype in 1941.

Primary source. *W. D. Matthew, Dinosaurs, with Special Reference to the American Museum Collections (New York: American Museum of Natural History, 1915), the section on Tyrannosaurus. Project Gutenberg eBook #19302.*

During ten years explorations in the Western Cretaceous formations, Mr. Brown has secured for the Museum three skeletons of this magnificent dinosaur, incomplete, but finely preserved. The first, found in 1900, included the jaws, a large part of backbone and ribs, and some limb bones. The second included most of skull and jaws, backbone, ribs and pelvis and the hind limbs and feet, but not tail. The third consisted of a perfect skull and jaws, the backbone, ribs, pelvis and nearly all of the tail, but no limbs.

Go deeper. Lowell Dingus and Mark A. Norell, *Barnum Brown: The Man Who Discovered Tyrannosaurus rex* (2010). W. D. Matthew, *Dinosaurs* (1915; free on Project Gutenberg). American Museum of Natural History: Tyrannosaurus rex and the Hall of Saurischian Dinosaurs. Carnegie Museum of Natural History: the T. rex holotype in “Dinosaurs in Their Time.” Second video: how fossils are jacketed and prepared.

Goes deeper in. Earth Science, field methods and the fossils unit (coming soon); Geography, the Great Plains and the badlands; and Art, Charles R. Knight’s murals.

For families. The 1902 skeleton (originally AMNH 973, now CM 9380) was collected from 1902 to 1905; Osborn’s paper is “Tyrannosaurus and Other Cretaceous Carnivorous Dinosaurs,” *Bulletin of the AMNH* 21 (October 1905). *Dinamosaurus* (the 1900 Wyoming find, AMNH 5866) was named in the same paper and later treated as T. rex; it is now at the Natural History Museum, London. The 1908 skeleton is AMNH 5027, mounted 1915 and remounted in the 1990s. Matthew’s three skeletons match the 1900, 1902 and 1908 finds in that order. The Carnegie sale price (\$7,000) is the commonly reported figure. The 🕒 dating of Hell Creek is handled at Stops B9 and B10; here “latest Cretaceous” is used only as museum vocabulary.

PRACTICE

1. **EASY** What does Tyrannosaurus rex mean, and who named it?
2. **EASY** Where did Barnum Brown find the 1902 skeleton?
3. **MEDIUM** List four steps in getting a dinosaur skeleton from the field to a museum display.
4. **MEDIUM** Why was the 1915 upright pose of T. rex changed in the 1990s?
5. **CHALLENGE** Use the primary source. Which of Matthew’s three skeletons is the holotype of T. rex, and which was first named *Dinamosaurus*? Explain using the parts each preserved.
6. **CHALLENGE** Suppose Brown’s crew hauled blocks about 100 miles by wagon trail to the railroad at Miles City. If a loaded wagon averaged 2 miles per hour for 8 hours a day,

how many days did one trip take? Give two reasons the actual trip might be slower.

Make it a game • Pose the Skeleton. One player stands as a T. rex in the 1915 pose (upright, tail on the ground). Others call out a piece of evidence (“footprints show no tail drag,” “the hips are the balance point,” “the backbone is stiff at the hips”). For each, the player adjusts the pose. End with the modern level stance and see if the player can balance on one leg in it.

Scripture. “Whatsoever thy hand findeth to do, do it with thy might; for there is no work, nor device, nor knowledge, nor wisdom, in the grave, whither thou goest.” (Ecclesiastes 9:10, KJV)

Barnum Brown worked at fossil hunting with all his might for sixty years. The Preacher reminds us that our working days are given by God and are limited, and that good work done well is a gift to use while we can.

Practice: answers

1. “Tyrant lizard king”; named by Henry Fairfield Osborn in 1905.
2. In the Hell Creek badlands of eastern Montana, near Jordan.
3. Find and expose the bone; map and record it in place; wrap it in a plaster field jacket; haul and ship it; prepare (clean) it in the laboratory; study and describe it; cast missing parts; mount it.
4. Studies of the skeleton’s balance, footprints and tail showed the body was held level, balanced over the hips, with the tail off the ground; the upright, tail-dragging pose did not fit the evidence.
5. The first (1900: jaws, backbone and ribs, some limbs) is the Wyoming skeleton named *Dinamosaurus*. The second (most of skull and jaws, pelvis, hind limbs and feet) is the 1902 Hell Creek holotype of *T. rex*. The third (perfect skull, nearly all the tail, no limbs) is the 1908 skeleton; that is why the 1915 mount borrowed the legs of the 1902 specimen as casts.
6. $2 \times 8 = 16$ miles a day; $100 \div 16 \approx 6.25$, so about 6–7 days. Slower because of rain turning roads to mud (“gumbo”), river crossings, broken wagons, resting the horses, heavy loads on hills, and the need to protect the jackets.

2.8 ROY CHAPMAN ANDREWS AND THE GOBI EGGS (1923)

OBJECTIVES

- Describe the Central Asiatic Expeditions: their goal, their methods (motor cars and camel caravans) and their most famous finds.
- Tell how the 1923 nest of eggs was interpreted and how a 1990s discovery reversed the interpretation of *Oviraptor*.
- Compare what an expedition sets out to find with what it actually finds, using Andrews' own 1921 words.

Warm-up. Plan a trip into a desert where you cannot buy gasoline, food or spare parts for 1,000 miles. Make a quick list of what you must carry. Andrews solved this problem with cars and a caravan of camels.

Video slot. Video coming. Roy Chapman Andrews, the Central Asiatic Expeditions and the Flaming Cliffs of Mongolia; *Oviraptor* brooding on its nest. Search approved channels (American Museum of Natural History, Smithsonian); preview first.

KEY TERMS

Gobi

A vast desert and dry grassland across southern Mongolia and northern China, cold in winter and hot in summer.

Central Asiatic Expeditions

The American Museum of Natural History's scientific expeditions to Mongolia and China led by Roy Chapman Andrews, 1922–1930.

Flaming Cliffs

Andrews' name for the red sandstone cliffs at Bayanzag (Shabarakh Usu) in Mongolia, where the eggs were found.

Protoceratops

A sheep-sized plant-eating dinosaur with a beak and a bony frill, very common at the Flaming Cliffs.

Oviraptor

"Egg seizer," a beaked, toothless dinosaur named in 1924 because it was found on a nest and thought to be stealing the eggs.

embryo

An unhatched young animal developing inside an egg. A 1993 embryo showed whose eggs they really were.

CORE IDEAS

From floor-sweeper to explorer. Roy Chapman Andrews (1884–1960) grew up in Beloit, Wisconsin, roaming the woods with a gun and a notebook. In 1906 he went to New York and asked for any job at the American Museum of Natural History; he started by sweeping floors in the taxidermy department. He studied whales, sailed to Asia, and by 1919 had traveled by car across Mongolia, as he described in *Across Mongolian Plains* (1921). Andrews was a gifted organizer, writer and fundraiser, more explorer than scientist, and he knew it. He brought top scientists with him, chief among them the paleontologist Walter Granger.

A theory and a plan. Henry Fairfield Osborn, the museum’s president, believed that Central Asia had been the birthplace of the mammals and of mankind. Andrews proposed to test this with a large expedition into the Gobi. Older explorers had crossed it by camel at two or three miles an hour. Andrews would use motor cars, Dodge touring cars and Fulton trucks, to cover ground quickly, with a caravan of about 75 camels sent ahead to set up depots of gasoline, food and supplies. Money came from private donors, and Andrews made the expedition famous in newspapers before it began.

The Flaming Cliffs. In September 1922, late in the first season, the expedition’s photographer, J. B. Shackelford, wandered to the edge of a basin and found red sandstone cliffs studded with white bone. Andrews named them the Flaming Cliffs. Among the first finds was a small frilled dinosaur, soon named *Protoceratops andrewsi* in his honor, and a fragment of eggshell. The next summer, on 13 July 1923, the team’s assistant George Olsen reported finding fossil eggs, long and narrow, roughly 6 to 8 inches long, lying in a cluster. Granger confirmed they were reptile eggs. Andrews announced to the world the first dinosaur eggs ever recognized by scientists. (Eggshell fragments had been found in southern France as early as 1859, but had not been widely accepted as dinosaurian.)

The egg thief. Because *Protoceratops* was the most common dinosaur at the site, the eggs were assumed to be its eggs. Lying on top of one nest was the skeleton of a small toothless dinosaur with a strong beak. Osborn named it *Oviraptor philoceratops* in 1924, “egg seizer, fond of ceratopsians,” supposing it had died while robbing the nest. Osborn himself cautioned in his paper that the name might mislead. For seventy years *Oviraptor* was pictured as a thief.

Reversed. In 1993 an American Museum team, led by Mark Norell and Michael Novacek and working with Mongolian scientists, found a new site in the Gobi called Ukhaa Tolgod. There they found an egg of the same elongated type with a tiny embryo inside, and the embryo was not a *Protoceratops* but an oviraptor-like dinosaur (1994). Then they found an adult oviraptorid skeleton sitting squarely on a nest of these eggs, its legs folded and its arms spread around the clutch, much as a brooding bird sits (1995). The “egg thief” had been a parent on its own nest. The observation in 1923, a skeleton on a nest, never changed. What changed was the interpretation, once a new observation, the embryo, decided between two explanations.

Other harvests, and a missing one. In five field seasons between 1922 and 1930 the expeditions brought back *Velociraptor* (named 1924), the skull of a gigantic hornless rhinoceros relative, early mammal skulls, and much more, along with maps and studies of Mongolia's geology, plants and animals. What they did not find was what Osborn had most hoped for: any trace of early man. The eggs also brought trouble. In 1923, to raise funds, Andrews auctioned one egg; it sold for \$5,000. Mongolian and Chinese officials concluded that the Americans were taking valuable treasures out of their lands. Political turmoil in China and a new Soviet-allied government in Mongolia brought increasing restrictions, and the last expedition went out in 1930.

What the story teaches. Andrews set out to find one thing and found another. A good researcher states his hypothesis honestly, as Osborn and Andrews did, and reports what is actually found even when it disappoints. The Oviraptor story also shows that a name can carry an interpretation for generations; scientific names, by the rules, cannot be changed simply because they turn out to be unfair. The egg auction shows that the way discoveries are funded and publicized can affect relations with the people whose land holds them.

PICTURE STUDY



Motor Trouble on the Mongolian Plains at Irden Manha, Roy Chapman Andrews (Central Asiatic Expeditions, American Museum of Natural History), 1922-1923 (published 1924) · Black-and-white photograph · Published in *Natural History* magazine, vol. 24 (1924); American Museum of Natural History Library

Wikimedia Commons · Public domain

A car that breaks down a thousand miles from a garage must be mended on the spot. Here the expedition's chief mechanic, C. Vance Johnson, straightens a bent part of a Dodge's rear axle housing over a fire of dried camel dung. Among the men watching are George Olsen, who found the eggs in 1923, and Professor Osborn, the museum's president. Photographs

like this one, printed in the museum's magazine, made the expedition famous and helped raise money for the next season.

Look closely

- Find the car and the fire. What is the mechanic doing, and why might heat help?
- Look at the ground. What problems might it cause a car with 1920s tires?
- Count the men. Who seems to be working and who seems to be watching?

Talk about it

1. The fire was made of camel dung. What does that tell you about why the expedition still needed its camels?
2. Why might a photograph of a breakdown in the desert raise more interest than a photograph of a bone? Is telling about adventure a strength or a danger for a scientist?

HANDS-ON: EXPECTED VS. FOUND

Read Andrews' words from 1921, before the great expeditions, and compare the plan with the results. Then test an egg hypothesis of your own.

You will need

- The primary source in the asides
- Two raw eggs of different shapes or sizes (chicken, duck or quail), or pictures
- Ruler, kitchen scale and a notebook

Steps

1. Read the primary source. Write down, in one sentence each, what Andrews says he hoped to do and how he describes the Gobi.
2. Make a two-column chart, "Planned or expected" and "Actually found," for the Central Asiatic Expeditions. Put at least four items in each column.
3. Measure the length, width and weight of your eggs. Calculate length $\div$ width for each.
4. A typical egg of the Flaming Cliffs type is about 7 inches long and 2.5 inches wide. Calculate their ratio. Which of your eggs is shaped most like them?
5. Write a short paragraph: why can an egg's shape alone not tell you which animal laid it, and what evidence finally did?

Check your work

- My chart has at least four items in each column.
- I measured and compared egg ratios.
- I can explain why the embryo settled the Oviraptor question.

FIELD NOTEBOOK

1. Draw the 1923 scene as Osborn imagined it (Oviraptor stealing eggs) and the 1995 scene (an oviraptorid brooding its nest). Write “observation” under what is the same in both and “interpretation” under what differs.
2. Map the expedition: Beijing (then Peking), Kalgan, Urga (Ulaanbaatar) and the Flaming Cliffs.
3. **Narration.** Write one paragraph telling how Oviraptor got its name and how scientists learned seventy years later that it was a parent, not a thief. A parent keeps this page.

Did you know? Andrews later served as director of the American Museum of Natural History (1935–1942). People have often said he inspired the film character Indiana Jones, but there is no firm evidence the filmmakers had him in mind. The egg he auctioned in 1923 was bought by Austen Colgate and given to Colgate University in New York State, where it is still kept.

Primary source. Roy Chapman Andrews, *Across Mongolian Plains* (New York: D. Appleton, 1921), the Preface and Chapter II, “Speed Marvels of the Gobi Desert.” Project Gutenberg eBook #29024.

Having made extensive collections along the southeastern edge of the great central Asian plateau, it was especially desirable to obtain a representation of the fauna from the northeastern part in preparation for the great expedition which, I am glad to say, is now in course of preparation, and which will conduct work in various other branches of science.

This area more nearly approaches a desert than any other part of the road to Urga. The soil is mainly sandy, but the Gobi sagebrush and short bunch grass, although sparse and dry, still give a covering of vegetation, so that in the distance the plain appears like a rolling meadowland.

Go deeper. Roy Chapman Andrews, *On the Trail of Ancient Man* (1926), his own account of the expeditions. Charles Gallenkamp, *Dragon Hunter: Roy Chapman Andrews and the Central Asiatic Expeditions* (2001). Mark Norell and Lowell Dingus, *A Nest of Dinosaurs* (1999). American Museum of Natural History: the Central Asiatic Expeditions and the brooding oviraptorid. Second video: the 1990s Ukhaa Tolgod discoveries.

Goes deeper in. Geography, Mongolia and the Gobi (coming soon); History, China and Mongolia in the 1920s; and Life Science, eggs and embryos.

For families. Expedition seasons: 1922, 1923, 1925, 1928 and 1930. The Flaming Cliffs were found 1 September 1922; Olsen’s egg find is dated 13 July 1923. The eggs are now assigned to oviraptorids, not Protoceratops. Norell et al., *Science* 266 (1994), the embryo; Norell et al., *Nature* 378 (1995), the brooding adult; the brooding animal was later named *Citipati* (2001). The 1923 auction price (\$5,000) and buyer are documented. The number

of camels varied by season (about 75 is often given for 1922). Osborn's hope for human origins in Asia is stated as the expedition's goal and as unfulfilled; the course does not endorse it. Andrews' 1921 book predates the eggs; it is used to show the plan before the finds.

PRACTICE

1. **EASY** Who found the Flaming Cliffs, and who found the 1923 nest of eggs?
2. **EASY** How did the expedition travel and supply itself in the Gobi?
3. **MEDIUM** Why was the beaked dinosaur on the nest named Oviraptor, and what was wrong with the name?
4. **MEDIUM** What had Osborn and Andrews most hoped to find in Central Asia, and did they find it?
5. **CHALLENGE** Use the primary source. What does Andrews' preface tell you about how the great expedition was planned, and what does his description of the Gobi suggest about the challenge for motor cars? Give one detail from each passage.
6. **CHALLENGE** A camel caravan travels about 2.5 miles per hour for 8 hours a day; the cars average about 15 miles per hour for 8 hours. How many days does each take to cover 600 miles? Why did Andrews still need camels?

Make it a game · Thief or Parent? The leader describes a scene with one fact at a time ("A dog is next to a torn bag of food"). After each fact, players vote: guilty or innocent? Then the leader adds a new fact ("The dog's own puppies are inside the bag"). Players must say which fact changed their minds and why.

Scripture. "It is the glory of God to conceal a thing: but the honour of kings is to search out a matter." (Proverbs 25:2, KJV)

God hid eggs in the sands of the Gobi, and it was an honor for men to search them out. Searching out a matter also means staying willing to be corrected, as the Oviraptor story shows.

Practice: answers

1. The photographer J. B. Shackelford found the Flaming Cliffs in 1922; George Olsen found the nest in July 1923.
2. By motor cars and trucks, with a camel caravan sent ahead to set up depots of gasoline, food and supplies.
3. It was found on a nest of eggs thought to belong to Protoceratops, so it was assumed to be stealing them. Later finds (an embryo of its own kind in the same type of egg, and an adult brooding a nest) showed it was the parent.
4. Evidence that Central Asia was the birthplace of mammals and of mankind, especially early human remains. They found no human ancestors, though they found many dinosaurs and fossil mammals.
5. Preface: earlier collecting trips were preparation ("in preparation for the great expedition"), and the expedition was to cover many branches of science, not only fossils. Chapter II: the

land is “mainly sandy” with sparse sagebrush and bunch grass and looks like rolling meadowland from a distance, suggesting much of it was passable for cars, but sand would be a hazard and distances deceptive.

6. Camels: $2.5 \times 8 = 20$ miles a day; $600 \div 20 = 30$ days. Cars: $15 \times 8 = 120$ miles a day; $600 \div 120 = 5$ days. The cars could not carry enough gasoline, food and water for months in the desert; the camels carried supplies ahead to depots so the cars could refuel.

2.9 SUE THE T. REX (1990)

OBJECTIVES

- Tell the story of SUE from discovery in South Dakota (1990) through the court case to the Field Museum (2000).
- Explain what the most complete large T. rex skeleton taught scientists about growth, injuries and the life of one animal.
- Reason through the ownership questions in the case: land, law, contracts and duty, without taking sides beyond the facts.

Warm-up. If you found a gold coin buried in a neighbor's field while helping with a fence, who would it belong to: you, the neighbor, the person who owns the land, or the government? Write your answer and one reason. The answer for SUE took seven years and several courts.

Video slot. Video coming. SUE the T. rex at the Field Museum in Chicago: discovery, preparation and the 2018 new mount. Search approved channels (Field Museum, Smithsonian); preview first.

KEY TERMS

SUE

The Tyrannosaurus rex skeleton FMNH PR 2081 at the Field Museum, Chicago, named for its finder, Sue Hendrickson; one of the largest and most complete T. rex skeletons known.

trust land

Land owned by an individual or tribe but held in trust by the U.S. government, which must approve its sale or the sale of anything from it.

gastralia

Belly ribs: thin bones in the wall of the belly, not joined to the backbone. SUE's are complete enough to show how they fit.

growth rings

Yearly lines in a cross-section of bone, used to estimate an animal's age at death.

pathology

A sign of injury or disease in a bone, such as a healed break or an infection.

commercial collector

A fossil hunter who digs and prepares fossils for sale, rather than for a university or museum.

CORE IDEAS

The find. In August 1990 a team from the Black Hills Institute of Geological Research, a commercial fossil company in Hill City, South Dakota, led by Peter Larson, was digging near

Faith in western South Dakota. On 12 August, while most of the crew drove into town to repair a flat tire, Sue Hendrickson, an experienced fossil hunter and diver, walked to a sandstone bluff she had been eyeing. At its foot lay pieces of large bone, and above them, in the cliff, vertebrae and a leg bone. It was a *Tyrannosaurus rex*, and the skeleton went deep into the hill. The team named it SUE in her honor.

Digging and buying. The crew spent seventeen days removing tons of overlying rock and jacketing the bones. The land belonged to a rancher, Maurice Williams, a member of the Cheyenne River Sioux Tribe, and lay within the tribe's reservation. Larson paid Williams \$5,000 for the right to remove the skeleton. The Institute took SUE to Hill City and began years of preparation, planning to build a museum around it.

Seizure and the courts. In May 1992 FBI agents and National Guard soldiers arrived at the Institute and took SUE into government custody. Williams' land was *trust land*: the U.S. Department of the Interior held it in trust for him, and by law nothing could be sold from it without the department's approval, which had not been obtained. The tribe also claimed SUE. After long legal battles, the courts ruled that the fossil was part of the land and belonged to Williams, under the government's trust, and that the \$5,000 transaction did not transfer it. Separately, Larson was prosecuted on unrelated federal charges about his fossil business and customs declarations, was convicted on two counts in 1995, and served a prison sentence. People disagree strongly about whether that prosecution was fair; the facts of the verdict are a matter of record.

The auction. In October 1997 SUE was sold at Sotheby's auction house in New York. The Field Museum in Chicago, backed by corporate partners, won with a bid that came to \$8.36 million including fees, by far the most ever paid for a fossil at that time. Field Museum preparators spent about 30,000 hours cleaning the bones, and SUE was unveiled to the public in May 2000. The real skull, about five feet long and roughly 600 pounds, was too heavy for the mounted skeleton, so a cast skull sits on the mount and the real one is displayed nearby.

What SUE shows. SUE is about 40 feet long and 13 feet tall at the hips. About 90 percent of the skeleton by bulk was recovered, which is rare for any large dinosaur. Its bones are a record of one life. Growth rings in the bones indicate an animal about 28 to 33 years old at death, and other *T. rex* specimens show that the species grew very fast in its teens. SUE has healed broken ribs, a damaged and infected shoulder bone, arthritis in the tail, and smooth-edged holes in the lower jaw that some researchers have compared to a parasite infection known in modern birds. SUE also preserves a complete set of gastralia and a wishbone. In 2018 the Field Museum remounted SUE in a new gallery with the belly ribs in place, which made the body look deeper and more powerful.

Questions of right and duty. The SUE story raises real moral questions that families can discuss. Who owns what is found in the ground? In the United States, fossils on private land generally belong to the landowner; on federal and tribal land, the law sets rules. What do contracts require, and what happens when a buyer and seller do not follow the law that governs a sale? What is owed to the finder and to the crew who did the hard work? Scripture

teaches that we must render to each what is due, and that boundaries and property are to be respected. The case also shows the tension between commercial collectors, who find many fossils, and museums, which want specimens kept for study by all.

Reading SUE's sign. The Field Museum describes SUE as having lived about 67 million years ago. Students should read that statement for what it is: an interpretation based on radiometric dating of nearby rock layers and assumptions about rates and starting conditions. The observations, the bones, the injuries and the growth rings, are things anyone can examine. The box below sets the claim beside the observations and a Christian reading.

PICTURE STUDY



The Tyrannosaurus rex mount at the American Museum of Natural History, American Museum of Natural History photographer, about 1915 · Photograph · American Museum of Natural History Library, New York (published in museum publications of the period)
Wikimedia Commons · CC BY-SA 2.0

Before SUE, this was the world's picture of T. rex: Barnum Brown's 1908 skeleton mounted upright in 1915 (Stop B7). Compare it with photographs of SUE today on the Field Museum's website.

Look closely

- Find the hips. Where is most of the weight?
- Find the belly. Are there belly ribs (gastralia) in this mount?
- Look at the arms and the skull. How large are they compared with the legs?

Talk about it

1. Name two differences between this mount and SUE's 2018 mount, and the evidence behind each change.

2. Why does a more complete skeleton like SUE's change a mount more than a new theory does?

HANDS-ON: READ A LIFE FROM THE BONES

Act as SUE's paleontologist. Use measurements and a simple growth model to reason about an animal's life, then rewrite a museum sign so it separates observation from interpretation.

You will need

- Graph paper and pencil
- Calculator
- Chalk and a tape measure (for the outdoor option)
- A copy of the  box below

Steps

1. Outdoors, if possible, chalk SUE's length (40 feet, about 12.2 m) on a driveway or playground. Mark the skull (5 feet) at one end and the hips about halfway. Stand at the hips and look up 13 feet.
2. Use this simplified model: T. rex grew slowly to age 10 (to about 1 ton), then gained about 0.6 tons a year from ages 10 to 18, then slowed and stopped growing near 8 tons. Graph weight against age from 0 to 28. Label the teenage growth spurt.
3. List SUE's pathologies from the core ideas. For each, write whether the animal lived long after the injury and how you can tell (healed bone means survival).
4. Rewrite the museum sign sentence "SUE lived 67 million years ago" as two sentences: one observation and one clearly labeled interpretation.
5. Write one paragraph: what can bones tell us about a life, and what can they never tell us?

Check your work

- My growth graph shows a teenage growth spurt.
- I explained why healed bone shows survival.
- My rewritten sign keeps observation and interpretation apart.

FIELD NOTEBOOK

1. Draw SUE's skeleton from the side. Mark with small red dots the healed ribs, the shoulder, the tail and the holes in the jaw.
2. Make a timeline: 1990 find, 1992 seizure, the court rulings, 1997 auction, 2000 unveiling, 2018 new mount.
3. **Narration.** Write one paragraph telling who found SUE, why the government took the skeleton, and how it came to the Field Museum. A parent keeps this page.

Did you know? SUE's skull was CT-scanned in a machine normally used to inspect rocket parts, because no hospital scanner was large enough. The scans showed large spaces for the parts of the brain that handle smell. Whether SUE was male or female is not known; nothing in the skeleton settles it.

 **What the sign says / What we observe / How Christians read it.**  **What the sign says:** "SUE lived about 67 million years ago." **What we observe:** a nearly complete T. rex skeleton buried in sandstone of the Hell Creek Formation in South Dakota, with healed injuries, growth lines in the bones, and layers above and below that can be described and sampled. The date itself comes from radiometric measurements of volcanic ash layers elsewhere in the formation, which assume known starting amounts, constant decay rates and no gain or loss of atoms over time. **How Christians read it:** young-earth Christians read SUE as a creature made on the sixth day of creation (Genesis 1:24-25), probably buried during or soon after the Flood only thousands of years ago, and they question the assumptions behind the long date. Other Christians accept the conventional dating while affirming God as Creator. The course teaches the young-earth reading as its position; everyone can agree on the observed bones.

Go deeper. Steve Fiffer, *Tyrannosaurus Sue* (2000). Peter Larson and Kristin Donnan, *Rex Appeal* (2002), the finders' side of the story. Field Museum: SUE the T. rex pages and the Griffin Halls of Evolving Planet. Second video: the 2018 move and remount of SUE; preview first. The documentary *Dinosaur 13* (2014) tells the finders' side; parents should preview it.

Goes deeper in. Earth Science, dating methods and the Flood (coming soon); Small Business & Economics, property, contracts and auctions; and Life Science, bones and healing.

For families. No public-domain primary source exists for this 1990s story, so there is no "Primary source." box; the court opinion (*Black Hills Institute v. South Dakota School of Mines and Technology*, 8th Cir. 1993) can be read online by older students. Find date 12 August 1990; seizure 14 May 1992; auction 4 October 1997 (\$8.36 million including commission); unveiling 17 May 2000; remount December 2018. Measurements and the 90 percent figure are the Field Museum's. Age estimates vary (Erickson et al., *Nature* 2004, about 28; the museum now often says 33). The jaw-hole parasite hypothesis is Wolff et al., *PLoS ONE* (2009). Larson was convicted in 1995 on two felony counts related to customs declarations and served about 18 months; the stop states this plainly and notes that opinions differ.  box included because the museum sign gives a date in millions of years.

PRACTICE

1.  Who found SUE, when and where?
2.  Which museum owns SUE, and what did it pay?

3. **MEDIUM** Why did the government seize SUE in 1992?
4. **MEDIUM** Name three injuries or diseases recorded in SUE's bones and what healing shows.
5. **CHALLENGE** In the simplified growth model (slow growth to 1 ton at age 10, then about 0.6 tons a year from 10 to 18), how much would a T. rex weigh at 18? If it then grew about 0.3 tons a year until it reached 8 tons, at what age would it stop growing?
6. **CHALLENGE** List the parties who claimed SUE or had a stake in it, and for each give the strongest reason for their claim. Then state what the courts decided and the legal principle behind it.

Make it a game · Who Owns It?. The leader reads a short case (a treasure found in a library book, a bone found in a city park, a coin found in a rented house). Players stand on one side of the room for "finder," the other for "owner," or the middle for "someone else." Each side gives its best reason, then the leader reads what the law usually says. Players score for good reasons, not for guessing right.

Scripture. "Render therefore to all their dues: tribute to whom tribute is due; custom to whom custom; fear to whom fear; honour to whom honour." (Romans 13:7, KJV)

Paul tells Christians to give everyone what is rightly theirs: obedience to lawful authority, payment of what is owed, and honor to those who deserve it. In the SUE story, landowner, finder, government and museum each had something due to them, and sorting it out took patience.

Practice: answers

1. Sue Hendrickson of the Black Hills Institute, on 12 August 1990, near Faith, South Dakota.
2. The Field Museum in Chicago, about \$8.36 million at Sotheby's auction in 1997.
3. The skeleton came from Maurice Williams' land, which was held in trust by the U.S. Department of the Interior; the sale to the Black Hills Institute had not been approved as the law required, so ownership was disputed.
4. Any three: healed broken ribs, an injured and infected shoulder, arthritis in the tail, holes in the lower jaw (possibly a parasite infection). Healed bone shows the animal survived the injury for some time afterward.
5. From 10 to 18 is 8 years $\times 0.6 = 4.8$ tons gained, so about 5.8 tons at 18. To reach 8 tons it needs 2.2 tons more at 0.3 a year ≈ 7.3 years, so it would stop at about age 25. (This is a classroom model; real growth curves are smooth and estimates differ.)
6. Black Hills Institute: they found, dug and prepared SUE and paid Williams \$5,000. Maurice Williams: SUE came from his land. The Cheyenne River Sioux Tribe: the land was within the reservation. The U.S. government: it held the land in trust and had to approve any sale. Courts: the fossil was part of the land and belonged to Williams, held in trust by the government, because trust land and things removed from it could not be sold without federal approval.

2.10 MARY SCHWEITZER'S SOFT TISSUE (2005)

OBJECTIVES

- Trace the sequence of Mary Schweitzer's discoveries from the early 1990s through the 2005 paper and the tests that followed.
- Explain how scientists tested whether the soft material was original dinosaur tissue, and how critics proposed other explanations.
- Separate the observations from the competing interpretations of age, and state the young-earth reading and the mainstream reading fairly.

Warm-up. Put a small piece of chicken bone in a cup of vinegar and leave it for two or three days. The minerals dissolve and the bone becomes rubbery. That is the same idea, in a much stronger and more careful form, that let Mary Schweitzer see what was left inside a T. rex bone. Start it today and check it at the end of the week.

Video slot. Video coming. Mary Schweitzer and dinosaur soft tissue and proteins; the T. rex MOR 1125 and the Brachylophosaurus study. Search approved channels (North Carolina State University, Smithsonian, Museum of the Rockies); for the creation-friendly reading, Answers in Genesis or Institute for Creation Research videos once vetted; preview first.

KEY TERMS

demineralize

To dissolve away the hard calcium-phosphate mineral of bone with a mild acid or chelating agent, leaving any organic material behind.

collagen

The main protein in bone, skin and tendons; its chain of amino acids can be partly read by mass spectrometry.

medullary bone

A special, temporary bone that female birds lay down inside their long bones as a calcium store for eggshells. Schweitzer found it in MOR 1125.

mass spectrometry

A method that sorts molecules by mass so scientists can identify fragments of proteins (peptides).

biofilm

A slimy film made by colonies of bacteria. Critics suggested the vessel-like structures might be biofilm rather than original tissue.

contamination

Material from modern sources (bacteria, handling, laboratory equipment) that can be mistaken for original ancient material.

CORE IDEAS

A late start. Mary Higby Schweitzer grew up in Montana, earned a degree in communicative disorders, became a teacher and raised three children. In 1989 she sat in on a dinosaur course taught by Jack Horner at Montana State University and asked to stay on as a graduate student. Around 1991 she was examining a thin slice of bone from a T. rex nicknamed for its finder (MOR 555) under a microscope when she saw tiny red, round structures inside the channels where blood vessels had run. They looked like red blood cells, and she could hardly believe it. Her 1997 tests found chemical signals consistent with heme, the iron-bearing part of hemoglobin, though she was careful not to claim the round structures were actual cells.

MOR 1125. In 2000 a crew from the Museum of the Rockies, working in Montana's Hell Creek Formation, dug out another T. rex (MOR 1125), found by Bob Harmon. The plaster jacket around the thigh bone was too heavy for the helicopter, so the bone was broken and the fragments went to Schweitzer, by then working at North Carolina State University. Because the pieces had not been coated with preservatives, they were ideal for testing. Her technician, Jennifer Wittmeyer, placed fragments in a solution that slowly removed the minerals. What remained was flexible, stretchy material that sprang back when pulled, transparent branching vessels, and inside them small round bodies, and cell-like shapes in the bone called osteocytes, with fine branching extensions.

The 2005 papers. On 25 March 2005, Schweitzer, Wittmeyer, Horner and Jan Toporski reported the finding in *Science*, along with similar structures from a few other specimens. They did not claim to know how it had survived. In June 2005 Schweitzer reported something else in the same thigh bone: medullary bone, the special calcium store female birds make when laying eggs. MOR 1125 was a female, the first dinosaur whose sex could be identified from its bones, and that finding was confirmed by chemical tests in 2016.

Testing the claim. The papers set off years of testing. Mainstream scientists had long held that proteins could not survive more than a few million years at most, so many doubted the result. In 2007 Schweitzer and John Asara's team reported short protein fragments from MOR 1125 that matched collagen, with sequences most like those of chickens. Critics questioned whether the fragments could be contamination. In 2008 Thomas Kaye and colleagues argued that the vessel-like structures were bacterial biofilm and that the round bodies were iron-rich mineral grains. Schweitzer's team responded with new work: in 2009 they reported collagen from a duck-billed dinosaur, *Brachylophosaurus*, dug specially to avoid contamination and tested independently in more than one laboratory, and found antibody reactions to proteins such as collagen, elastin and laminin. Other teams have since reported traces of proteins or cell-like structures in other fossils, though debate continues over each case. This is how science should work: a surprising observation, careful repetition, hard criticism and better tests.

How could it last? The question "How old?" sits underneath every one of these papers. In 2014 Schweitzer's team proposed that iron released from blood after death formed tiny particles and free radicals that cross-linked proteins, as formaldehyde does in a laboratory,

and that this might preserve tissue for very long periods. In their experiment, ostrich blood vessels soaked in a concentrated solution of red blood cells showed no visible decay after two years at room temperature, while vessels in water decayed within days. Critics on several sides note that two years is a long way from tens of millions of years, and that the conditions in the experiment were different from burial in sandstone.

Two readings. Here observation and interpretation must be kept apart. The observation, now repeated by several teams, is that some dinosaur bones contain flexible, vessel-like structures and traces of original proteins. Many young-earth Christians read this as strong evidence that these bones are thousands, not millions, of years old, buried in the Flood, because known decay rates of proteins make survival for tens of millions of years hard to explain. Most paleontologists accept the long ages and look for a preservation process, such as iron cross-linking, to explain the survival. Schweitzer herself is a professing Christian who holds an old-earth view. She has said that her faith and her science do not conflict, and she has complained that her work is used by both sides for their own purposes.

What a student should take away. Mary Schweitzer's story is not finished, and the course does not pretend otherwise. It is a model of honest work: she reported what she saw, invited testing, accepted criticism and kept experimenting. A Christian student can respect that integrity, recognize the strength of the young-earth argument from soft tissue, understand the mainstream reply, and keep watching the evidence.

PICTURE STUDY



*Cork cells, Scheme XI from Micrographia, Robert Hooke, 1665 · Engraving · From Robert Hooke, Micrographia (London, 1665); copies in many libraries
Wikimedia Commons · Public domain*

In 1665 Robert Hooke looked at a thin slice of cork through his microscope and saw tiny compartments that he called “cells,” the first time the word was used that way. Three and a

half centuries later, Mary Schweitzer's microscope showed cell-like shapes in a dinosaur bone. Both began with someone looking closely and drawing exactly what was there.

Look closely

- Find the two views of the cork. How are they different?
- Look at the walls of the compartments. Are they all the same size and shape?
- Notice how Hooke shows the sprig. Why include it?

Talk about it

1. Hooke saw only the empty walls of dead cork cells. What can a microscope show, and what can it not show, about whether something was once alive?
2. Why is a careful drawing or photograph the first step in testing a surprising claim?

Safety first. Vinegar is a mild acid; keep it away from eyes and wash hands after handling raw or cooked bones. Do not use stronger acids.

HANDS-ON: DEMINERALIZE A BONE; BUILD AN EVIDENCE TABLE

Repeat the core idea of Schweitzer's method safely at home, then lay out the soft-tissue evidence the way a scientist reviewing a paper would.

You will need

- Two clean chicken leg bones (boiled and scrubbed)
- Two jars with lids, white vinegar and plain water
- Magnifying glass or a cheap phone microscope
- Notebook with a table drawn in it
- The ⏰ box below

Steps

1. Put one bone in vinegar and one in water (the control). Label both jars with the date.
2. Check every day for five days. Record color, smell and how much the bone bends. Change the vinegar on day 3.
3. On day 5, rinse both bones. Bend them gently and look at a cut end under magnification. Draw what you see.
4. Build a table with four columns: "Observation," "Who reported it and when," "Proposed explanation(s)," "How it was tested." Fill in at least five rows from the core ideas (for example, flexible vessels 2005, collagen fragments 2007, biofilm critique 2008, Brachylophosaurus 2009, iron experiment 2014).
5. Under the table, write one paragraph: what is agreed by everyone, and where the interpretations divide?

Check your work

- I used a control jar and recorded results daily.
- My table has at least five rows with dates.
- My paragraph separates what is observed from how it is interpreted.

FIELD NOTEBOOK

1. Draw what Schweitzer saw: a branching vessel with small round bodies inside, and an osteocyte with fine branches. Label each.
2. Draw your vinegar bone and your water bone side by side on day 5, with notes.
3. **Narration.** Write one paragraph telling what Mary Schweitzer found in MOR 1125 and how other scientists tested it, ending with the two ways people interpret it. A parent keeps this page.

Did you know? MOR 1125 is sometimes called “B. rex” after its finder, Bob Harmon. Schweitzer has said that early in her life she held a young-earth view and that her graduate studies changed her mind, and that some critics on both sides have treated her unkindly. She has encouraged students to follow evidence wherever it leads and to treat people who disagree with respect.

 **What the sign says / What we observe / How Christians read it.**  **What the sign says:** “This Tyrannosaurus rex lived about 68 million years ago, and its soft tissue was preserved by iron from its blood.” **What we observe:** after the minerals were removed from fragments of a T. rex thigh bone (MOR 1125), flexible, branching, vessel-like structures and cell-like shapes remained; later tests on this and other specimens reported fragments of proteins such as collagen; a laboratory experiment showed iron-rich blood slowed decay of ostrich vessels for two years. **How Christians read it:** young-earth Christians read original proteins and flexible tissue as evidence that the bones are thousands of years old, buried in the Flood, because the long date requires preservation far beyond any measured decay rate. Christians who accept an old earth, including Dr. Schweitzer, think a process such as iron cross-linking may explain long survival. The date and the preservation mechanism are interpretations; the soft material itself is the observation.

Go deeper. Helen Fields, “Dinosaur Shocker,” *Smithsonian* magazine (May 2006). Mary H. Schweitzer, “Blood from Stone,” *Scientific American* (December 2010). North Carolina State University: news pages on Schweitzer’s research. For the young-earth reading, articles on dinosaur soft tissue from the Institute for Creation Research and Answers in Genesis (parents may preview). Second video: the Brachylophosaurus excavation and protein tests.

Goes deeper in. Earth Science, the creation and dating units (coming soon); Life Science, cells, proteins and the microscope; and Trail D, Stop D9 “Soft tissue and dating.”

For families. This is a  stop. Key papers: Schweitzer et al., *PNAS* 94 (1997), heme compounds in MOR 555; Schweitzer, Wittmeyer, Horner and Toporski, *Science* 307 (25

March 2005); Schweitzer, Wittmeyer and Horner, *Science* 308 (June 2005), medullary bone; Asara et al. and Schweitzer et al., *Science* 316 (April 2007), collagen sequences; Kaye et al., *PLoS ONE* (2008), biofilm hypothesis; Schweitzer et al., *Science* 324 (2009), Brachylophosaurus; Schweitzer et al., *Proc. R. Soc. B* (2014), iron preservation; Schweitzer et al., *Scientific Reports* (2016), medullary bone confirmed. No public-domain primary source exists for this recent work, so there is no “Primary source.” box. Dr. Schweitzer’s faith and old-earth view are stated as she has described them publicly. The stop does not repeat the Scout story of the helicopter in detail. Students wanting the full dating discussion should continue to Trail D, Stop D9.

PRACTICE

1. **EASY** What did Schweitzer’s team find when they demineralized pieces of MOR 1125?
2. **EASY** What is medullary bone, and what did it show about MOR 1125?
3. **MEDIUM** Name two alternative explanations critics offered, and one way Schweitzer’s team answered them.
4. **MEDIUM** Describe the 2014 iron experiment and one limitation of it.
5. **CHALLENGE** Sort these statements into observation or interpretation and explain each: (a) The demineralized material stretched and returned to shape. (b) The tissue is 68 million years old. (c) Iron from blood preserved the tissue. (d) Peptides matching collagen were detected by mass spectrometry. (e) The bones were buried in the Flood.
6. **CHALLENGE** Suppose a protein loses half of its intact molecules every 10,000 years under certain burial conditions (an illustrative rate). What fraction would remain after 100,000 years? After 1,000,000 years? What does this show about why the soft-tissue finding is debated?

Make it a game • Peer Review. One player makes a surprising claim about something in the house (“The bread in the kitchen is from last month”). Others act as reviewers: each may ask for one test (smell it, check the date, look for mold). After the tests, the group votes whether the claim stands, falls, or needs more evidence. Rotate roles. Reviewers must be polite and specific.

Scripture. “He that answereth a matter before he heareth it, it is folly and shame unto him.” (Proverbs 18:13, KJV)

The soft-tissue debate rewards patience. Hear the evidence fully and hear both readings fairly before answering, and keep holding fast to the truth of God’s Word while the testing goes on.

Practice: answers

1. Flexible, stretchy material with transparent branching vessel-like structures, small round bodies inside them, and cell-like shapes (osteocytes).
2. A temporary calcium-storage bone made by female birds when laying eggs; it showed MOR 1125 was female.

3. Critics: the vessels might be bacterial biofilm; the round bodies might be iron-mineral grains; the protein fragments might be modern contamination. Answers: they dug a new specimen (*Brachylophosaurus*) to avoid contamination, had samples tested in more than one laboratory, and used antibody tests and mass spectrometry for specific dinosaur-like proteins.
4. Ostrich blood vessels soaked in concentrated red-blood-cell solution (iron-rich) showed no visible decay for two years, while vessels in water decayed within days. Limitation: two years is vastly shorter than the claimed age, and laboratory conditions differ from burial in rock.
5. (a) Observation: seen and tested directly. (b) Interpretation: depends on dating methods and their assumptions. (c) Interpretation: a proposed mechanism, partly supported by a short experiment. (d) Observation, though whether the peptides are original or contamination is debated. (e) Interpretation: a historical reading based on Genesis and the rock record.
6. 100,000 years is 10 half-lives: $(1/2)^{10} = 1/1,024$, about 0.1% remains. 1,000,000 years is 100 half-lives: $(1/2)^{100} \approx 8 \times 10^{-31}$, effectively none. Under any steady decay rate in that range, survival for tens of millions of years would be impossible without a special preserving process. Young-earth readers take this as evidence of a young age; mainstream scientists look for a mechanism (such as iron cross-linking) that slows decay drastically. The debate turns on decay rates and conditions.

TRAIL 2 BADGE QUIZZES

The badge quizzes are optional and may be written or oral. Answers should be in complete sentences; for “why” questions, give a reason from the stop. Four good answers out of five earns the first badge; five out of six earns the second. Badges and the certificate are earned by doing the stops and the portfolio, not by scores.

Badge quiz 1 (Stops 1–5)

1. What did the Anning family find in 1811–1812, and why did Mary Anning’s name often go missing from papers about her specimens?
2. How did Buckland know Megalosaurus was a meat-eater, and why was his size estimate too large?
3. What did Cuvier predict in his 1824 letter about the Iguanodon teeth, and how was the prediction tested?
4. Which three animals did Owen group as Dinosauria, and what features defined the group?
5. Name one thing the Crystal Palace models got right and one they got wrong, and explain why the mistake was reasonable in 1854.

Badge quiz 2 (Stops 6–10)

6. Give one good result and one harmful result of the Bone Wars.
7. What is the holotype of *Tyrannosaurus rex*, who found it and who named it?
8. Why was *Oviraptor* named “egg seizer,” and what later discovery reversed the interpretation?
9. Why did the courts rule that SUE belonged to Maurice Williams rather than the Black Hills Institute?
10. State the main observation in Mary Schweitzer’s 2005 paper and two different interpretations of it.
11. Give one way scientists tested whether the material was original dinosaur protein rather than contamination.

TRAIL CERTIFICATE: DINOSAUR HUNTERS RESEARCH PORTFOLIO AND TRAIL B CERTIFICATE

Gather your Field Notebook pages from all ten stops into one portfolio with a cover: “Dinosaur Hunters,” your name and the dates you began and finished. Include all ten narration paragraphs.

Add a timeline page from 1811 to 2005 with every discovery on the trail, plus at least three corrections (for example, the *Iguanodon* horn in 1878, the *T. rex* pose in the 1990s, *Oviraptor* in the 1990s).

Write a final essay of 500–700 words on this question: “How does knowledge about the past grow?” Use at least three stops and at least two primary sources from the trail, and include one paragraph on observation and interpretation in the soft-tissue debate.

When the portfolio is complete, a parent reviews it with the rubric and signs the Trail B certificate.

- **Completeness:** Pages and a narration paragraph for all ten stops, each with a title and date, plus the timeline with discoveries and corrections.
- **Use of sources:** The essay quotes or closely refers to at least two primary sources accurately, naming author, title and date, and separates what each source shows from what it omits.
- **Reasoning:** The essay clearly separates observation from interpretation, explains at least one correction and the evidence behind it, and states the young-earth and mainstream readings fairly.
- **Character and care:** People are judged fairly by the standards of their own time, real wrongs and real virtues are named plainly, and the writing is neat, organized and proofread.

Answer key

1. The first ichthyosaur skeleton to reach scientists (Joseph found the skull, Mary the body). Collectors and dealers were rarely named in papers, she was a tradeswoman, and the learned societies did not admit women; the buyer or describer was treated as the scientific owner.
2. Its teeth were curved, flattened blades with serrated edges. He scaled the bones as if it were built like a giant lizard, giving more than 40 feet; it was really an upright, two-legged animal about 6 m (20 ft) long.
3. That the teeth came from a new herbivorous reptile and that a skeleton with jaws and teeth together would one day confirm or refute it. The Maidstone slab (1834) and the Bernissart skeletons (1878) confirmed a large plant-eating reptile, and Bernissart showed the “horn” was a thumb spike.
4. Megalosaurus, Iguanodon and Hylaeosaurus; five fused vertebrae in the sacrum, upright limbs under the body like large mammals, and a build fitted for heavy walking on land.
5. Right (any): the ichthyosaurs, plesiosaurs or giant sloth, based on near-complete skeletons. Wrong (any): Iguanodon’s nose horn, four-legged Megalosaurus. Reasonable because only scattered dinosaur bones were known and Owen believed dinosaurs were heavy, four-legged, mammal-like reptiles; Owen even called the horn “more than doubtful.”
6. Good (any): dozens of new dinosaurs named, such as Stegosaurus, Allosaurus, Triceratops and Camarasaurus; great museum collections. Harmful (any): hasty descriptions and many duplicate names (Brontosaurus/Apatosaurus); destroyed trust; public quarrels in 1890 that damaged both men and American science.
7. The partial skeleton Barnum Brown found in 1902 in the Hell Creek badlands of Montana; Henry Fairfield Osborn named it in 1905. It is now at the Carnegie Museum in Pittsburgh.
8. It was found in 1923 on a nest of eggs thought to be Protoceratops eggs, so it was assumed to be a thief. In the 1990s an embryo of an oviraptorid was found in the same type of egg, and an adult was found brooding a nest; it was a parent.
9. SUE came from Williams’ land, which was held in trust by the U.S. government; the fossil was treated as part of the land, and the sale could not be valid without federal approval, which had not been obtained.
10. After demineralizing a T. rex thigh bone (MOR 1125), flexible, branching vessel-like structures and cell-like shapes remained. Young-earth interpretation: original soft tissue means the

bones are thousands of years old, buried in the Flood. Mainstream interpretation: the bones are tens of millions of years old and some process, such as iron cross-linking, preserved the tissue.

11. Any one: digging a new specimen (*Brachylophosaurus*) under clean conditions; testing samples in more than one laboratory; mass spectrometry of peptide sequences; antibody tests for proteins such as collagen.

DINOSAURS TRAIL C: HOW DINOSAURS LIVED

The third trail of the Dinosaurs track asks how dinosaurs actually lived and how we can know: what their teeth and dung reveal about diet, how they laid and guarded eggs, what footprints and trackways record, whether they lived in herds, how fast they ran, whether they were warm-blooded, what the fossils really show about feathers, how babies grew into giants, how sauropods carried their enormous necks, and what dinosaurs may have sounded like. Every stop trains one habit: separate what is observed from how it is interpreted.

This is the  **Expert** level, for ages 14 and up, written at a high-school level. Each stop takes 35 to 50 minutes and includes core ideas with numbers and honest debates, key terms, a picture study, a hands-on investigation, a written narration paragraph for the parent to keep, six practice problems (two of them “challenge” problems with worked answers), and a “Go deeper” list. Five stops include a public-domain primary source (King James Version passages and Frederic A. Lucas’s *Animals of the Past*, 1901). The track is creation-friendly: period names such as Jurassic are taught as museum vocabulary, and the two stops where museum dates appear (C3 and C7) carry the  box, *What the sign says / What we observe / How Christians read it*.

Five stops earn the **Dinosaur Life Expert badge, part 1**, and ten stops earn part 2 and the **Trail C certificate**. The two badge quizzes at the end are optional; badges and the certificate are earned by doing the stops and keeping the Field Notebook.

BEFORE YOU BEGIN

- Comfort with ratios, powers and simple formulas (a calculator is fine), and with reading a graph.
- Know the difference between an observation and an interpretation (Trail B, Stop B10, at any level, is a good introduction).

MASTERY CHECKLIST

- ☐ I can explain how teeth, coprolites, trackways, bone slices and eggshell each give evidence about how dinosaurs lived.
- ☐ I can estimate a dinosaur’s hip height, gait and speed from a trackway using Alexander’s formula.
- ☐ I can describe the evidence and the debates about herds, warm-bloodedness, feathers and sauropod neck posture without overstating either side.
- ☐ I can read a museum sign and sort its claims into what the sign says, what we observe, and how Christians read it.
- ☐ I can write a clear paragraph that names the evidence for a claim and one honest limit of that evidence.

GO DEEPER: BOOKS, MUSEUM PAGES AND RESOURCES

- **Project Gutenberg: Frederic A. Lucas, *Animals of the Past* (1901)** (<https://www.gutenberg.org/ebooks/38013>): Free public-domain book by a Smithsonian curator, quoted in Stops C3 and C7; good for comparing 1901 science with today's.
- **Biodiversity Heritage Library** (<https://www.biodiversitylibrary.org>): Free scans of old scientific works, including Edward Hitchcock's *Ichnology of New England* (1858) and Richard Owen's papers.
- **Natural History Museum, London** (<https://www.nhm.ac.uk>): Free pages and images on Iguanodon, the London Archaeopteryx, Diplodocus and Richard Owen.
- **American Museum of Natural History** (<https://www.amnh.org>): Pages on the Central Asiatic Expeditions, brooding oviraptorids and Charles R. Knight's paintings.

3.1 TEETH TELL DIET

OBJECTIVES

- Explain how tooth shape, tooth wear, tooth replacement and coprolites each give evidence about what a dinosaur ate.
- Compare a tyrannosaur tooth, a sauropod tooth and a hadrosaur dental battery and say what each was built to do.
- Weigh how Christians read sharp teeth in light of Genesis 1:29–30, keeping observation and interpretation apart.

Warm-up. Look in a mirror at your own teeth. Find the chisels (incisors), the points (canines) and the grinders (molars). Now find a picture of a dog's teeth and a cow's teeth. Write one sentence for each: what would a scientist guess about that animal's food if only the teeth survived?

Video slot. Video coming. Dinosaur teeth and diet: serrated theropod teeth, sauropod tooth replacement, hadrosaur dental batteries, coprolites. Search approved channels (American Museum of Natural History, Natural History Museum London, Royal Tyrrell Museum, Smithsonian, Answers in Genesis); preview first.

KEY TERMS

serration

A row of tiny saw-like bumps (denticles) along the edge of a tooth, used for slicing flesh.

dental battery

A block of hundreds of tightly packed teeth, worn together into one grinding surface, found in hadrosaurs and ceratopsians.

microwear

Microscopic scratches and pits on a tooth's chewing surface left by food and grit.

coprolite

Fossilized dung. Its contents (bone, wood, seeds) give direct evidence of diet.

tooth replacement

The steady growth of new teeth beneath old ones, so that a reptile sheds and replaces teeth all its life.

convergence of evidence

Several independent lines of evidence pointing to the same conclusion, which makes the conclusion stronger.

CORE IDEAS

A tooth in the road. The first dinosaur known from its teeth was *Iguanodon*. In 1822 Gideon Mantell (the story belongs to Trail B) studied large worn teeth from Sussex, England,

that looked like giant versions of an iguana's teeth, and in 1825 he named the animal "iguana tooth." From the start, teeth have been one of the best clues to how dinosaurs lived. Enamel is the hardest material in a vertebrate body, so teeth survive when almost nothing else does. Many dinosaur species are known from little more than a handful of teeth.

Shape: blades, pegs and grinders. A *Tyrannosaurus* tooth is a thick, curved cone with fine **serrations** on its front and back edges. The largest, with root, are about 30 cm (12 in) long. Serrated, blade-like teeth slice flesh, the way a steak knife cuts better than a butter knife. Sauropods had very different teeth: *Diplodocus* had a comb of slender pencil-shaped pegs at the front of its jaws, good for stripping leaves from branches but useless for chewing. Hadrosaurs and horned dinosaurs went the other way: they packed hundreds of teeth into **dental batteries**. A single *Edmontosaurus* jaw held stacks of teeth in about 60 columns, worn together into a file-like surface. A 2012 study found that hadrosaur teeth were built from six different tissues, more than in a horse or cow tooth, so that softer and harder tissues wore at different rates and kept ridges sharp.

Wear and replacement. Teeth record use. Under a microscope, a tooth's surface shows **microwear**: long parallel scratches from grinding tough plants, or pits from crushing hard seeds or bone. Wear facets show which way the jaw moved. Reptile teeth are replaced throughout life, and fine daily growth lines in the dentine let scientists count how long each tooth took to form. One study (D'Emic and others, 2013) estimated that *Diplodocus* replaced each tooth about every 35 days, and the small sauropod *Nigersaurus*, with more than 500 teeth, perhaps every two weeks. Fast replacement suggests heavy wear, which points to gritty, low-growing plants. A *T. rex*, by contrast, took more than two years to grow each tooth.

Direct evidence: dung and stomachs. Tooth shape is indirect evidence. **Coprolites** are direct. In 1998 Karen Chin and colleagues described a coprolite from Saskatchewan about 44 cm long, very likely from a tyrannosaur, packed with crushed bone from a young plant-eater. That shows a tyrannosaur not only ate meat but crunched bone. Other coprolites contain chewed conifer wood. Rare stomach contents add more: the armored dinosaur *Borealopelta* (described 2020) still held a mass of ferns, and fish scales have been found inside the ribs of *Baryonyx*. Bite marks on bones, matched to tooth spacing, show who bit whom. Engineers have even estimated bite force: one computer model (Bates and Falkingham, 2012) gave an adult *T. rex* a back-tooth bite of roughly 35,000 to 57,000 newtons.

Honest complexity. Teeth do not always tell a simple story. Spinosaurus had cone-shaped teeth like a crocodile's, but they were not crocodiles. Some small theropods such as *Incisivosaurus* had rabbit-like front teeth, and many ornithomimids had no teeth at all, only beaks. Scientists now think several groups once called "meat-eaters" ate plants or a mix. Living animals warn us, too: the giant panda has the skull and teeth of a carnivore but lives almost entirely on bamboo, and fruit bats have sharp teeth for piercing fruit. The best conclusions use **convergence of evidence**: tooth shape, wear, coprolites, stomach contents and bite marks agreeing together.

How Christians read it. Genesis 1:29–30 says God gave “every green herb for meat” to the beasts, fowl and creeping things, and then called His creation “very good.” Many young-earth Christians read this as a world without animal predation before the Fall, so sharp teeth either served plant foods at first (as the panda’s do today) or took on new uses after the curse of Genesis 3. Others hold that some features were designed with a fallen world in view. Christians who hold an old earth often read Genesis 1:30 as describing God’s provision rather than forbidding predation. What everyone can observe is the same: blades, pegs, grinders, scratches and dung. Learning to say clearly which part is observation and which is interpretation is the habit this whole trail trains.

PICTURE STUDY



*The Iguanodon and the Megalosaurus, from Louis Figuier's The World Before the Deluge, Édouard Riou, 1863 · Wood engraving (book illustration) · From Louis Figuier, La Terre avant le déluge (Paris, 1863); English edition The World Before the Deluge
Wikimedia Commons · Public domain*

Édouard Riou drew this scene only about forty years after Mantell’s teeth were found. Almost everything Riou knew about *Iguanodon* came from teeth and a few scattered bones, so he drew a heavy, four-legged lizard with a horn on its nose. Later finds showed that the “horn” was a thumb spike.

Look closely

- Find each animal’s mouth. What kind of teeth did Riou give the meat-eater, and what kind (if any) did he show on *Iguanodon*?
- Look at the legs and body. Is this how a modern museum would show these dinosaurs?
- Look at the plants. What foods did Riou put within reach of a plant-eater?

Talk about it

1. Riou had teeth and a few bones. Which parts of his picture are observations and which are guesses?
2. Why should a careful scientist hold a reconstruction loosely when it rests on very little evidence?

HANDS-ON: TOOTH DETECTIVE: BUILD A DIET CASE

Use clay tooth models and a short evidence table to argue for an animal's diet, then test your claim against Genesis 1:29-30 and the living world.

You will need

- Air-dry or modeling clay and a toothpick
- A ruler and a hand lens or phone camera with zoom
- Pictures of a T. rex tooth, a Diplodocus tooth and a hadrosaur dental battery (museum websites)
- Pictures of a panda skull and a fruit bat skull
- Notebook paper ruled into a 4-column table

Steps

1. Model three teeth at true scale or half scale: a serrated tyrannosaur tooth (make the serrations with the toothpick), a sauropod peg, and a small block of hadrosaur teeth stacked in columns.
2. Make a table with columns: Evidence, What we observe, What it suggests, How strong? Fill one row each for shape, wear, replacement rate and coprolites, using the numbers from this stop.
3. Now compare the panda and fruit bat. Write two sentences: what would a scientist guess from their teeth alone, and what do they actually eat?
4. Read the Primary source (Genesis 1:29-30). Write a short paragraph: what does the text say about food in the beginning, and what does it not say? Keep your own interpretation labeled as interpretation.
5. Present your case aloud to a parent in two minutes, ending with "The strongest evidence is ... because ...".

Check your work

- My three models show clear differences in shape and edge.
- My table separates what we observe from what it suggests.
- I used the panda or fruit bat to show a limit of tooth evidence.
- I quoted Genesis 1:30 exactly and labeled my interpretation.

FIELD NOTEBOOK

1. Draw a T. rex tooth, a Diplodocus tooth and a section of a hadrosaur dental battery side by side, to scale, with a 5 cm scale bar. Label serrations, crown, root and wear surface.

2. Make a two-column list: “Indirect evidence” (shape, wear) and “Direct evidence” (coprolites, stomach contents).
3. **Narration.** Write one paragraph (6–8 sentences) explaining how a scientist can tell what a dinosaur ate, using at least two kinds of evidence and one honest limit. Your parent keeps this page.

Did you know? Shed dinosaur teeth are among the most common dinosaur fossils, because a single animal could shed hundreds or even thousands in its life. A *T. rex* tooth with a worn, broken tip may have been shed while the animal was feeding. Many museum gift shops sell real *Spinosaurus* teeth from Morocco for a few dollars because so many have been found.

Primary source. *Genesis 1:29–30, King James Version (1611)*

And God said, Behold, I have given you every herb bearing seed, which is upon the face of all the earth, and every tree, in the which is the fruit of a tree yielding seed; to you it shall be for meat. And to every beast of the earth, and to every fowl of the air, and to every thing that creepeth upon the earth, wherein there is life, I have given every green herb for meat: and it was so.

In 1611 English, “meat” means food of any kind.

Go deeper. Natural History Museum (London), online pages on *Iguanodon* and Gideon Mantell. Royal Tyrrell Museum (Alberta) pages on hadrosaurs and coprolites. Gregory M. Erickson et al., “Complex Dental Structure and Wear Biomechanics in Hadrosaurid Dinosaurs,” *Science* (2012), abstract online. Second video topic: “How coprolites are studied.”

Goes deeper in. Life Science, high-school biology unit on vertebrate anatomy and feeding (coming soon); and Earth Science, the fossils unit.

For families. Figures are from published studies and are rounded: *T. rex* tooth length (up to about 30 cm with root); hadrosaur six-tissue teeth (Erickson et al., *Science*, 2012); replacement rates (D’Emic et al., *PLoS ONE*, 2013); tyrannosaur coprolite (Chin et al., *Nature*, 1998); *Borealopelta* gut contents (Brown et al., 2020); bite force (Bates and Falkingham, *Biology Letters*, 2012). Estimates vary between studies. The stop presents young-earth and old-earth readings of Genesis 1:30 fairly and teaches the young-earth reading as the course’s position without mocking others. No dates in “millions of years” are used here.

PRACTICE

1. **EASY** Name four kinds of evidence scientists use to work out a dinosaur’s diet.
2. **MEDIUM** Why is a coprolite full of crushed bone stronger evidence than a sharp tooth?
3. **MEDIUM** What is a dental battery, and what kind of food does it suggest?

4. **MEDIUM** Using the Primary source: what food does Genesis 1:30 say God gave to the beasts and fowl? Quote the phrase exactly.
5. **CHALLENGE** If Diplodocus replaced each tooth every 35 days and had about 40 tooth positions in use at a time, roughly how many teeth would it shed in one year? Show your work.
6. **CHALLENGE** A student says, “Sharp teeth prove an animal killed other animals.” Give two counterexamples and rewrite the claim so it is careful and true.

Make it a game · Name That Diet. One player describes a tooth without naming the animal (“long, curved, with saw edges”; “flat, ridged, packed with others”). The others guess the diet and one living animal with similar teeth. A bonus point goes to anyone who can name a living animal whose teeth would fool the guesser.

Scripture. “And to every beast of the earth, and to every fowl of the air, and to every thing that creepeth upon the earth, wherein there is life, I have given every green herb for meat: and it was so.” (Genesis 1:30, KJV)

God provided food for every creature He made. When we study a dinosaur’s teeth we are studying how a creature was fitted to receive His provision.

Practice: answers

1. Any four: tooth shape, microwear, tooth replacement rate, coprolites, stomach contents, bite marks on bones, jaw mechanics or bite-force models.
2. The coprolite is direct evidence of what was actually eaten; tooth shape is indirect and only suggests what the animal could eat (pandas show shape can mislead).
3. Hundreds of tightly packed teeth worn into one grinding surface; it suggests tough, fibrous plant food that needed heavy chewing.
4. “every green herb for meat” (meat meaning food).
5. $365 \div 35 \approx 10.4$ replacements per position per year; $10.4 \times 40 \approx 417$, so roughly 400 teeth a year.
6. Counterexamples: the giant panda (carnivore-type teeth, eats bamboo) and fruit bats (sharp teeth, eat fruit). A careful claim: “Sharp, serrated teeth are well suited to slicing flesh, so they suggest meat in the diet; direct evidence such as coprolites or stomach contents is needed to confirm it.”

3.2 EGGS AND NESTS

OBJECTIVES

- Describe the main kinds of dinosaur eggs and nests and what eggshell, embryos and nest layout reveal.
- Explain why even the largest dinosaurs laid eggs no bigger than about a football, using the physics of shell and oxygen.
- Compare Job 39's ostrich with the fossil evidence for nest guarding, and tell the story of the Oviraptor correction.

Warm-up. Hold a raw chicken egg up to a bright flashlight in a dark room. Can you see the air cell and the shape of the yolk? Now look at the shell with a hand lens and find the tiny pores. Write down why an egg needs holes in its shell.

Video slot. Video coming. Dinosaur eggs and nests: Oviraptor brooding fossils, Maiasaura Egg Mountain, titanosaur nesting grounds at Auca Mahuevo, dinosaur embryos. Search approved channels (American Museum of Natural History, Museum of the Rockies, Natural History Museum London, Smithsonian, Answers in Genesis); preview first.

KEY TERMS

clutch

A group of eggs laid together in one nest.

eggshell porosity

How many and how large the pores are in a shell; it controls how quickly oxygen, carbon dioxide and water vapor pass through.

embryo

A young animal still developing inside the egg.

brooding

Sitting on eggs to warm and protect them, as birds do.

oogenus (plural oogenera)

A name given to a type of fossil egg by its shell structure, used when the animal that laid it is not known.

CORE IDEAS

Eggs found before they were understood. In 1859 a French priest and naturalist, Jean-Jacques Pouech, described large eggshell fragments from the foothills of the Pyrenees, but no one realized they were dinosaur eggs. The world's attention came in 1923, when the American Museum of Natural History's Central Asiatic Expeditions under Roy Chapman Andrews uncovered nests of elongated eggs at the Flaming Cliffs in Mongolia's Gobi Desert.

(The expedition itself is told in Trail B.) Since then, dinosaur eggs have been found on every continent except Antarctica, in places such as Montana, Argentina, India, Spain, France, Portugal and China, where farmers in some provinces have dug up thousands.

How big? The surprise is how small dinosaur eggs were. Most are between the size of a hen's egg and a grapefruit. Round sauropod eggs from Argentina and India are about 13 to 20 cm across, and the largest known dinosaur eggs, long eggs of giant oviraptorosaurs called *Macroelongatoolithus*, reach about 45 cm. Compare an ostrich egg: about 15 cm long and 1.4 kg. Why did a 50-tonne sauropod not lay a 50-kilogram egg? Physics sets limits. A bigger egg needs a thicker shell to bear its weight, but a thicker shell slows the passage of oxygen to the embryo and makes it harder for a hatchling to break out. So the largest dinosaurs laid many medium-sized eggs instead, sometimes 20 to 40 in a clutch.

Reading the shell. Eggshell is a record of how the egg was incubated. Under a microscope it shows crystal layers that differ from group to group, which is why fossil eggs are classified into **oogenera**, a system of names based on shell alone. **Porosity** matters most. A study by Kohei Tanaka and colleagues (2015) compared fossil shells with living birds and crocodiles: highly porous shells match eggs buried in soil or plant mounds, as crocodiles and megapode birds do, while less porous shells match eggs in open nests. Most sauropod and hadrosaur eggs were very porous and probably buried, while many small theropods, close to birds, laid eggs in partly open nests. In 2018 Jasmina Wiemann and colleagues found pigments in oviraptorid shells that gave them a blue-green color, as in some birds' eggs today.

Nests and colonies. In 1978 Marion Brandvold, a rock shop owner in Choteau, Montana, showed tiny bones to Jack Horner and Bob Makela. They led to a site later called Egg Mountain and to a nesting ground of the hadrosaur Horner named *Maiasaura* (1979), "good mother lizard." The nests were bowl-shaped mounds about 2 m across, spaced roughly an adult's length apart, as in a modern seabird colony. In 1997 a team in Patagonia found the titanosaur nesting ground at Auca Mahuevo, where thousands of eggs lie in several layers and some embryos still show fossil skin. Embryo teeth carry daily growth lines; using them, Gregory Erickson and colleagues (2017) estimated that eggs of *Protoceratops* took about three months to hatch and those of *Hypacrosaurus* about six.

The egg thief who wasn't. One skull found with the 1923 eggs belonged to a toothless theropod. Henry Fairfield Osborn named it *Oviraptor philoceratops*, "egg seizer, fond of ceratopsians," supposing it had died robbing *Protoceratops* eggs. In 1993 an American Museum team found an embryo of an oviraptorid inside the same kind of egg, and soon afterward an adult *Citipati* fossil sitting on a ring of eggs, arms spread over them like a brooding bird. The "thief" was a parent. Science corrected itself, but the name stays, because the rules of naming do not allow a name to be changed just because it proved wrong.

Job's ostrich and the dinosaur parent. In Job 39 God asks Job about the ostrich, which "leaveth her eggs in the earth, and warmeth them in dust." Ostriches really do lay in a shallow scrape in the ground, and eggs can be left for periods in the heat of the day. Some dinosaur eggs, buried in warm soil, may have been warmed the same way. Others were

guarded by a parent sitting on the clutch. The variety itself is a lesson: God did not make one plan for every creature. Job learned to marvel at creatures he could not explain, and paleontologists still disagree about how much care particular dinosaurs gave. Hold the evidence firmly and the conclusions humbly.

PICTURE STUDY



A nest of fossil eggs from the Gobi, labeled Protoceratops, Photograph by Gary Todd, Photographed 2017 · Color photograph of a fossil specimen · Central Museum of Mongolian Dinosaurs, Ulaanbaatar, Mongolia · Wikimedia Commons · CC0

This nest of long eggs from the Gobi is shown in a museum in Mongolia's capital under the name *Protoceratops*, the name given to eggs like these after 1923. Since the 1990s, embryos and brooding adults have shown that eggs of this long shape were laid by oviraptorids. Look carefully: the eggs themselves are the observation; the label is an interpretation that can be corrected.

Look closely

- Count the eggs you can see. Are they scattered or arranged?
- Look at the shape of each egg. Is it round like a ball or long like a chicken egg stretched out?
- Look at the rock around the eggs. Does it look like it was laid down gently or roughly?

Talk about it

1. The label on a nest like this one was written before the 1993 embryo was found. What should a museum do when new evidence shows a label is wrong?
2. What could the arrangement of eggs in a nest tell you about how the mother laid them?

Safety first. Raw eggs can carry salmonella: wash hands and surfaces after handling them, and do not taste the eggs.

HANDS-ON: SHELL, PORES AND SIZE: AN EGG INVESTIGATION

Measure real eggs, model the size problem, and compare Job 39 with the dinosaur evidence.

You will need

- A dozen raw chicken eggs (and a quail or duck egg if you can)
- A kitchen scale, ruler and string
- Food coloring and a bowl of water
- Graph paper

Steps

1. Measure the length, width and mass of four eggs. Find the average. Record an ostrich egg (about 15 cm, 1.4 kg) and a 45 cm Macroelongatoolithus egg beside them.
2. Pores: crack an egg, rinse the empty half shell, and float it on water dyed with a few drops of food coloring for 20 minutes. Look at the inside with a hand lens for dots of color where dye came through pores.
3. Size problem: on graph paper, draw circles for eggs of 5, 10, 20 and 40 cm. Note that doubling the width multiplies the volume (the embryo's oxygen need) by eight but the shell area (the surface for breathing) only by four. Write two sentences on why giant eggs are a problem.
4. Read the Primary source (Job 39:13-16). Make two columns: what the text says ostriches do, and what fossil nests show some dinosaurs did. Mark one way they are alike and one way they differ.
5. Wash hands after handling raw eggs.

Check your work

- I measured and averaged real eggs.
- I saw (or tried to see) dye pass through the pores.
- I can explain the volume and surface problem in my own words.
- I compared Job 39 with the fossil evidence and quoted it exactly.

FIELD NOTEBOOK

1. Draw a Maiasaura nesting colony seen from above: mounds about 2 m across, spaced about 7 m apart, with a scale bar.
2. Draw the Citipati brooding fossil from a museum photo and label arms, legs and the ring of eggs.
3. **Narration.** Write one paragraph telling the story of how Oviraptor went from "egg thief" to parent, and what it teaches about changing your mind when the evidence changes. Your parent keeps this page.

Did you know? Some dinosaur eggs from China were laid in pairs, which suggests the mother had two working oviducts like a crocodile, but laid only one egg from each at a time, like a bird. A bird has only one working oviduct. Dinosaur parents seem to have been a mixture of the two.

Primary source. *Job 39:13–16, King James Version (1611)*

Gavest thou the goodly wings unto the peacocks? or wings and feathers unto the ostrich? Which leaveth her eggs in the earth, and warmeth them in dust, And forgetteth that the foot may crush them, or that the wild beast may break them. She is hardened against her young ones, as though they were not hers: her labour is in vain without fear;

Go deeper. American Museum of Natural History online pages on the Central Asiatic Expeditions and the brooding *Citipati*. Museum of the Rockies (Bozeman, Montana) pages on Egg Mountain and *Maiasaura*. Jack Horner and James Gorman, *Digging Dinosaurs* (1988), for Horner’s own account (old-earth framing; read with a parent). Second video topic: “How eggshell is studied under the microscope.”

Goes deeper in. Life Science, high-school biology unit on reproduction and the amniotic egg (coming soon); and Gardening & Animals, raising chickens.

For families. Facts checked against published sources and rounded: Pouech’s 1859 eggshell description; the 1923 Flaming Cliffs eggs; Norell et al., *Science* (1994) on the oviraptorid embryo and Norell et al., *Nature* (1995) on the brooding adult; Tanaka et al. (2015) on porosity and nest type; Wiemann et al. (2018) on eggshell color; Erickson et al., *PNAS* (2017) on incubation time. The 1923 photograph’s photographer is usually given as J. B. Shackelford; confirm the credit on the museum’s image page before printing. Some sources say Marion Brandvold found the first *Maiasaura* bones; others credit her and her son; the stop names her. The KJV spelling “her’s” is original.

PRACTICE

1. **EASY** What does the name *Maiasaura* mean, and why was it chosen?
2. **MEDIUM** What does high eggshell porosity suggest about how an egg was incubated?
3. **MEDIUM** Why was *Oviraptor* first called an egg thief, and what showed otherwise?
4. **MEDIUM** From the Primary source: where does the ostrich leave her eggs, and how are they warmed? Quote the words.
5. **CHALLENGE** An egg doubles in width (keeping the same shape). By what factor do its volume and its surface area change? Why does this matter for a giant egg?
6. **CHALLENGE** *Protoceratops* eggs took about 3 months to hatch and *Hypacrosaurus* eggs about 6. A chicken egg takes 21 days. How many times longer is each? What risk would long incubation bring to a nest?

Make it a game · Guard the Nest. Place a ring of soft balls (eggs) around one player, the parent, who sits in the middle. Other players try to tap an egg without being tagged by the parent, who may not stand up. Switch parents after one minute and count eggs saved.

Scripture. “O Jerusalem, Jerusalem, thou that killest the prophets, and stonest them which are sent unto thee, how often would I have gathered thy children together, even as a hen gathereth her chickens under her wings, and ye would not!” (Matthew 23:37, KJV)

Jesus used a brooding hen to show His love. A Citipati spreading its arms over its eggs gives a picture of the same tender guarding.

Practice: answers

1. “Good mother lizard”; it was found with nests, eggs and young, suggesting parental care.
2. That it was buried in soil or a plant mound, where humid air requires many pores for gas exchange, as in crocodile and megapode eggs.
3. Its skull was found with eggs thought to be Protoceratops; later an oviraptorid embryo was found inside the same kind of egg and an adult was found brooding a clutch.
4. “in the earth, and warmeth them in dust.”
5. Volume $\times 8$ (2^3), surface area $\times 4$ (2^2). The embryo’s oxygen need grows with volume but gas exchange happens through the surface, and the shell must also thicken to bear the weight, slowing gas exchange further.
6. About $90 \div 21 \approx 4.3$ times and $180 \div 21 \approx 8.6$ times longer. Longer exposure to predators, floods, drought and temperature swings.

3.3 FOOTPRINTS AND TRACKWAYS

OBJECTIVES

- Explain what a trackway shows that bones cannot: posture, gait, speed, behavior and the conditions of the ground.
- Estimate hip height and gait from footprint length and stride length.
- Read a museum sign about a trackway and separate what is observed from how it is dated and interpreted.

Warm-up. Wet your feet and walk, then run, across a strip of dry pavement or brown paper. Measure the length of one footprint and the distance from one print to the next print of the same foot. Which changes more when you run: the print or the stride?

Video slot. Video coming. Dinosaur trackways: Dinosaur State Park (Connecticut), Dinosaur Valley State Park (Glen Rose, Texas), Roland T. Bird's sauropod trackway, how ichnologists measure stride. Search approved channels (American Museum of Natural History, Texas Parks and Wildlife, Connecticut Dinosaur State Park, Smithsonian, Institute for Creation Research); preview first.

KEY TERMS

ichnology

The study of trace fossils: footprints, burrows, nests and other marks left by living things.

trackway

A series of footprints made by one animal as it moved.

stride length

The distance from one footprint to the next print of the same foot (two paces).

ichnogenus

A name given to a type of track (such as *Eubrontes* or *Grallator*) when the exact maker is not known.

trackway gauge

How wide apart the left and right prints are; a narrow gauge shows legs held under the body.

undertrack

A blurred copy of a footprint pressed into a deeper layer beneath the surface the animal actually walked on.

CORE IDEAS

“Noah’s raven.” In 1802 a Massachusetts farm boy named Pliny Moody turned up a slab of sandstone in South Hadley with three-toed prints across it. Local people called them the tracks of Noah’s raven. In the 1830s Edward Hitchcock, a Congregational minister, geologist

and later president of Amherst College, began to study thousands of such tracks from the Connecticut River valley. He was sure they were made by giant birds, and his great book *Ichnology of New England* (1858) described them in detail. Later scientists showed most were made by theropod and ornithischian dinosaurs, and they kept Hitchcock's track names, such as *Eubrontes* and *Grallator*. His careful measurements remained valuable even when his interpretation changed.

What tracks show that bones cannot. A skeleton is a dead animal; a trackway is a living one in motion. Tracks show how the feet were placed: dinosaur trackways have a narrow gauge, with prints nearly in a line, proving that dinosaurs held their legs straight under the body like a horse, not sprawled like a lizard. This settled an old argument long before full skeletons were properly mounted. Tracks also show whether an animal walked on two legs or four, whether it dragged its tail (almost never), and how fast it moved. Rare swim tracks show claw tips scratching the bottom. Resting traces, like those Lucas describes in the Primary source, show a dinosaur crouching with its hip bones touching the mud.

Measuring a track. Ichnologists measure footprint length, width, the angle between toes, the pace and the stride. For many bipedal dinosaurs, hip height is roughly four times footprint length, a rule of thumb from comparing skeletons with feet. The ratio of stride length to hip height shows the gait: below about 2.0 the animal was walking, between about 2.0 and 2.9 it was trotting, and above about 2.9 it was running. Example: a theropod print 40 cm long gives a hip height of about 1.6 m. If its stride is 2.4 m, the ratio is 1.5, a walk. Most dinosaur trackways show walking, which makes sense: animals spend most of their lives walking, not sprinting. (Stop C5 turns these numbers into speed.)

Famous sites. In 1966 a bulldozer operator in Rocky Hill, Connecticut, uncovered a bed of *Eubrontes* tracks; about 2,000 were found, and roughly 500 are protected today under a geodesic dome at Dinosaur State Park. Along the Paluxy River near Glen Rose, Texas, the American Museum's Roland T. Bird excavated in 1940 a long section of sauropod trackway with a theropod trackway following the same direction, and sections are now displayed at the American Museum in New York and at the Texas Memorial Museum in Austin. Other famous sites include the Lark Quarry in Queensland, Australia, the cliffs of Cal Orck'o in Bolivia, a nearly vertical wall with more than 5,000 prints, and the coast of the Isle of Skye in Scotland.

The ground matters. A track forms only when the mud is soft enough to take a print but firm enough to hold it, and it is preserved only if it is covered before rain, wind or water erase it. Too wet, and the print collapses; too dry, and no print forms. Tracks are often found with ripple marks, raindrop pits and mud cracks. Because the feet pushed down through layers, one footstep can leave a sharp print on the surface and blurred **undertracks** beneath, which can trick a careless observer into mismeasuring.

Honesty about the Paluxy "man tracks." In the 1930s through the 1980s some claimed that human footprints appeared beside the dinosaur tracks in the Paluxy River. Careful study, including work by creationist researchers, found that the elongated prints were dinosaur tracks with the toe marks filled in by sediment, or were carvings. In 1986 the Institute for

Creation Research and the producers of a creationist film withdrew the claims, and major creationist organizations today advise Christians not to use them. Christians owe the truth to everyone. A weak argument, even for a true conclusion, should be set aside. Trackways raise real questions for every view: how fast were they buried, and how did so many animals walk across so many surfaces?

PICTURE STUDY



Footprints of Brontozoum and Amblonyx, from Edward Hitchcock's Ichnology of New England, Edward Hitchcock (author; plate drawn for his report), 1858 · Printed book plate · From Ichnology of New England: A Report on the Sandstone of the Connecticut Valley, Especially Its Fossil Footmarks (Boston, 1858)
Wikimedia Commons · Public domain

Hitchcock's report was printed for the Commonwealth of Massachusetts with sixty plates drawn from the slabs he collected. This one shows two of the kinds of track he named, *Brontozoum* and *Amblonyx*. The drawings are careful enough that later ichnologists could still use them, even though Hitchcock believed the makers were giant birds. (*Brontozoum* tracks are now usually called *Eubrontes*.)

Look closely

- Count the toes on each print. Are the toes thin like a bird's or thick and padded?
- Compare the two kinds of print. Which is larger, and how are the toes spread differently?
- Look for anything that shows scale.

Talk about it

1. Hitchcock's measurements were right but his interpretation was later changed. Why are good measurements valuable even when a conclusion changes?

2. Why might three-toed tracks look so much like the tracks of big birds?

HANDS-ON: MAKE AND READ A TRACKWAY

Make your own trackway, measure it like an ichnologist, and then read Lucas's 1901 description of resting tracks.

You will need

- A long strip of brown paper (3–4 m) or a smooth patch of damp sand
- A shallow tray of water or washable paint
- Tape measure, pencil and a calculator
- A family member willing to walk and jog barefoot

Steps

1. Have one person walk, then jog, barefoot along the paper with wet or painted feet (or in damp sand). Label each trackway.
2. Measure footprint length (FL), pace and stride (SL) for each. Measure the walker's real hip height (h) and test the rule $h \approx 4 \times \text{FL}$ for a human. (It will not fit perfectly; write why: human feet are proportioned differently.)
3. Compute $\text{SL} \div h$ for the walk and the jog. Does the walk fall below 2.0? Does the jog rise toward 2.9?
4. Have the person crouch on hands and feet in the sand and stand up again. Compare the marks with Lucas's description in the Primary source. Underline his observations in one color and his interpretations in another.
5. Clean up paint and sand right away.

Check your work

- I recorded FL, pace, stride and hip height for two trackways.
- I calculated $\text{SL} \div h$ correctly for both.
- I marked Lucas's observations and interpretations in two colors.
- I can explain what an undertrack is.

FIELD NOTEBOOK

1. Draw a theropod trackway of six prints to scale (1 cm = 20 cm), labeling footprint length, pace, stride and gauge.
2. Draw a cross-section showing a true track on the surface and two undertracks beneath it.
3. **Narration.** Write one paragraph explaining what a trackway can tell us that a skeleton cannot, with at least two examples from this stop. Your parent keeps this page.

Did you know? Dinosaur footprints are found far more often than dinosaur skeletons, because one animal can make millions of prints in its lifetime but leave only one skeleton.

Some tracks show skin texture on the sole of the foot, preserved when the mud was just the right consistency.

Primary source. *Frederic A. Lucas, Animals of the Past (1901), Chapter III, "Impressions of the Past."* Project Gutenberg eBook #38013 (footnote marker omitted).

In the light of our present knowledge we are able to read many things in these tracks that were formerly more or less obscure, and to see in them a complete verification of Dr. Deane's suspicion that they were not made by birds. We see clearly that the long tracks called *Anomæpus*, with their accompanying short fore feet, mark where some Dinosaur squatted down to rest or progressed slowly on all-fours, as does the kangaroo when feeding quietly; and we interpret the curious heart-shaped depression sometimes seen back of the feet, not as the mark of a stubby tail, but as made by the ends of the slender pubes, bones that help form the hip-joints.

Lucas was a curator at the United States National Museum (Smithsonian). "Dr. Deane" is James Deane, a Massachusetts physician who studied the tracks in the 1840s.

 **What the sign says / What we observe / How Christians read it.**  **What the sign says:** "These tracks were made about 200 million years ago, in the Early Jurassic, along the shore of an ancient lake." **What we observe:** three-toed prints pressed into layers of reddish sandstone and mudstone, some with ripple marks, raindrop pits and mud cracks; many trackways on one surface; prints covered and preserved by the next layer. **How Christians read it:** many young-earth geologists read large trackway surfaces as made during the Flood year, when animals walked on briefly exposed sediment that was soon buried again, and they are working on how mud cracks and raindrop marks fit that picture. Christians who hold an old earth accept the mainstream date and see tracks made along lake shores over long ages. The date on the sign rests on assumptions (constant decay rates and starting amounts in nearby volcanic rock); the prints themselves are what everyone can see. "Early Jurassic" is museum vocabulary for where these layers sit in the rock record.

Go deeper. Dinosaur State Park, Rocky Hill, Connecticut (state park website, with visitor information and a track-casting area in season). Dinosaur Valley State Park, Glen Rose, Texas (Texas Parks and Wildlife website). Edward Hitchcock, *Ichnology of New England* (1858), free scans at the Biodiversity Heritage Library. Second video topic: "Roland T. Bird and the sauropod trackway."

Goes deeper in. Earth Science, the rock layers and fossils units (coming soon); and Arithmetic, ratios and measurement.

For families. Facts checked and rounded: Pliny Moody's find (1802); Hitchcock, *Ichnology of New England* (1858); Rocky Hill tracks (1966; about 2,000 found, about 500 displayed); Roland T. Bird's Paluxy excavation (1940). The hip-height rule (about 4 ×

footprint length) and gait thresholds (about 2.0 and 2.9) follow R. McNeill Alexander (1976) and Thulborn (1990) and are approximations. On the Paluxy “man tracks,” see the ICR statement of 1986 and the “arguments we think creationists should not use” lists of Answers in Genesis and Creation Ministries International. This is a stop where a date in millions of years appears, so it includes the ⌚ box.

PRACTICE

1. **EASY** What is the difference between a footprint and a trackway?
2. **MEDIUM** How do trackways show that dinosaurs held their legs under their bodies?
3. **MEDIUM** In the Primary source, what did Lucas say made the heart-shaped mark behind the feet? Is that an observation or an interpretation?
4. **MEDIUM** Why did creationist researchers and organizations stop using the Paluxy “man tracks”?
5. **CHALLENGE** A theropod footprint is 30 cm long and its stride is 3.9 m. Estimate the hip height and the gait.
6. **CHALLENGE** Name two conditions needed for a footprint to form and be preserved, and explain what each says about the time between the step and burial.

Make it a game · Track Detective. One player makes a short trackway in sand or with painted feet on paper while the others look away: walking, running, hopping, turning, stopping or crouching. The others read the trackway and tell the story of what happened. Points for each correct detail.

Scripture. “Thy way is in the sea, and thy path in the great waters, and thy footsteps are not known.” (Psalm 77:19, KJV)

We can measure a dinosaur’s footsteps, but God’s ways are beyond our tracing. The psalmist remembered the Red Sea crossing: God was present even where no footprints could be seen.

Practice: answers

1. A footprint is a single print; a trackway is a series of prints made by one animal as it moved.
2. The prints fall nearly in a straight line (narrow gauge), not spread wide apart as in a sprawling lizard.
3. “the ends of the slender pubes, bones that help form the hip-joints.” It is an interpretation of an observed mark (he even writes “we interpret”).
4. Careful study showed the prints were elongated dinosaur tracks with infilled toes, or carvings; honest Christians set aside a weak argument.
5. $h \approx 4 \times 0.30 = 1.2 \text{ m}$; $SL \div h = 3.9 \div 1.2 = 3.25$, which is above 2.9, so it was running.
6. Mud firm enough to hold a print but soft enough to take it; and burial before wind, rain or water erased it. The second shows the print was covered fairly soon after it was made, before erosion; how soon depends on the setting.

3.4 HERDS

OBJECTIVES

- Name the three main kinds of evidence for dinosaur groups: bonebeds, parallel trackways and nesting colonies.
- Explain why a bonebed does not automatically prove a herd, and what further evidence helps decide.
- Weigh how catastrophic burial is read in mainstream and creationist geology.

Warm-up. Watch a flock of birds, a herd of cattle or a school of fish (in person or in a nature video) for three minutes. Write down where the young ones are, who leads, and what happens when something startles them.

Video slot. Video coming. Dinosaur herds: the Bernissart *Iguanodons*, *Centrosaurus* bonebeds in Alberta, the Davenport Ranch sauropod trackway, *Mussaurus* age groups. Search approved channels (Royal Belgian Institute of Natural Sciences, Royal Tyrrell Museum, American Museum of Natural History, Smithsonian, Answers in Genesis); preview first.

KEY TERMS

bonebed

A layer of rock containing the bones of many individual animals, often of one species.

monodominant

Made up mostly of one species, as in a bonebed where nearly every bone belongs to the same kind of dinosaur.

taphonomy

The study of what happens to an organism from death to discovery: decay, transport, burial and fossilization.

mass death assemblage

A deposit of many animals that died at or near the same time in one event.

age segregation

A pattern in which young and adult animals gather in separate groups.

attritional

Built up gradually from animals dying one at a time over a long period, rather than all at once.

CORE IDEAS

Down a coal mine. In 1878 coal miners at Bernissart in Belgium broke into a clay-filled pocket about 322 m underground and struck bones. Over the next three years, workers removed the skeletons of at least 29 *Iguanodon*, many nearly complete, from the mine. Louis

Dollo spent decades studying them, and the first was mounted in 1882 in the chapel of a former palace in Brussels. They still stand in the Royal Belgian Institute of Natural Sciences. At first many assumed a herd had fallen together into a ravine. Later study of the layers showed the skeletons lay at several levels, so they were probably buried in several events. A single pile of bones is not yet proof of a herd.

Bonebeds. Most evidence for dinosaur groups comes from **bonebeds**. At Ghost Ranch, New Mexico, Edwin Colbert's team in 1947 uncovered hundreds of the slender theropod *Coelophysis* tangled together. In Alberta, the Hilda "mega-bonebed" of the horned dinosaur *Centrosaurus* stretches for kilometers and has been estimated to hold thousands of individuals. A Montana bonebed of *Maiasaura* was estimated by Jack Horner's team to represent around 10,000 animals. When a bed is **monodominant**, holds young and old together, and shows the bones buried at one time, the simplest explanation is that the animals lived together and died together.

Taphonomy: how did they get there? Scientists must ask the **taphonomy** question before calling a bonebed a herd. Were the bones carried in by water and sorted by size, with small bones washed away? Were they gathered over many years at a water hole where animals died one by one (an **attritional** deposit)? Or did the whole group die in one event (a **mass death assemblage**), such as a flood, mudflow or drought? Clues include whether bones are still connected, whether they are broken or weathered, whether they lie in one direction as if aligned by a current, and what kind of rock surrounds them. Many large bonebeds are found in flood deposits; the mainstream explanation is usually a river flood or a mudflow, sometimes after a drought.

Trackways together. Trackways give a second, independent kind of evidence, because footprints record living animals. At Davenport Ranch, Texas, Roland T. Bird recorded parallel trackways of about 23 sauropods heading the same way. John Ostrom argued in 1972 that many parallel trackways at one site showed group travel; others pointed out that a lakeshore can channel unrelated animals in the same direction. At Lark Quarry in Queensland, about 3,300 small prints were long read as a stampede of small dinosaurs fleeing a predator; in 2013 a new study argued many were made by small dinosaurs swimming or wading, and the debate continues. Parallel trackways with even spacing, matching speeds and similar sizes are the strongest case for travel in a group.

Ages and predators. In 2021 a team in Patagonia described more than 100 eggs and about 80 skeletons of the early sauropodomorph *Mussaurus*, with juveniles found together in one group and young adults together in another: **age segregation**, as in some living herds. Predators may have grouped too. In 1910 Barnum Brown found a bonebed in Alberta with several *Albertosaurus*; later work there counted at least 12 and possibly more than 20 individuals of different ages. That is suggestive of a pack, but a common danger or a common food supply can also gather animals who did not hunt together. Most paleontologists today accept that many plant-eating dinosaurs lived in groups for at least part of life; group hunting by large theropods is still argued.

How Christians read it. Herds of animals buried together, often in flood deposits, are just what many young-earth geologists expect from the catastrophe of Noah's Flood, when animals fled rising water and were buried quickly in sediment. Mainstream geologists also invoke floods and mudflows to explain bonebeds, but local ones repeated over long ages. Both readings agree that rapid burial is needed to preserve a bonebed. A Christian can study these sites with confidence that God made animals "after their kind" with the instinct to live together (Genesis 1:24-25), and with honest care to name what is observed and what is interpreted.

PICTURE STUDY



Workmen assembling the first Bernissart Iguanodon, Aimé Rutot (photographer), 1882 · Black-and-white photograph · Royal Belgian Institute of Natural Sciences, Brussels (archives)
Wikimedia Commons · Public domain

When the first Bernissart *Iguanodon* was mounted, no one had ever seen a complete dinosaur skeleton stand up. Aimé Rutot, a geologist at the museum, photographed the work in the Chapel of Saint George in Brussels in 1882. Dollo and his workers stood the animal upright like a kangaroo. Today we know *Iguanodon* often walked on all fours with its back nearly level; the old pose had bent the tail.

Look closely

- Find the supports holding up the skeleton. Why were they needed?
- Compare the size of the skeleton with the people or the room.
- Look at the angle of the tail. Does it look natural?

Talk about it

1. How could seeing many skeletons of the same kind together help scientists reconstruct one skeleton correctly?
2. Why might scientists change a museum mount after a hundred years?

HANDS-ON: HERD OR NOT? A BONEBED INVESTIGATION

Build a model bonebed, then decide like a taphonomist whether it shows a herd.

You will need

- A shallow plastic tub, sand and gravel
- About 40 small objects in two sizes to stand for bones (pasta shapes, toothpicks, small and large paper clips)
- A pitcher of water
- Notebook and pencil

Steps

1. Scenario A (attritional): drop the “bones” into the tub a few at a time over five rounds, scattering a thin layer of sand between rounds.
2. Scenario B (flood): set all the bones on one side of a second tub of sand, then pour water steadily across them from that side. Let it settle.
3. Dig each tub carefully. Record for each: how many layers, whether bones are aligned in one direction, whether small bones were carried farther or lost.
4. Write a short report: which features would tell a scientist that animals died together? Which features suggest a gradual build-up?
5. Add a final paragraph: what further evidence (trackways, age groups, nests) would you want before calling a bonebed a herd?

Check your work

- I built and dug two different model bonebeds.
- I recorded layering, alignment and sorting.
- I named at least two features of a mass death assemblage.
- I listed independent evidence needed to confirm a herd.

FIELD NOTEBOOK

1. Draw a map of a model bonebed seen from above, with bones drawn as lines showing their direction and an arrow for the current.
2. Make a table of the evidence for herds from this stop: site, kind of evidence, strength of the case.
3. **Narration.** Write one paragraph explaining why a pile of bones is not automatically a herd, and what scientists look for to decide. Your parent keeps this page.

Did you know? The Bernissart skeletons were coated in mineral (pyrite) that began to decay in damp air, a problem called “pyrite disease.” Museum workers have fought it for more than a century with varnishes, and since the 2000s with careful humidity control.

Go deeper. Royal Belgian Institute of Natural Sciences (Brussels), online pages on the Bernissart Iguanodons. Royal Tyrrell Museum pages on *Centrosaurus* bonebeds and Dinosaur Provincial Park. Ghost Ranch (New Mexico) and its Ruth Hall Museum of Paleontology pages on *Coelophysis*. Second video topic: “How a bonebed is excavated and mapped.”

Goes deeper in. Earth Science, the fossils and Flood geology units (coming soon); and Gardening & Animals, herd animals and their behavior.

For families. Facts checked and rounded: Bernissart discovery (1878, at about 322 m depth; at least 29 individuals, some counts higher); Ghost Ranch *Coelophysis* (Colbert, 1947); the Hilda bonebed (Eberth and others, 2010); the *Maiasaura* bonebed estimate (Horner and colleagues); Davenport Ranch (Bird, 1944; Ostrom, 1972); Lark Quarry (Thulborn and Wade, 1984; Romilio and others, 2013); *Mussaurus* (Pol and others, *Scientific Reports*, 2021); the *Albertosaurus* Dry Island bonebed (Brown, 1910; Currie and others). Estimates of individuals in bonebeds vary widely. No dates in millions of years are used here.

PRACTICE

1. **EASY** Name three kinds of evidence that some dinosaurs lived in groups.
2. **MEDIUM** Why did later scientists doubt that the Bernissart Iguanodons all died together as one herd?
3. **MEDIUM** What is the difference between an attritional deposit and a mass death assemblage?
4. **MEDIUM** What did the 2021 *Mussaurus* find show about age groups?
5. **CHALLENGE** You find 23 parallel sauropod trackways heading north along an ancient shoreline. Give one reason this suggests a herd and one alternative explanation. What extra measurement would help decide?
6. **CHALLENGE** Mainstream and young-earth geologists both say rapid burial is needed to preserve a bonebed. Explain why, and state where the two views differ.

Make it a game · Herd Instinct. Players are a herd and walk around the yard together. A leader secretly chooses one “predator” signal (a clap). When it sounds, the herd must form a tight group with the youngest or smallest players in the middle within five seconds. Then discuss: why might a real herd place its young in the center?

Scripture. “Two are better than one; because they have a good reward for their labour. For if they fall, the one will lift up his fellow: but woe to him that is alone when he falleth.” (Ecclesiastes 4:9-10, KJV)

God made many creatures to live together for protection and help. The Preacher applies the same truth to people: we were made for fellowship, not for life alone.

Practice: answers

1. Bonebeds (many of one species buried together), parallel trackways, and nesting colonies (also age-grouped skeletons).
2. The skeletons lay at several levels in the deposit, suggesting several burial events.
3. An attritional deposit builds up from animals dying one at a time over a long period; a mass death assemblage forms when many die at once in one event.
4. Juveniles were found together in one group and young adults in another, suggesting age segregation within a herd.
5. Herd: many animals moving the same way together. Alternative: the shoreline channeled separate animals along the same route at different times. Helpful: whether the trackways overlap or cross (order of making), even spacing, matching speed (stride ratios), and whether they are on one surface made at one time.
6. Exposed carcasses are scavenged, scattered, weathered and decayed within months or a few years, so complete or associated skeletons require quick burial. They differ on the scale and timing: mainstream geology invokes many local floods or mudflows over long ages; young-earth geology reads many bonebeds as burial during the one global Flood.

3.5 HOW FAST COULD THEY RUN?

OBJECTIVES

- Use Alexander's formula to estimate a dinosaur's speed from a trackway.
- Explain three other methods scientists use to estimate speed (leg proportions, muscle mass, computer models) and why their answers differ.
- Evaluate the claim that T. rex could outrun a car, using evidence and the limits of the methods.

Warm-up. Time yourself walking 20 m, then jogging 20 m, then sprinting 20 m. Divide 20 by each time to get your speed in meters per second, and multiply by 3.6 for kilometers per hour. Keep your numbers: you will compare them with dinosaurs.

Video slot. Video coming. How scientists estimate dinosaur running speed: trackway formulas, T. rex biomechanics and computer models, ostrich running. Search approved channels (Royal Veterinary College, Natural History Museum London, American Museum of Natural History, Smithsonian, Answers in Genesis); preview first.

KEY TERMS

biomechanics

The study of how living bodies move, using the laws of physics and engineering.

relative stride length

Stride length divided by hip height ($SL \div h$); it shows whether an animal walked, trotted or ran.

Froude number

A ratio of speed to leg length ($v^2 \div g \cdot h$) that lets scientists compare the gaits of animals of very different sizes.

cursorial

Built for running: long lower legs, long feet and a light build, as in ostriches and horses.

extensor muscles

The leg muscles that straighten the joints and push the body forward and up in each step.

scaling

How an animal's properties change with size; weight grows faster than the strength of bones and muscles.

CORE IDEAS

A formula from a zoologist. In 1976 the British zoologist R. McNeill Alexander noticed that living animals of very different sizes, from people to elephants, move in a similar way when their speeds are scaled to leg length. From that he built a formula to estimate speed from a trackway: $v \approx 0.25 \times g^{0.5} \times SL^{1.67} \times h^{-1.17}$, where v is speed in meters per second, g

is gravity (9.8 m/s^2), SL is stride length and h is hip height, both in meters. Hip height comes from footprint length (about four times it, as Stop C3 showed). Example: a theropod with 40 cm prints ($h \approx 1.6 \text{ m}$) and a stride of 3.2 m works out to about 3.1 m/s, roughly 11 km/h: a brisk walk.

What the tracks say. Most dinosaur trackways give walking speeds of about 3 to 8 km/h, the speed of a person walking. That is expected: animals spend most of their time walking, and sprints are rare and short, so running tracks are rare. A few are faster. In 1981 James Farlow described theropod trackways in Texas that gave about 40 km/h. In 2021 a team studying trackways in La Rioja, Spain, estimated that a medium-sized theropod reached about 45 km/h, among the fastest known from footprints. Tracks have one great strength: they record what an animal actually did, not only what it could do.

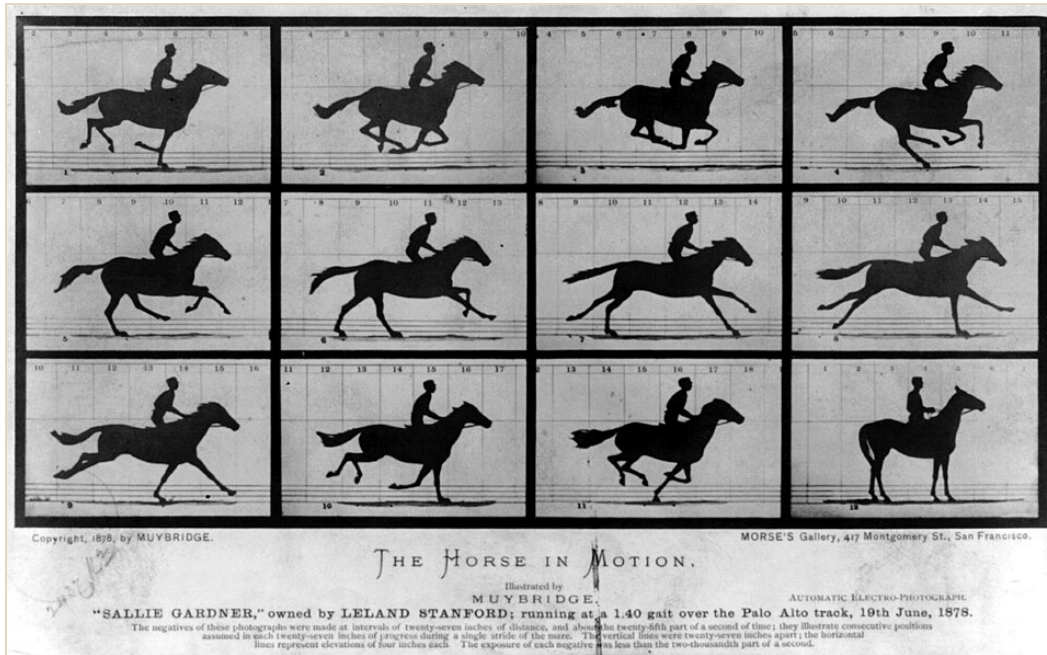
Built to run? Bones give a second method. Fast animals today are **cursorial**: long shins and feet compared with the thigh, and a light build. By this measure the ornithomimids, the “ostrich mimic” dinosaurs, look built for speed, with long, slender lower legs very like an ostrich’s. Many estimates put them at 50 to 60 km/h, but these come from proportions, not tracks, and should be held loosely. An ostrich, the fastest two-legged runner alive, reaches about 70 km/h in short bursts and can cruise near 50 km/h for long distances.

The T. rex problem. Films have shown *Tyrannosaurus* chasing cars at highway speed. Biomechanics says otherwise, for reasons of **scaling**: when an animal doubles in length, its weight rises about eight times, but the cross-section of its bones and muscles (their strength) rises only about four times. In 2002 John Hutchinson and Mariano Garcia calculated that to run at 20 m/s (72 km/h), a 6-tonne *T. rex* would need leg **extensor muscles** amounting to most of its body weight, which is impossible. Later computer models gave top speeds of about 18 to 40 km/h; a 2017 study by William Sellers and colleagues argued its bones would have limited it to a fast walk of about 20 km/h. Young tyrannosaurs, lighter and longer-legged for their size, were probably faster than adults.

Why the answers differ. Every method rests on assumptions. Alexander’s formula assumes dinosaurs moved like living animals and that hip height can be estimated from footprints. Muscle models must guess how much muscle an animal had, since muscle does not fossilize. Computer models depend on body mass, which itself is estimated within perhaps 20 to 30 percent. That is why careful scientists give ranges, not single numbers, and why a range like “18 to 40 km/h” is more honest than “*T. rex* ran 32 km/h.” When different methods agree, as they do that adult *T. rex* was not a highway sprinter, confidence rises.

The ostrich and the horse. When God answered Job out of the whirlwind, He pointed to the ostrich: “What time she lifteth up herself on high, she scorneth the horse and his rider.” A galloping horse reaches about 70 km/h only for short distances, while an ostrich can run fast for much longer. The verse is accurate observation, and it also humbles. Job could not explain why God made the ostrich swift and strange. We can measure speed and build formulas, but the design of a running animal, with tendons that store energy like springs and bones that balance strength and lightness, points to the wisdom of the One who made it.

PICTURE STUDY



The Horse in Motion, Eadweard Muybridge, 1878 · Sequence of photographs, printed as a cabinet card ·
Library of Congress, Prints and Photographs Division (and other collections)
Wikimedia Commons · Public domain

In 1878 at Palo Alto, California, Eadweard Muybridge set a row of cameras along a track, triggered by threads as a horse named Sallie Gardner galloped past. For the first time people could see that a galloping horse has a moment with all four hooves off the ground. It was one of the first scientific studies of how animals move.

Look closely

- Find the frame or frames where all four hooves are off the ground. Where are the legs: stretched out or tucked under?
- Follow one hoof through the frames. How far does it travel compared with the horse's body?
- Look at the lines in the background. What might they have been used for?

Talk about it

1. How does stopping motion help a scientist measure stride and speed?
2. Why could no painter before 1878 be sure how a horse's legs moved at a gallop?

HANDS-ON: SPEED FROM STRIDE: TEST THE FORMULA ON YOURSELF

Test Alexander's formula on a human, then use it on dinosaur trackways and compare the results with Job 39:18.

You will need

- A tape measure and stopwatch (or phone)
- A long strip of paper or a sandy path
- A calculator that can do powers (a phone calculator in landscape mode works)
- Your warm-up speeds

Steps

1. Measure your hip height (h): floor to the top of the thigh bone at the hip.
2. Walk, jog and run over damp sand or with wet feet on paper. Measure the stride (SL) for each and time yourself over 20 m.
3. For each gait, compute $v = 0.25 \times \sqrt{9.8 \times SL^{1.67} \times h^{-1.17}}$. Compare it with your timed speed. Write the percentage error.
4. Use the formula on two dinosaur trackways: (a) footprint 40 cm, stride 3.2 m; (b) footprint 30 cm, stride 5.0 m. Estimate hip height as $4 \times$ footprint length. Convert to km/h.
5. Read the Primary source (Job 39:18). Using this stop's numbers, write two sentences comparing an ostrich with a horse and with an ornithomimid.
6. Run only on a flat, safe surface and warm up first.

Check your work

- I measured my own hip height and strides.
- I compared the formula's answer with my real speed and found the error.
- I estimated speeds for two dinosaur trackways correctly.
- I quoted Job 39:18 exactly and used it in a comparison.

FIELD NOTEBOOK

1. Make a bar chart of top speeds in km/h: you (from the warm-up), a walking theropod trackway (about 6), the fastest Spanish trackway (about 45), adult T. rex (range 18–40, drawn as a range), an ostrich (about 70) and a galloping horse (about 70).
2. Draw an ostrich leg and an ornithomimid leg side by side and label femur, tibia and foot bones.
3. **Narration.** Write one paragraph answering "Could a T. rex catch a car?" using scaling and at least two kinds of evidence. Your parent keeps this page.

Did you know? An elephant, the heaviest land animal alive, never gets all four feet off the ground at once. At its fastest, about 25 km/h, it does a fast "amble" with at least one foot always touching. Many scientists think the largest dinosaurs, including sauropods and adult tyrannosaurs, moved in the same way.

Primary source. *Job 39:18, King James Version (1611)*

What time she lifteth up herself on high, she scorneth the horse and his rider.

The "she" is the ostrich, named in Job 39:13.

Go deeper. R. McNeill Alexander, “Estimates of speeds of dinosaurs,” *Nature* 261 (1976), the original short paper (abstract online). John Hutchinson’s research blog “What’s in John’s Freezer?” (Royal Veterinary College) for clear explanations of dinosaur biomechanics (old-earth framing). Library of Congress online collection of Muybridge’s motion studies. Second video topic: “How ostriches run.”

Goes deeper in. Arithmetic and algebra, powers and formulas (coming soon); and Life Science, high-school biology unit on muscles and skeletons.

For families. Facts checked and rounded: Alexander (1976); Farlow (1981) on fast Texas trackways; Navarro-Lorbés and others (2021) on the La Rioja trackways (about 45 km/h); Hutchinson and Garcia, *Nature* (2002); Sellers and Manning (2007); Sellers and others, *PeerJ* (2017). Ornithomimid speeds come from proportions and vary widely between studies. The formula’s exponents follow Alexander’s published version; results are estimates, typically within a factor of about 1.5 of real speeds in living animals. No dates in millions of years are used here.

PRACTICE

1. **EASY** Why are trackways showing running so rare compared with walking trackways?
2. **MEDIUM** Name three methods for estimating dinosaur speed.
3. **MEDIUM** If an animal doubles in length but keeps the same shape, how do its weight and the strength of its legs change? Why does this limit big runners?
4. **MEDIUM** In the Primary source, what does the ostrich “scorn,” and is that accurate?
5. **CHALLENGE** A theropod trackway has footprints 30 cm long and a stride of 5.0 m. Estimate its speed with Alexander’s formula ($h = 4 \times \text{footprint length}$). Give the answer in m/s and km/h.
6. **CHALLENGE** A website says “T. rex ran 72 km/h.” Write a three-sentence reply that a careful scientist would accept.

Make it a game • Stride Match. Lay a tape measure on the ground. The leader calls a gait (“walk,” “trot,” “run”) and a dinosaur (“small theropod,” “sauropod”). Each player takes three steps trying to match the relative stride for that gait using their own hip height ($SL \div h$ below 2, about 2.5, or above 3). Measure; the closest wins the round.

Scripture. “I returned, and saw under the sun, that the race is not to the swift, nor the battle to the strong, neither yet bread to the wise, nor yet riches to men of understanding, nor yet favour to men of skill; but time and chance happeneth to them all.” (Ecclesiastes 9:11, KJV)

Speed is a gift, but it does not decide every outcome. The fastest dinosaur still depended on God’s providence, and so do we.

1. Animals spend most of their time walking; sprints are short and rare, so most prints record walking.
2. Trackway formulas (stride and hip height), leg proportions compared with living runners, muscle-mass calculations, and computer models of the skeleton (any three).
3. Weight rises about 8 times; bone and muscle strength (cross-section) rises about 4 times. Each unit of muscle and bone must carry twice the load, so big animals cannot run as fast for their size.
4. "the horse and his rider." Yes: ostriches reach about 70 km/h and can sustain high speed longer than a horse.
5. $h = 1.2 \text{ m}$. $5.0^{1.67} \approx 14.7$; $1.2^{-1.17} \approx 0.81$; $0.25 \times 3.13 \approx 0.78$. $v \approx 0.78 \times 14.7 \times 0.81 \approx 9.3 \text{ m/s} \approx 34 \text{ km/h}$ ($SL \div h \approx 4.2$, a run).
6. Sample: Biomechanical studies (Hutchinson and Garcia, 2002) found that running at 72 km/h would require leg muscles making up most of the animal's body weight, which is impossible. Computer models give adult T. rex top speeds of roughly 18-40 km/h, and one study argues it could only walk fast. Because muscle mass and body weight are estimated, the honest answer is a range, but every method agrees adults were far slower than 72 km/h.

3.6 WERE THEY WARM-BLOODED?

OBJECTIVES

- Define endotherm, ectotherm and mesotherm and explain why “warm-blooded” is not one simple thing.
- Describe at least four lines of evidence used in the debate: posture, bone tissue, growth rates, air sacs, polar fossils and chemical thermometers.
- Explain why scientists still disagree and why the answer may differ between kinds of dinosaurs.

Warm-up. On a cool morning, feel a lizard, a snake or a turtle (at a pet store or a friend’s, if allowed) and then a dog or cat. Or compare a thermometer reading of your own mouth with the air. Write: what keeps your body at the same temperature on a cold day?

Video slot. Video coming. Were dinosaurs warm-blooded? Bone histology, growth rings, air sacs in dinosaurs and birds, polar dinosaurs in Alaska. Search approved channels (American Museum of Natural History, Natural History Museum London, Museum of the North (University of Alaska), Smithsonian, Answers in Genesis); preview first.

KEY TERMS

endotherm

An animal that makes most of its body heat from its own metabolism and keeps a steady temperature, such as birds and mammals.

ectotherm

An animal whose body temperature depends mainly on its surroundings, such as lizards, snakes and crocodiles.

metabolic rate

How fast an animal burns food for energy; endotherms have high rates and need much more food.

fibrolamellar bone

A fast-growing, spongy-looking bone tissue packed with blood vessels, common in birds and mammals and in many dinosaurs.

mesotherm

An animal in between: it makes some of its own heat but does not hold a steady temperature as closely as a bird or mammal.

inertial homeothermy

Keeping a fairly steady body temperature simply by being very large, because a big body loses heat slowly.

CORE IDEAS

Owen's surprising suggestion. When Richard Owen named the Dinosauria in 1842, he noticed that their legs stood straight under the body and their hips were braced with five fused vertebrae, more like an elephant than a lizard. He suggested that dinosaurs may have had a more efficient heart and body, approaching that of warm-blooded animals. Yet for nearly a century afterward, most books and museum murals showed dinosaurs as sluggish, cold-blooded reptiles dragging their tails. Then in the 1960s John Ostrom described the agile theropod *Deinonychus* (1969), and his student Robert Bakker argued boldly that dinosaurs were as warm-blooded as birds. The debate, sometimes called the "Dinosaur Renaissance," has run ever since.

What the words mean. "Warm-blooded" mixes up several ideas. An **endotherm** makes its own heat by a high **metabolic rate**; an **ectotherm** borrows heat from the sun and surroundings. Body temperature can be steady or variable. A desert lizard basking at noon can be warmer than a mammal. A hummingbird lets its temperature drop at night. Endothermy is costly: a mammal needs roughly ten times the food of a reptile of the same weight. So the real questions are: how much heat did dinosaurs make, how steady were their temperatures, and how much did they eat?

Evidence from bone. Thin slices of fossil bone under a microscope show its tissue. Many dinosaurs have **fibrolamellar bone**, laid down fast and full of channels for blood vessels, as in birds and mammals. Growth lines (Stop C8 counts them) show that many dinosaurs grew far faster than any living reptile: a *Maiasaura* reached adult size in about eight years, and a young *T. rex* may have added around 2 kg a day. Fast growth needs a high metabolic rate. Upright posture, which Owen noticed, is found today only in endotherms. Theropods and sauropods also had hollow bones connected to air sacs, the flow-through breathing system of birds, which supplies oxygen efficiently.

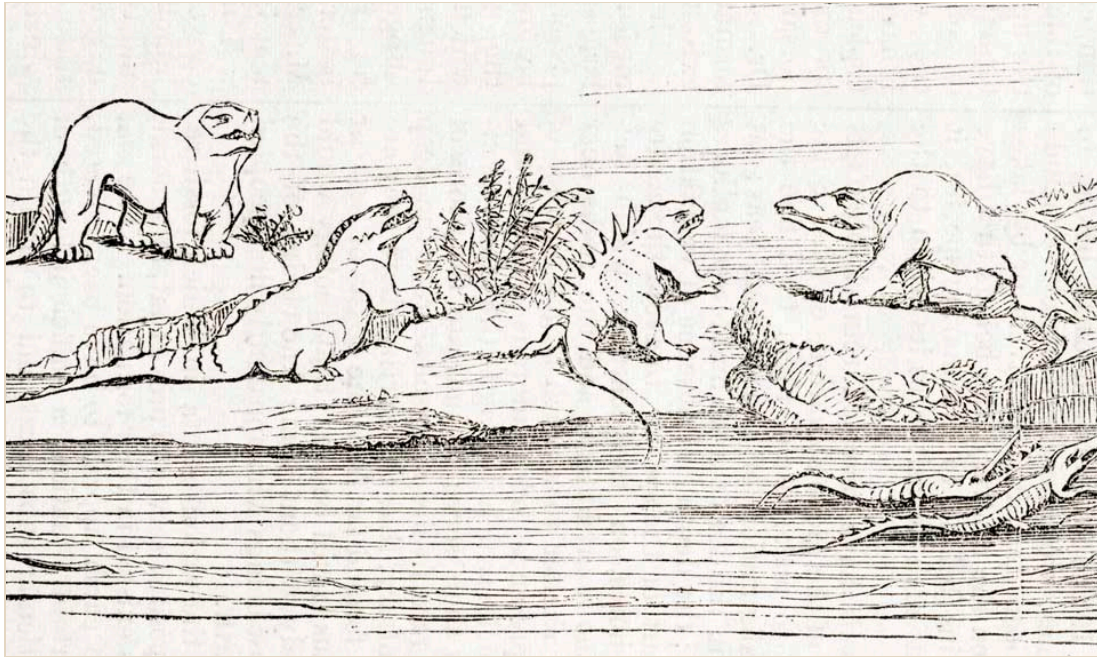
Evidence from the cold and from chemistry. Dinosaur fossils have been found in places that are polar today, such as northern Alaska, including tiny bones of hatchlings described in 2024. Animals that nested where winters are long and dark were probably able to keep themselves warm. Chemists have tried to take dinosaurs' temperatures directly. Methods using rare isotopes of carbon and oxygen in tooth enamel and eggshell (2011 onward) gave estimates of about 36 to 38 °C for some sauropods, close to ours. A 2022 study by Jasmina Wiemann and colleagues measured chemical by-products of metabolism in fossil bone and concluded that most dinosaurs had high metabolic rates, though some ornithischians seemed lower.

Honest complexity. Not all evidence points one way. Most mammals and birds have scroll-like nasal bones called respiratory turbinates that save heat and moisture, and dinosaurs appear to lack them, though the evidence is debated. A 2014 study by John Grady and colleagues placed dinosaur growth rates between reptiles and mammals and proposed that many were **mesotherms**, like tuna, some sharks and the leatherback turtle. Giant sauropods may have kept steady temperatures simply by size (**inertial homeothermy**), and might even have risked overheating; their air sacs may have helped shed heat. So the answer may be:

different dinosaurs, different solutions. A small feathered theropod and a 50-tonne sauropod faced very different problems.

Why it matters. Metabolism affects everything else: how much food a dinosaur needed, how many could live in one area, how fast they grew, whether they could live in cold places and how active they were. Christians hold that God made each creature with a body suited to its life, and the more we learn about dinosaur bodies, the more intricate they appear. Holding a conclusion lightly while the evidence is still being gathered is not weakness but honesty.

PICTURE STUDY



*Iguanodon and Megalosaurus sculptures, Crystal Palace Park (from Benjamin Waterhouse Hawkins' lithograph and the sculptures themselves), Benjamin Waterhouse Hawkins, under the scientific direction of Richard Owen, 1854 · Concrete and brick sculptures over iron frames (and a lithograph of the same scene) · Crystal Palace Park, Sydenham, London
Wikimedia Commons · Public domain*

Hawkins built these life-size models with Owen's advice for the reopening of the Crystal Palace in 1854. They are wrong in many details (Iguanodon's thumb spike is on its nose), but notice the legs: Owen insisted they stand straight under the body like a mammal's, not sprawled like a lizard's. That idea led Owen to suspect dinosaurs had a more mammal-like physiology.

Look closely

- Look at the legs. Are they under the body or out to the sides?
- Compare the bodies with an elephant or a rhinoceros. What is similar?
- Find one detail we now know is wrong.

Talk about it

1. Why might an upright posture suggest a more active, warmer animal?
2. Hawkins and Owen were partly right and partly wrong. What does that teach about building models from limited evidence?

Safety first. Use warm tap water only, never boiling water, and have a parent help pour.

HANDS-ON: SIZE AND HEAT: THE COOLING EXPERIMENT

Test inertial homeothermy with jars of warm water, then build an evidence table for the warm-blooded debate.

You will need

- Three containers of different sizes (a small cup, a jar, a large pot)
- Warm tap water (not boiling) and a kitchen thermometer
- A clock and graph paper

Steps

1. Fill each container with warm tap water at the same starting temperature (about 45 °C). Record the temperature of each every 5 minutes for 40 minutes.
2. Graph temperature against time for all three on one chart. Which cools fastest? Why? (Hint: surface area compared with volume.)
3. Write a paragraph applying your result to a small theropod and a giant sauropod. Which needed insulation (feathers) more? Which might have had trouble getting rid of heat?
4. Make an evidence table with three columns: Evidence, Points toward endothermy, Points toward lower metabolism. Fill at least six rows from this stop.
5. Use hot tap water only, with a parent nearby.

Check your work

- I graphed cooling curves for three sizes.
- I explained the result using surface area and volume.
- My evidence table has at least six rows and includes evidence on both sides.
- I can define endotherm, ectotherm and mesotherm.

FIELD NOTEBOOK

1. Draw a magnified slice of fibrolamellar bone and a slice of slow-growing lizard bone side by side; label blood-vessel channels and growth lines.
2. Draw a simple diagram of a bird's air-sac breathing system and mark which dinosaurs show evidence of it (hollow vertebrae).
3. **Narration.** Write one paragraph explaining why scientists still disagree about whether dinosaurs were warm-blooded, naming evidence on both sides. Your parent keeps this page.

Did you know? A leatherback sea turtle, a reptile, can keep its body many degrees warmer than the cold ocean water around it, partly because it is so large and partly because of fat and blood-vessel arrangements that trap heat. It is a living example that “reptile” and “cold-blooded” do not always go together.

Go deeper. Natural History Museum (London), online pages on Richard Owen and the Crystal Palace dinosaurs. Friends of Crystal Palace Dinosaurs website (cpdinosaurs.org). University of Alaska Museum of the North pages on Alaska’s polar dinosaurs. Second video topic: “How bone histology slides are made.”

Goes deeper in. Life Science, high-school biology units on metabolism and respiration (coming soon); and Earth Science, the fossils unit.

For families. Facts checked and rounded: Owen’s 1842 report (he described dinosaurs as approaching mammals in structure and suggested a more efficient circulation; the stop paraphrases rather than quoting); Ostrom’s *Deinonychus* (1969); Bakker’s papers of 1968 and 1972; clumped-isotope sauropod temperatures (Eagle and others, *Science*, 2011); Grady and others, *Science* (2014); Wiemann and others, *Nature* (2022); Alaskan perinatal dinosaurs (Druckenmiller and others, 2024). The “about ten times the food” comparison is a common rough figure. This topic is still debated, and the stop says so. No dates in millions of years are used here.

PRACTICE

1. **EASY** What is the difference between an endotherm and an ectotherm?
2. **MEDIUM** What did Richard Owen notice about dinosaur legs, and what did he suggest from it?
3. **MEDIUM** Name two lines of evidence that point to high metabolic rates in many dinosaurs.
4. **MEDIUM** What is a mesotherm, and name a living example.
5. **CHALLENGE** A cube 1 m on a side and a cube 4 m on a side are both warm. Compare their surface-to-volume ratios and explain which loses heat faster for its size.
6. **CHALLENGE** If a mammal needs about ten times the food of a reptile of the same weight, what would that mean for the number of large endothermic dinosaurs one region could support? What fossil evidence might test it?

Make it a game · Warm or Cold?. The leader names an animal (alive or extinct) and a situation (“an Alaskan winter night,” “a desert noon”). Players stand if they think the animal would be warmer than the air, crouch if colder, and must give one reason. Debate the dinosaur ones.

Scripture. “O LORD, how manifold are thy works! in wisdom hast thou made them all: the earth is full of thy riches.” (Psalm 104:24, KJV)

“Manifold” means many and varied. Dinosaurs may have kept warm in different ways, a small sign of the variety of God’s wise works.

Practice: answers

1. An endotherm makes most of its own body heat by metabolism; an ectotherm depends mainly on heat from its surroundings.
2. They stood straight under the body like a mammal’s; he suggested dinosaurs had a more efficient, more mammal-like heart and physiology.
3. Any two: fast-growing fibrolamellar bone, rapid growth rates from growth lines, upright posture, bird-like air sacs, polar nesting, isotope body temperatures near 36–38 °C, metabolic by-products in bone (2022).
4. An animal between endotherm and ectotherm that makes some heat but does not hold a steady temperature; examples: tuna, some sharks, the leatherback turtle.
5. 1 m cube: area 6 m², volume 1 m³, ratio 6. 4 m cube: area 96 m², volume 64 m³, ratio 1.5. The small cube has four times as much surface per unit volume, so it loses heat about four times faster for its size; the big one keeps heat much longer.
6. The same amount of plant food would support roughly a tenth as many endothermic animals, so predators and plant-eaters would be rarer. Tests: predator-to-prey ratios in fossil collections (Bakker used these), the abundance of plant-eaters in bonebeds, and plant productivity estimates; all are complicated by preservation bias.

3.7 FEATHERS: WHAT THE FOSSILS SHOW

OBJECTIVES

- Describe the main fossil evidence for feathers and filaments: Archaeopteryx, the Chinese feathered fossils, quill knobs, amber and skin impressions.
- Distinguish true pennaceous feathers from simple filaments and explain why the filaments are debated.
- Read a museum sign on feathered dinosaurs and state the observation, the mainstream interpretation and how Christians read it.

Warm-up. Find a bird feather (a craft feather or one from a yard, then wash hands). Look at it with a hand lens. Find the central shaft, the vanes and the tiny barbs. Gently pull two barbs apart and stroke them back together. Write what you think holds them.

Video slot. Video coming. Feathered dinosaurs: Archaeopteryx specimens, Sinosauropteryx and Microraptor from China, dinosaur feather in amber, how fossil feather color is studied. Search approved channels (Natural History Museum London, American Museum of Natural History, Field Museum, Smithsonian, Answers in Genesis); preview first.

KEY TERMS

pennaceous feather

A true vaned feather with a central shaft and barbs locked together by tiny hooked barbules, like a flight feather.

filament

A simple hair-like structure in the skin; in some dinosaur fossils, called “protofeathers” or “dino-fuzz” by many scientists.

quill knob

A small bump on a bird’s forearm bone (ulna) where a flight feather’s base attaches by ligament.

melanosome

A tiny packet of pigment (melanin) in feathers and skin; its shape can hint at color.

Lagerstätte

A rock deposit with exceptional preservation, including soft parts like feathers and skin (German, “storage place”).

mosaic

A creature that combines features usually found in different groups, such as feathers with teeth.

CORE IDEAS

One feather, then a bird with teeth. The fine-grained limestone of Solnhofen in Bavaria was quarried for printing stones. In 1861 a single fossil feather from those quarries was announced by Hermann von Meyer, who named it *Archaeopteryx*, “ancient wing.” Months later a skeleton turned up: feathered wings and tail, but also teeth, three clawed fingers on each wing and a long bony tail. The British Museum bought it in 1862, and Richard Owen described it. A more complete specimen, the Berlin specimen, was found in 1877 (a date Lucas gives in the Primary source). About a dozen skeletal specimens are known today. *Archaeopteryx* is a **mosaic**: unmistakable flight feathers on a body with many reptile-like features.

Huxley’s comparison. In 1868 Thomas Henry Huxley compared *Archaeopteryx* and birds with the small Solnhofen dinosaur *Compsognathus* and argued that birds and dinosaurs share many skeletal features: hollow bones, a wishbone-like arrangement, three main toes, and hips and ankles of similar build. The idea faded and returned in the 1970s with John Ostrom’s study of *Deinonychus*. Most paleontologists now classify birds within the theropod dinosaurs. Christians differ on how to read those resemblances, as the box below explains.

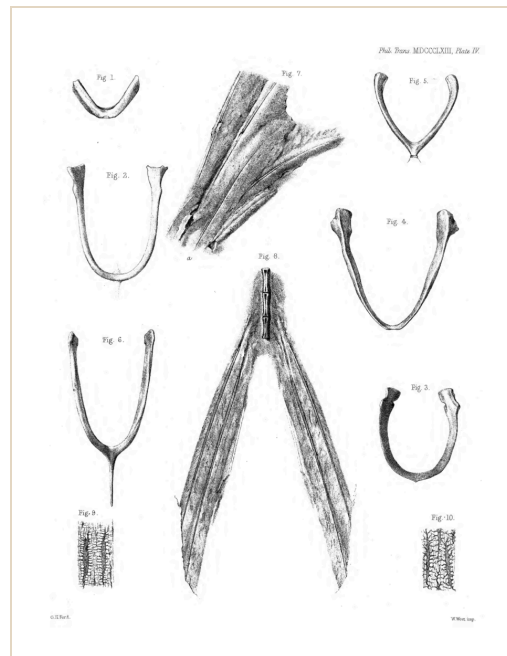
The Chinese fossils. In 1996 farmers and scientists in Liaoning, China, revealed *Sinosauropteryx*, a small theropod with a fringe of dark **filaments** along its back and tail. Since then the fine volcanic-ash lake deposits there, a **Lagerstätte**, have produced thousands of fossils. *Caudipteryx* and *Protarchaeopteryx* (1998) had true **pennaceous feathers** on arms and tails. *Microraptor* (2003) had flight feathers on all four limbs. *Yutyrannus* (2012), a tyrannosauroid about 9 m long, preserved filaments up to about 20 cm long. Outside China, quill knobs were reported on the forearm of a *Velociraptor* in 2007, and in 2016 a feathered tail section of a small dinosaur was found in amber from Myanmar.

Even the colors. In 2010 two teams studied fossil feathers under scanning electron microscopes and found tiny shapes they identified as **melanosomes**. Comparing their shapes with those in living birds, they proposed that *Sinosauropteryx* had a ginger-and-white banded tail and *Anchiornis* a black-and-white body with a reddish crest. In 2012 *Microraptor* was reconstructed as glossy, iridescent black like a crow. These results are exciting but rest on an assumption: that the microscopic shapes really are pigment packets and not bacteria, which can look similar. Most specialists accept them; a few remain cautious.

Honest complexity. Three points keep the picture honest. First, many large dinosaurs show scaly skin: patches from a *T. rex* skeleton described in 2017 show small scales, and hadrosaur and sauropod skin impressions are scaly. Feathers are not found on every dinosaur. Second, the simple filaments of *Sinosauropteryx* and others are debated: a minority of researchers (for example Alan Feduccia and Theagarajan Lingham-Soliar) have argued that some are degraded collagen fibers from the skin, not feathers. Third, every fossil with true flight feathers raises the question of where the line between “bird” and “dinosaur” falls; several such animals are classified differently by different experts.

How Christians read it. Many young-earth creationists hold that animals with true vaned feathers, like *Archaeopteryx*, *Microraptor* and *Caudipteryx*, are birds made on day five (Genesis 1:21), some of them with teeth and claws as the hoatzin chick has claws today, while the filaments on dinosaurs are either disputed collagen or simple skin structures God gave to land animals of day six. Others in the creationist community accept that some dinosaurs bore feather-like coverings as a designed feature, without common descent. The mainstream reading is that birds descended from feathered theropods. Notice where all sides agree: the fossils show feathers on some animals, scales on others and mosaics that resist easy sorting. Describe the fossil first; then state the interpretation and its assumptions.

PICTURE STUDY



The London specimen of Archaeopteryx, plate from Richard Owen's paper "On the Archeopteryx of von Meyer", Lithograph plate prepared for Richard Owen (lithographer not confirmed), 1863 · Lithograph · Philosophical Transactions of the Royal Society of London, vol. 153 (1863); the fossil is in the Natural

*History Museum, London
Wikimedia Commons · Public domain*

When the London specimen reached the British Museum, Richard Owen wrote a long description with detailed plates. The artist drew every feather impression and bone on the slab, so the plate is a record of what Owen and his contemporaries could actually see. (The head of this specimen was mostly missing; Owen did not recognize the teeth, which were noticed later on its slab and in other specimens.)

Look closely

- Follow the long tail. How are the feathers arranged along it?
- Find the wing feathers. Are they spread like a fan or folded?
- Look for the fingers and claws on the wings.

Talk about it

1. Why might scientists in 1863 have argued over whether this was a bird or a reptile?
2. Why are careful drawings like this still useful even after photography?

HANDS-ON: FEATHER, FILAMENT OR SCALE? AN EVIDENCE SORTING LAB

Study a real feather, model the three kinds of body covering, and test Lucas's 1901 description against a modern photograph.

You will need

- A real feather (craft or found, washed hands afterward) and a hand lens
- Yarn, tissue paper, sequins or scale-shaped paper bits
- Printed photographs (from museum websites) of the London Archaeopteryx, Sinosauropteryx and a T. rex skin patch
- Notebook

Steps

1. Examine the feather. Sketch the shaft, vane, barbs and (with the lens) the barbules. "Unzip" and "zip" the vane.
2. Make three small cards: glue yarn strands for filaments, a paper feather with a shaft for a pennaceous feather, and sequins for scales.
3. Look at each photograph and decide which card it matches. For each, write one observation and one interpretation.
4. Read the Primary source (Lucas, 1901). List three facts he gives about Archaeopteryx and check each against the London specimen photograph. Which can you see for yourself?
5. Write a museum label (60–80 words) for Sinosauropteryx that separates what is observed from what is interpreted.

Check your work

- I sketched and labeled a real feather.
- I sorted three fossils into feather, filament or scale and explained each choice.
- I checked Lucas's description against a photograph.
- My museum label separates observation from interpretation.

FIELD NOTEBOOK

1. Draw and label three coverings: scale, simple filament, pennaceous feather (with shaft, barbs and barbules).
2. Make a timeline of discoveries: 1861 feather and London specimen, 1868 Huxley, 1877 Berlin specimen, 1996 Sinosauropteryx, 1998 Caudipteryx, 2003 Microraptor, 2007 Velociraptor quill knobs, 2012 Yutyrannus, 2016 amber tail, 2017 T. rex skin.

3. **Narration.** Write one paragraph describing what the fossils actually show about feathers on dinosaurs, naming one point of agreement and one point of debate. Your parent keeps this page.

Did you know? The young of the hoatzin, a South American bird, have two working claws on each wing and use them to climb back up into trees if they fall into the water. They lose the claws as they grow. A living bird with wing claws helps us picture *Archaeopteryx*.

Primary source. *Frederic A. Lucas, Animals of the Past (1901), Chapter V, "Birds of Old."* Project Gutenberg eBook #38013. Two separate passages.

Archæopteryx was considerably smaller than a crow, with a stout little head armed with sharp teeth (as scarce as hens' teeth was no joke in that distant period), while as he fluttered through the air he trailed after him a tail longer than his body, beset with feathers on either side.

The first intimation of their presence was the imprint of a single feather found in that ancient treasure-house, the Solenhofen quarries; but as Hercules was revealed by his foot, so the bird was made evident by the feather whose discovery was announced August 15, 1861. And a little later, in September of the same year, the bird itself turned up, and in 1877 a second specimen was found, the two representing two species, if not two distinct genera.

Lucas's idea that the two specimens were different species was common in his day; most scientists today place them in one genus.

 **What the sign says / What we observe / How Christians read it.**  **What the sign says:** "*Archaeopteryx* lived about 150 million years ago in the Late Jurassic. It shows that birds evolved from dinosaurs." **What we observe:** in fine-grained limestone, skeletons with true flight feathers on wings and tail, teeth, clawed fingers and a long bony tail; in Chinese lake deposits, many small animals with filaments or feathers. **How Christians read it:** many young-earth creationists read *Archaeopteryx* as a true bird with unusual features, created on day five and buried quickly (fine feather detail requires rapid burial), many in the Flood; some see dinosaur filaments as disputed or as a created skin covering. Old-earth Christians generally accept the mainstream age, and some accept common descent while others do not. The date rests on correlation of the limestone with dated volcanic layers elsewhere and the assumptions of radiometric dating. The feathers themselves are what everyone can see. "Late Jurassic" is museum vocabulary for the position of the Solnhofen limestone in the rock record.

Go deeper. Natural History Museum (London), online page on the London *Archaeopteryx*. American Museum of Natural History, online exhibition material "Dinosaurs Among Us." Answers in Genesis articles on *Archaeopteryx* and feathered

dinosaurs (young-earth view). Second video topic: “How fossil feather color is studied with an electron microscope.”

Goes deeper in. Life Science, high-school biology units on birds and classification (coming soon); and Earth Science, the fossils unit.

For families. Facts checked and rounded: von Meyer’s feather (1861); London specimen bought 1862, described by Owen (1863); Huxley (1868); Berlin specimen (1877); *Sinosauropteryx* (1996); *Caudipteryx* and *Protarchaeopteryx* (1998); *Microraptor* (2003; flight feathers on four limbs); *Velociraptor* quill knobs (Turner and others, 2007); melanosome color studies (Zhang and others; Li and others, 2010; Li and others, 2012); *Yutyrannus* (Xu and others, 2012); amber tail (Xing and others, 2016); *T. rex* scales (Bell and others, 2017). The number of *Archaeopteryx* specimens is about a dozen; counts differ because some are fragmentary. The picture-study lithographer is not confirmed here; check the Royal Society or Biodiversity Heritage Library scan. This is a stop where a date in millions of years appears, so it includes the ⌚ box.

PRACTICE

1. **EASY** Name three features of Archaeopteryx that are bird-like and three that are not usually found in living birds.
2. **MEDIUM** What is the difference between a pennaceous feather and a simple filament?
3. **MEDIUM** According to the Primary source, what was found first at Solnhofen, and on what date was it announced?
4. **MEDIUM** Give one reason some scientists are cautious about melanosome color reconstructions.
5. **CHALLENGE** A friend says, “All dinosaurs had feathers.” Using evidence from this stop, write a more accurate sentence.
6. **CHALLENGE** Lucas wrote in 1901 that the two specimens might be “two species, if not two distinct genera.” Today most scientists place them in one genus. What does this show about how scientific conclusions change, and what part of Lucas’s account remains solid?

Make it a game • Bird or Not?. The leader reads out a list of features one at a time (teeth, feathers, beak, long bony tail, claws on wings, hollow bones, scales, wishbone). Players hold up a feather card for “usually bird” or a scale card for “usually reptile.” Then reveal the animal: Archaeopteryx, hoatzin chick, crocodile, ostrich. Discuss the mosaics.

Scripture. “But ask now the beasts, and they shall teach thee; and the fowls of the air, and they shall tell thee: Or speak to the earth, and it shall teach thee: and the fishes of the sea shall declare unto thee. Who knoweth not in all these that the hand of the LORD hath wrought this?” (Job 12:7–9, KJV)

Job points us to the creatures and to the earth itself as teachers. Feathers pressed into stone still declare the skill of the hand that made them.

Practice: answers

1. Bird-like: feathered wings with true flight feathers, a feathered tail, a wishbone (furcula). Not usual in living birds: teeth, clawed fingers, long bony tail.
2. A pennaceous feather has a central shaft and vanes of barbs hooked together by barbules; a filament is a simple hair-like strand with no vane.
3. The imprint of a single feather, announced August 15, 1861.
4. The microscopic shapes might be fossil bacteria, which look similar, rather than pigment packets; and shape-color matches from living birds are assumptions.
5. Sample: Some small theropods had true feathers and some other dinosaurs had filaments whose nature is debated, but skin impressions of large dinosaurs such as T. rex, hadrosaurs and sauropods show scales, so not all dinosaurs had feathers.
6. Interpretations (classification) change as more specimens are found and compared; the observations (a feather found first, a toothed, long-tailed feathered skeleton, a second specimen in 1877) remain solid.

3.8 BABIES AND GROWTH

OBJECTIVES

- Explain how growth lines in bone let scientists estimate a dinosaur's age and growth rate.
- Describe how dinosaur skulls and bodies changed as they grew, and why that has caused naming mistakes and debates.
- Weigh the evidence for and against parental care in dinosaurs.

Warm-up. Find a cut log or a stump and count its rings, or look at a photo of tree rings online. Then measure your height against a door frame and compare it with your height in an old family photo or record. How many centimeters did you grow last year?

Video slot. Video coming. Dinosaur growth: bone growth rings (lines of arrested growth), T. rex growth curve, juvenile dinosaurs, Maiasaura hatchlings. Search approved channels (Museum of the Rockies, Field Museum, American Museum of Natural History, Natural History Museum London, Answers in Genesis); preview first.

KEY TERMS

ontogeny

The growth and development of an individual from embryo to adult.

line of arrested growth (LAG)

A thin ring in bone where growth paused, usually once a year, like a tree ring.

growth curve

A graph of body size against age; for most animals it is S-shaped: slow, then fast, then leveling off.

bone histology

The study of the microscopic structure of bone tissue in thin slices.

medullary bone

A special calcium-rich bone that female birds lay down inside their leg bones to supply eggshell; it has been reported in some dinosaurs.

altricial and precocial

Altricial young are helpless at hatching and need care; precocial young can walk and feed soon after hatching.

CORE IDEAS

From grapefruit to giant. The growth of the largest dinosaurs is staggering. A titanosaur hatchling from an egg about the size of a grapefruit may have weighed about 3 to 5 kg; an adult of the biggest kinds may have weighed 50 tonnes or more, roughly a 10,000-fold increase. An elephant calf, by comparison, is born weighing about 100 kg and grows about

50-fold. A 2016 study of a baby *Rapetosaurus* from Madagascar found that the young sauropod, about the size of a Labrador at death, had skeletal proportions like an adult's and was probably on its own and able to walk soon after hatching.

Counting rings. Many living animals pause their growth each year, during winter or a dry season, and the pause leaves a thin dark ring in the bone called a **line of arrested growth**. In 2004 Gregory Erickson and colleagues sliced bones from several *Tyrannosaurus* skeletons and counted the rings. The famous SUE was about 28 years old at death. The study suggested that *T. rex* grew slowly for its first ten years, then shot up in its teens, gaining up to about 2 kg a day (more than 700 kg a year) between roughly 14 and 18, before leveling off. That S-shaped **growth curve** is like a human teenager's, but far steeper. A 2015 study of about 50 *Maiasaura* leg bones found they reached adult size in about eight years.

Honest complexity in counting. Rings are not perfect clocks. As bone grows, its inner core is hollowed out to form the marrow cavity, destroying the earliest rings, so scientists must estimate how many are missing. Some animals lay down two rings in a year, or none in an easy year. Large sauropods often show few clear rings at all. Growth rates are therefore estimates with ranges. Careful researchers compare several bones from the same animal and several individuals of different sizes before drawing a curve.

Babies that looked different. Young dinosaurs did not always look like small adults. Hatchlings had big eyes and short faces, as many baby animals do. Horned and crested dinosaurs changed the most. In 2009 Jack Horner and Mark Goodwin argued that two dinosaurs named *Dracorex* and *Stygomoloch* were really young *Pachycephalosaurus* whose spikes shrank and domes grew with age. In 2010 John Scannella and Horner argued that *Torosaurus*, with its long frill with holes, was the fully adult form of *Triceratops*; others disagreed, and the question is still debated. The best-known case is *Nanotyrannus*: for decades many considered it a juvenile *T. rex*, but studies in 2024 and 2025, including one of a nearly complete skeleton from Montana, argued it was a separate small tyrannosaur. Growth can fool even experts.

Did parents care? Evidence for parental care is real but debated. At Egg Mountain, Montana, hatchling *Maiasaura* were found in and near nests, and Jack Horner argued their poorly formed leg joints meant they had to stay in the nest and be fed (altricial). Others have since argued the joints were normal for young animals that could walk (precocial). The brooding oviraptorids (Stop C2) show parents sitting on eggs. In China, a block with about two dozen young *Psittacosaurus* and one older individual (described in 2004) has been read as a family group, though the older animal was later suggested to be an older juvenile rather than a parent. A female *T. rex* (MOR 1125) has **medullary bone**, suggesting she was preparing to lay eggs at about 18 years old.

How Christians read it. Growth rings count the years of an animal's life, not the age of the rocks, so there is no conflict here between views: a *T. rex* that lived 28 years lived 28 years. Christians see in growth the wisdom of the Creator, who gave each kind a pattern of development from egg to adult. Even the Lord Jesus, fully God, "increased in wisdom and

stature” (Luke 2:52) as a real boy. Growth, in bodies and in wisdom, is part of God’s good design.

PICTURE STUDY



Triceratops, Charles R. Knight, 1901 · Watercolor (painted for the American Museum of Natural History) · American Museum of Natural History, New York
Wikimedia Commons · Public domain

Charles R. Knight worked closely with museum scientists and painted from skeletons and from living animals at the zoo. This early *Triceratops* shows a full-grown animal, with long brow horns and a solid frill. Fossils found since show that young *Triceratops* had short, curved horns and a frill edged with triangular bones that flattened as the animal aged.

Look closely

- Look at the horns. How long are they compared with the head?
- Look at the edge of the frill. Is it smooth or bumpy?
- Look at the legs and posture. Does this animal look slow or ready to move?

Talk about it

1. If you found a skull with short horns and a spiky frill edge, how would you tell whether it was a young *Triceratops* or a different kind of dinosaur?
2. Why do artists need to know an animal’s age before painting it?

HANDS-ON: GRAPH A GROWTH CURVE

Use family data and published dinosaur estimates to draw and compare S-shaped growth curves.

You will need

- Graph paper or a spreadsheet
- Your own height or weight records (from a doctor's chart or baby book), if available
- A ruler and colored pencils

Steps

1. Plot your height (or a sibling's) against age from birth to now. Mark where growth was fastest.
2. Plot this simplified T. rex curve (body mass in kg against age in years, rounded from published estimates): 2 yrs, 30; 6 yrs, 300; 10 yrs, 800; 14 yrs, 2,000; 16 yrs, 3,500; 18 yrs, 4,800; 22 yrs, 5,500; 28 yrs, 5,700.
3. Find the steepest part of the T. rex curve. Calculate the average daily gain between ages 14 and 18 ($\text{kg per year} \div 365$).
4. Write a paragraph comparing your curve with T. rex: when is each fastest, and when does each level off?
5. Add a note about uncertainty: why might the first few years of the T. rex curve be the least certain? (Hint: lost rings.)

Check your work

- I plotted at least one human and one dinosaur growth curve with labeled axes.
- I calculated a daily growth rate correctly.
- I explained the S-shape in my own words.
- I named one source of uncertainty in counting growth rings.

FIELD NOTEBOOK

1. Draw a cross-section of a leg bone with a marrow cavity and five growth rings. Shade the area where early rings were lost.
2. Draw a young and an adult Triceratops skull side by side, showing horn and frill changes.
3. **Narration.** Write one paragraph explaining how scientists estimate a dinosaur's age at death and why growth has caused naming mistakes. Your parent keeps this page.

Did you know? Crocodiles and alligators, close relatives of dinosaurs, guard their nests, help hatchlings out of their eggs and carry them to the water in their mouths. Many birds feed their young for weeks. Dinosaur parental behavior is usually reconstructed by comparison with these two groups.

Go deeper. Museum of the Rockies (Bozeman, Montana) pages on its *Triceratops* and *T. rex* growth series. Field Museum pages on SUE the T. rex. Jack Horner and James Gorman, *Digging Dinosaurs* (1988), Horner's account of the *Maiasaura* nests (old-earth framing). Second video topic: "How a bone thin section is cut and polished."

Goes deeper in. Life Science, high-school biology unit on growth and development (coming soon); and Arithmetic, graphs and rates.

For families. Facts checked and rounded: Erickson and others, *Nature* (2004) on *T. rex* growth (SUE about 28; peak gain about 2 kg a day); Woodward and others (2015) on *Maiasaura* growth; Curry Rogers and others, *Science* (2016) on baby *Rapetosaurus*; Horner and Goodwin (2009); Scannella and Horner (2010); Meng and others (2004) and Hedrick and others (2014) on the *Psittacosaurus* group; Schweitzer and others (2005) on medullary bone in MOR 1125. On *Nanotyrannus*, see Longrich and Saitta (2024) and Zanno and Napoli, *Nature* (2025); some paleontologists still disagree. The T. rex growth table in the project is a simplified teaching version of published curves, not data from one paper. No dates in millions of years are used here.

PRACTICE

1. **EASY** What is a line of arrested growth, and what does counting them tell scientists?
2. **MEDIUM** Why might scientists undercount growth rings in an adult dinosaur bone?
3. **MEDIUM** Give one example of a dinosaur that may have been named twice because juveniles looked different from adults.
4. **MEDIUM** What is medullary bone, and what did finding it in MOR 1125 suggest?
5. **CHALLENGE** If a T. rex grew from 2,000 kg at age 14 to 4,800 kg at age 18, what was its average gain per year and per day?
6. **CHALLENGE** A titanosaur grew from 5 kg to 50,000 kg. An elephant grows from 100 kg to 5,000 kg. Compute each growth factor and explain what the difference suggests about dinosaur growth rates.

Make it a game · Juvenile or New Species?. The leader draws (or shows pictures of) pairs of skulls or animals: a puppy and a dog, a duckling and a duck, a young and adult Triceratops, a tadpole and a frog. Players vote: same kind at different ages, or different kinds? Award a point for each correct vote and an extra point for naming the feature that gave it away.

Scripture. “And Jesus increased in wisdom and stature, and in favour with God and man.” (Luke 2:52, KJV)

The Son of God grew as a real child. God designed growth, in body and in wisdom, as a good part of life.

Practice: answers

1. A thin ring in bone where growth paused, usually once a year; counting them estimates the animal’s age at death.
2. The marrow cavity expands as the bone grows and destroys the innermost (earliest) rings; some years may also leave no ring.

3. Dracorex and Stygimoloch as young Pachycephalosaurus; or Torosaurus as adult Triceratops (debated); or Nanotyrannus (once thought a juvenile T. rex; now argued to be separate).
4. A calcium-rich bone females lay down to supply eggshell; it suggested this T. rex was a female preparing to lay eggs.
5. $2,800 \text{ kg} \div 4 = 700 \text{ kg per year}$; $700 \div 365 \approx 1.9 \text{ kg per day}$.
6. Titanosaur: $50,000 \div 5 = 10,000\text{-fold}$. Elephant: $5,000 \div 100 = 50\text{-fold}$. The titanosaur's growth was about 200 times greater as a factor, which (if it reached adult size in a few decades) required very fast growth and a high metabolic rate.

3.9 SAUROPOD NECKS

OBJECTIVES

- Describe how sauropod necks were built: many long vertebrae lightened by air spaces.
- Explain the debate over neck posture and the blood-pressure problem, using simple physics.
- Give reasons scientists think long necks helped sauropods feed, and trace how pictures of sauropods have changed since 1897.

Warm-up. Hold a broom straight out in front of you by the end of the handle. Now hold it straight up. Which is easier? Now imagine your neck were 12 m long and your head at the far end. Write down two problems you would have to solve.

Video slot. Video coming. How sauropod necks worked: air-filled vertebrae, Mamenchisaurus neck length, neck posture debate, giraffe blood pressure for comparison. Search approved channels (Natural History Museum London, American Museum of Natural History, Field Museum, Smithsonian, Answers in Genesis); preview first.

KEY TERMS

cervical vertebrae

The bones of the neck. Mammals almost always have seven; some sauropods had up to nineteen.

pneumaticity

Air spaces inside bones, connected to the lungs and air sacs, as in birds.

osteological neutral pose

The posture of a neck when the joints are set in their middle position, as estimated from bones alone.

blood pressure

The force of blood pushing on the walls of blood vessels, measured in millimeters of mercury (mmHg).

feeding envelope

The whole space an animal can reach with its mouth without moving its feet.

CORE IDEAS

The longest necks ever. Sauropods had the longest necks of any land animals known. A giraffe's neck is about 2 m long, built on seven vertebrae. The neck of *Mamenchisaurus sinocanadorum* from China has been estimated at about 15 m, longer than a city bus, with up to nineteen **cervical vertebrae**, some more than a meter long. *Supersaurus* and *Barosaurus*

had necks perhaps 9 to 15 m long. A *Brachiosaurus* holding its head up may have reached about 12 to 13 m, the height of a four-story building.

Light as air. How could such a neck be lifted at all? The vertebrae were not solid. Like the bones of birds, they were hollowed by air spaces (**pneumaticity**) connected to the lungs and air sacs. Cross-sections of sauropod neck bones look like an I-beam or a honeycomb: thin bony walls and struts with large air chambers between. Mathew Wedel and others have estimated that air filled well over half the volume of some neck vertebrae. Sauropods also had small heads with no heavy chewing teeth; they cropped and swallowed plants whole, leaving digestion to a huge gut. The neck had to carry only a light head. Strong ligaments along the top of the neck, as in grazing mammals today, may have helped hold it up without constant muscular effort.

Up, out or in between? How did sauropods hold their necks? In 1999 Kent Stevens and Michael Parrish used computer models of the bones (the “DinoMorph” project) and found that, with the joints in their middle position, the necks of *Diplodocus* and *Apatosaurus* extended nearly straight forward with the head low. In 2009 Michael Taylor, Mathew Wedel and Darren Naish answered that in almost every living vertebrate the neck is held raised and the head angled up, more than the **osteological neutral pose** suggests, because cartilage between the bones adds bend. Most experts now think different sauropods held their necks differently: *Brachiosaurus*, with long front legs, probably carried its head high, while some diplodocids may have swept their necks low and wide.

The blood-pressure problem. Lifting a head high means pumping blood uphill. Pressure from a column of blood equals density $\times$ gravity $\times$ height. For a head 8 m above the heart: $1,050 \text{ kg/m}^3 \times 9.8 \text{ m/s}^2 \times 8 \text{ m} \approx 82,000 \text{ pascals}$, or about 620 mmHg, just to lift the blood, plus about 80 to 100 mmHg to push it through the brain. A human’s pressure is about 120 mmHg; a giraffe, with its head about 2 m above its heart, has about 250 to 300 mmHg, the highest of any living mammal. Roger Seymour and others have argued that a sauropod pumping 700 mmHg would need an enormous heart. Others answer that sauropods fed mostly with heads lower, raising them only briefly, or had arrangements of valves and vessels we cannot see in fossils. The question is unresolved.

Why a long neck? P. Martin Sander and colleagues (2011) pointed to the **feeding envelope**. A sauropod standing in one spot could sweep its head across a huge area of plants, high and low, without walking, saving a great deal of energy for an animal of 20 to 70 tonnes. It could reach vegetation other animals could not, and reach into thickets or over wet ground without stepping in. A long neck works together with the other sauropod traits: small head, no chewing, bird-like breathing, huge body and gut.

Changing pictures. For much of the twentieth century, museum paintings showed sauropods wallowing in swamps, as if their legs could not hold them up on land; Charles R. Knight’s 1897 *Brontosaurus* is a famous example. Trackways, slender feet, deep narrow chests and the realization that water pressure would have crushed their lungs at depth persuaded scientists by the 1970s that sauropods lived on land. The name *Brontosaurus* itself was set aside for decades as a synonym of *Apatosaurus* and revived in 2015 by a large

study of diplodocid bones. Christians who read Job 40 see in Behemoth a great creature with a tail “like a cedar” (Trail D takes that up). Whatever view we hold, the sauropod neck is a lesson in engineering: lightness, strength and balance united in one body.

PICTURE STUDY



Brontosaurus, Charles R. Knight, 1897 (reproduced in the New-York Tribune, 1919) · Painting (painted for the American Museum of Natural History) · American Museum of Natural History, New York
Wikimedia Commons · Public domain

Knight painted this for the American Museum of Natural History with the advice of Henry Fairfield Osborn and Jacob Wortman. It shows the scientific opinion of its time: a heavy, water-loving *Brontosaurus* wading in a swamp while a *Diplodocus* stands on shore. The painting is skillful and was copied for decades; this copy was printed in a New York newspaper in 1919. Today it is valuable as a record of how ideas change.

Look closely

- Look at the necks. Are they held high, straight out or low?
- Where is each animal standing, and why do you think Knight put the *Brontosaurus* in the water?
- Compare the size of the head with the size of the body.

Talk about it

1. Which features of this painting would a museum change today, and what evidence led to the change?
2. Why is it valuable to study old scientific pictures even when they are out of date?

HANDS-ON: BUILD A LIGHTWEIGHT NECK

Engineer a model sauropod neck that is long, light and strong, then do the blood-pressure calculation for real animals.

You will need

- Drinking straws, cardboard tubes or rolled paper
- Tape, string and a few rubber bands
- A small ball of clay (the head, about 30 g)
- A kitchen scale and a ruler

Steps

1. Build a neck at least 60 cm long from a chain of “vertebrae” (straw or tube sections) joined so it can bend. Weigh it.
2. Attach the clay head. Fix the base to a box (the body). Can the neck hold itself straight out? Add string along the top as a ligament, tied to the box, and test again.
3. Try a heavier, solid neck (rolled sheets taped tight, or a wooden dowel) of the same length. Compare weight and how hard it is to hold level by hand.
4. Calculate the pressure needed to lift blood ($P = 1,050 \times 9.8 \times h$, then $\div 133$ for mmHg) for: a human ($h = 0.4$ m), a giraffe (2 m), a sauropod with head low (2 m), and a sauropod with head high (8 m).
5. Write a paragraph: which design worked best, and what does your calculation suggest about how often a sauropod held its head high?

Check your work

- My model neck is at least 60 cm long and I weighed it.
- I tested the effect of a top “ligament.”
- I calculated blood pressures for four cases correctly.
- My paragraph connects lightness and posture to the evidence.

FIELD NOTEBOOK

1. Draw a sauropod neck vertebra in cross-section showing the thin walls and air chambers, next to a solid mammal vertebra.
2. Draw three silhouettes of a sauropod with neck held high, horizontal and low, and shade the feeding envelope for each.
3. **Narration.** Write one paragraph explaining how a sauropod could carry such a long neck and why scientists still argue about how it held it. Your parent keeps this page.

Did you know? A giraffe has special valves in its neck veins and a tight sheath of skin on its legs that keep blood from pooling, and its heart wall is unusually thick. When it lowers its head to drink, a network of small vessels at the base of the brain helps prevent a rush

of blood to the head. Sauropods may have had their own solutions, but soft tissues like these do not fossilize.

Go deeper. Natural History Museum (London) pages on *Diplodocus* (“Dippy”). Field Museum (Chicago) pages on its *Brachiosaurus* and titanosaur casts. Sauropod Vertebra Picture of the Week (svpow.com), the blog of Mathew Wedel and Michael Taylor, for photos of air-filled vertebrae (old-earth framing). Second video topic: “How giraffes manage blood pressure.”

Goes deeper in. Life Science, high-school biology unit on the circulatory system (coming soon); and Arithmetic, formulas and units.

For families. Facts checked and rounded: *Mamenchisaurus sinocanadorum* neck about 15 m (Moore and others, 2023); Stevens and Parrish, *Science* (1999); Taylor, Wedel and Naish (2009); Seymour (2009) on sauropod blood pressure; Sander and others, *Biological Reviews* (2011); Tschopp, Mateus and Benson (2015) reviving *Brontosaurus*. Giraffe blood pressure figures vary by source (often given as about 220–300 mmHg at the heart). The stop mentions Behemoth only briefly and leaves its discussion to Trail D. No dates in millions of years are used here.

PRACTICE

1. **EASY** How many neck vertebrae does a giraffe have, and how many did some sauropods have?
2. **MEDIUM** Name two features that made a sauropod’s long neck light enough to carry.
3. **MEDIUM** Summarize the two sides of the neck-posture debate.
4. **MEDIUM** Why did scientists stop picturing sauropods living in swamps?
5. **CHALLENGE** Calculate the pressure (in mmHg) needed just to lift blood 8 m, using $P = \rho gh$ with $\rho = 1,050 \text{ kg/m}^3$, $g = 9.8 \text{ m/s}^2$, and $1 \text{ mmHg} \approx 133 \text{ Pa}$. Compare it with a human’s 120 mmHg.
6. **CHALLENGE** A sauropod standing still can sweep its head through an arc of radius 10 m. Approximately how much ground area (a half circle in front) can it reach without moving its feet? Why does this save energy?

Make it a game • Long Neck Reach. Mark a spot on the floor. Players stand with both feet on it and try to touch as many sticky notes as possible placed around the room at different heights and distances, using a grabber tool or a broom as a “neck.” No moving the feet. Then discuss: what were the hardest notes to reach, and why?

Scripture. “In whose hand is the soul of every living thing, and the breath of all mankind.” (Job 12:10, KJV)

Every breath that passed down a sauropod’s long neck, and every breath we take, is held in God’s hand.

Practice: answers

1. A giraffe has 7; some sauropods (Mamenchisaurus) had up to 19.
2. Air-filled (pneumatic) vertebrae with thin walls, and a small, light head without heavy chewing teeth (also: ligaments along the top).
3. Stevens and Parrish (1999) found from bones alone that some sauropod necks extended nearly horizontally; Taylor, Wedel and Naish (2009) argued that living animals hold necks raised beyond the bone-only pose, so sauropods probably raised theirs. Many now think it varied by species.
4. Trackways on land, slender feet and deep chests built for weight-bearing, and the fact that water pressure would have made breathing at depth nearly impossible.
5. $P = 1,050 \times 9.8 \times 8 \approx 82,300 \text{ Pa}$; $\div 133 \approx 620 \text{ mmHg}$, more than five times a human's total blood pressure, before adding pressure to push blood through the brain.
6. Half circle: $\frac{1}{2} \times \pi \times 10^2 \approx 157 \text{ m}^2$. By feeding over a large area without walking, a 20–70 tonne animal avoids moving its huge body, which costs far more energy than moving the light neck and head.

3.10 DINOSAUR SOUNDS

OBJECTIVES

- Explain why dinosaur sounds must be inferred and name the kinds of evidence used: crests, larynx bones, inner ears and living relatives.
- Describe how the hollow crest of Parasaurolophus was modeled to produce sound.
- Separate film sound effects from scientific evidence and write a careful description of what dinosaurs may have sounded like.

Warm-up. Hum with your mouth closed, then say “ahh” with your mouth open. Feel your throat and your chest with your hand each time. Now blow across the top of an empty bottle, then a bottle half full of water. Which gives a lower note? Write why you think so.

Video slot. Video coming. Dinosaur sounds: Parasaurolophus crest sound simulation, closed-mouth vocalization in birds and crocodiles, cassowary and alligator low-frequency calls. Search approved channels (New Mexico Museum of Natural History and Science, Cornell Lab of Ornithology, American Museum of Natural History, Smithsonian, Answers in Genesis); preview first.

KEY TERMS

larynx

The voice box at the top of the windpipe; in mammals it holds the vocal cords.

syrix

The voice organ of birds, deep in the chest where the windpipe divides; it has never been found in a non-bird dinosaur.

resonance

The strengthening of certain sound frequencies by a hollow space; longer tubes resonate at lower notes.

infrasound

Sound too low for human ears to hear (below about 20 hertz), used by elephants and some other animals.

closed-mouth vocalization

Making a sound by pushing air into a stretchy throat or esophagus with the mouth shut, like a dove’s coo or an ostrich’s boom.

extant phylogenetic bracket

Inferring a feature of an extinct animal by checking its closest living relatives on either side (for dinosaurs: crocodilians and birds).

CORE IDEAS

The silence of the stones. No one has ever heard a dinosaur. Sound leaves no fossil, and the soft tissues that make it, vocal folds and air sacs and muscles, are almost never preserved. So every dinosaur sound is an inference. Scientists use three kinds of evidence: the anatomy of the head and throat that can fossilize (crests, nasal passages, rare larynx bones), the inner ear, which shows what pitches an animal could hear, and comparison with the closest living relatives, crocodilians and birds. This last method has a name: the **extant phylogenetic bracket**. If both relatives share a trait, the extinct animal probably did too.

What living relatives do. Crocodilians have a **larynx** and bellow: male American alligators rumble so low that the water on their backs dances in a “water dance.” Birds sing with a **syrinx** deep in the chest, a voice organ unique to birds; the oldest fossil syrinx, found in a bird called *Vegavis*, was described in 2016, and no syrinx has yet been found in a non-bird dinosaur. Many birds and crocodilians also make **closed-mouth vocalizations**: doves coo, emus and cassowaries boom, and ostriches give a deep booming call, all with the mouth shut and the throat inflated. A 2016 study by Tobias Riede and colleagues proposed that large dinosaurs may have made similar low, closed-mouth booms. That would sound less like a lion’s roar and more like a deep, resonant hum or rumble.

The trombone head. The best evidence for a dinosaur sound is the crest of *Parasaurolophus*, a hadrosaur whose curved crest stretched back more than a meter from its head. Inside, the crest held hollow tubes running from the nostrils up to the tip and back down to the throat, a total air path of several meters. In 1981 David Weishampel analyzed the crests of lambeosaurine hadrosaurs as **resonating** chambers like the tubes of wind instruments. In 1995 a well-preserved *Parasaurolophus* skull from New Mexico was scanned by computed tomography, and in 1997 researchers at the New Mexico Museum of Natural History and Science and Sandia National Laboratories built a computer model of the air passages and simulated the sound: a low, rumbling, horn-like tone. Different crest shapes in *Corythosaurus* and *Lambeosaurus* would have given different calls, perhaps telling species, ages or sexes apart.

Ears and throats. The inner ear’s cochlear duct is preserved as a cavity in the skull. Its length roughly tracks the range of pitches an animal hears best: long ducts suggest good low-frequency hearing. Studies of hadrosaurs and tyrannosaurs suggest they heard low sounds well, which fits low-pitched calls. In 2023 a team led by Junki Yoshida described the larynx bones of the ankylosaur *Pinacosaurus* from Mongolia. Its larynx was large and bird-like, and the authors suggested it might have helped shape and modify sounds. That is one fossil, but it shows that throats are sometimes preserved if we look carefully.

Hollywood versus evidence. The famous film roar of *T. rex* in 1993 was built by a sound designer from recordings of a baby elephant, a tiger, an alligator and other animals. It is good drama, but there is no evidence for it. A more careful description, based on what is known, might be: large dinosaurs probably produced low-pitched sounds, perhaps booms or rumbles made with the mouth closed, some of them below the range of human hearing (**infrasound**), and hadrosaurs with hollow crests could resonate distinctive horn-like calls.

Small theropods closest to birds may have hissed, chirped or called in ways we cannot yet know.

Every thing that hath breath. The last verse of the Psalms calls on “every thing that hath breath” to praise the LORD. The Bible pictures the whole creation giving voice to God’s glory (Psalm 148 calls even the great sea creatures to praise). We cannot recover the exact sound of a *Parasaurolophus* on a still morning, but we can study its crest with wonder, speak honestly about what we know and do not know, and use our own voices for the purpose God gave them.

PICTURE STUDY



Leaping Laelaps, Charles R. Knight, 1897 · Watercolor (painted for the American Museum of Natural History) · American Museum of Natural History, New York
Wikimedia Commons · Public domain

Knight painted these theropods, then called *Laelaps* and now *Dryptosaurus*, under the guidance of Edward Drinker Cope, who had described the animal. It was one of the first paintings to show dinosaurs as active and agile. Knight painted open jaws, as if the animals were snarling or calling. Artists often show dinosaurs with mouths wide open, but what sound, if any, should we imagine?

Look closely

- Look at the mouths. Do they look like they are roaring, hissing or biting?
- Look at the leaping animal’s body. What does Knight suggest about how agile it was?
- Find the background. How does Knight make the scene feel dramatic?

Talk about it

1. If many large dinosaurs made closed-mouth booms, how might an artist show a calling dinosaur differently?
2. What is the difference between artistic drama and scientific evidence in a picture like this?

HANDS-ON: BUILD A CREST: RESONANCE IN TUBES

Use tubes to discover how the length of an air passage changes its note, then design a model hadrosaur crest.

You will need

- Several lengths of PVC pipe, cardboard tube or flexible plastic tubing (30 cm, 60 cm, 120 cm, 240 cm if possible)
- A free tuner or frequency app on a phone
- Tape, scissors and a funnel or mouthpiece
- Notebook and graph paper

Steps

1. Buzz your lips (like a trumpet player) into each tube, or blow across one end. Use the app to record the lowest steady note in hertz for each length.
2. Graph frequency against tube length. Describe the pattern: what happens to the note when the length doubles?
3. A closed-end tube resonates at about $f = 343 \div (4 \times L)$, where 343 m/s is the speed of sound and L is length in meters. Calculate f for each of your tubes and compare with your measurements.
4. Design a Parasaurolophus crest from flexible tubing about 2–3 m long, looped as in a real crest. Predict its note, then test it.
5. Write a short scientific description of what Parasaurolophus may have sounded like, separating what is measured from what is guessed.

Check your work

- I measured notes from at least three tube lengths.
- I graphed the results and described the pattern.
- I compared my measurements with the formula.
- My description separates evidence from guesswork.

FIELD NOTEBOOK

1. Draw a Parasaurolophus skull with its crest in cross-section, tracing the air path from nostril to tip and back to the throat.
2. Make a chart of living animals' calls with their approximate lowest pitches: human voice, alligator bellow, ostrich boom, elephant rumble (infrasound).

3. **Narration.** Write one paragraph describing what dinosaurs may have sounded like, giving the evidence for each claim and naming one thing we do not know. Your parent keeps this page.

Did you know? Elephants communicate with infrasound rumbles that can travel several kilometers, and other elephants may feel them through their feet as well as hear them. If large dinosaurs used very low sounds, a herd could have kept in touch across long distances or through thick forest.

Go deeper. New Mexico Museum of Natural History and Science, pages on *Parasaurolophus* and its crest. Cornell Lab of Ornithology, Macaulay Library recordings of cassowaries, emus and ostriches booming. American Museum of Natural History pages on hadrosaur crests. Second video topic: “How alligators bellow.”

Goes deeper in. Life Science, high-school biology unit on the senses and communication (coming soon); and the physics of sound in Earth Science.

For families. Facts checked and rounded: Weishampel (1981) on lambeosaur crest acoustics; the 1995 *Parasaurolophus* skull and the 1997 Sandia/New Mexico Museum sound simulation; Clarke and others, *Nature* (2016) on the *Vegavis* syrinx; Riede and others, *Evolution* (2016) on closed-mouth vocalization; Yoshida and others, *Communications Biology* (2023) on the *Pinacosaurus* larynx. The 1993 film sound design is widely reported in interviews with the sound designer. All dinosaur sounds are inferences, and the stop says so. No dates in millions of years are used here.

PRACTICE

1. **EASY** Why can no one know exactly what a dinosaur sounded like?
2. **MEDIUM** What is the extant phylogenetic bracket, and which living animals bracket dinosaurs?
3. **MEDIUM** How did scientists in 1997 work out what *Parasaurolophus* may have sounded like?
4. **MEDIUM** What is a closed-mouth vocalization? Give two living examples.
5. **CHALLENGE** Using $f = 343 \div (4 \times L)$, estimate the lowest resonant note of a closed tube 3 m long. Is it within human hearing (about 20–20,000 Hz)? What about a 5 m tube?
6. **CHALLENGE** Rewrite this museum caption to match the evidence: “T. rex let out a terrifying roar that shook the forest.”

Make it a game · Who’s Calling?. Each player chooses a tube of a different length (or a bottle filled to a different level) as their “crest.” One player turns away while another sounds their crest. The listener guesses whose crest it was. Then discuss how different crests could help hadrosaurs recognize one another.

Scripture. “Let every thing that hath breath praise the LORD. Praise ye the LORD.”

The Psalms end with a call to every breathing creature. We do not know the sound of a dinosaur's voice, but we know the purpose of our own.

Practice: answers

1. Sound leaves no fossil, and the soft tissues that make sound (vocal folds, air sacs, muscles) are almost never preserved.
2. Inferring a trait of an extinct animal from its closest living relatives on either side; for dinosaurs, crocodilians and birds.
3. They CT-scanned a well-preserved skull, built a computer model of the air passages in the crest and simulated the resonance, producing a low, horn-like rumble.
4. A sound made by inflating the throat or esophagus with the mouth shut; examples: a dove's coo, an ostrich's boom, an emu's or cassowary's boom.
5. 3 m: $343 \div 12 \approx 29$ Hz, a very low note just within human hearing. 5 m: $343 \div 20 \approx 17$ Hz, below 20 Hz, so infrasound.
6. Sample: "We do not know what T. rex sounded like. Its closest living relatives, birds and crocodilians, suggest it may have made low-pitched sounds, perhaps booms with its mouth closed; its inner ear suggests it heard low sounds well. Film roars are sound effects, not evidence."

TRAIL 3 BADGE QUIZZES

The badge quizzes are optional and may be taken open-notebook. Answer in complete sentences; show work on the calculation problems. Four right out of five on quiz 1, and five right out of six on quiz 2, earns that badge. Badges and the certificate are earned by doing the stops, not by scores.

Badge quiz 1 (Stops 1-5)

1. Why is a coprolite containing bone stronger evidence of meat-eating than a sharp tooth? Name a living animal that shows the limit of tooth evidence.
2. Why did even the largest dinosaurs lay eggs no bigger than about a football?
3. A theropod footprint is 25 cm long and the stride is 2.0 m. Estimate the hip height and the gait.
4. Name two things a scientist should check before calling a bonebed a herd.
5. Explain in two sentences why an adult T. rex could not run 72 km/h.

Badge quiz 2 (Stops 6-10)

6. Give one piece of evidence for high metabolic rates in dinosaurs and one reason the debate continues.
7. What is the difference between a pennaceous feather and a filament, and which kind does Archaeopteryx have?
8. How do growth rings in bone help estimate a dinosaur's age, and why might they undercount?
9. Name two features that let sauropods carry long necks, and one unsolved problem with holding the head high.
10. What evidence suggests what Parasaurolophus sounded like?
11. A sign says "Archaeopteryx lived 150 million years ago and proves birds evolved from dinosaurs." Sort it into what the sign says, what we observe and how Christians read it.

TRAIL CERTIFICATE: MY DINOSAUR LIFE FIELD NOTEBOOK AND TRAIL C CERTIFICATE

Gather the Field Notebook pages from this trail into one booklet with a cover: "How Dinosaurs Lived: Field Notebook," your name and the dates you started and finished.

Include all ten narration paragraphs, each dated, and at least three worked calculations (trackway speed, growth rate, blood pressure or sound frequency).

Add a final two-page essay (about 500 words) titled "How Do We Know How Dinosaurs Lived?" that uses evidence from at least five stops, names one debate fairly, and explains the difference between observation and interpretation, with one 🕒 example.

When the booklet is done, a parent reads the essay and signs the Trail C certificate.

- **Ten stops:** A dated narration paragraph and at least one drawing or table for each stop.

- **Quantitative reasoning:** At least three calculations are set up correctly, with units and a sentence explaining what the result means.
- **Observation and interpretation:** The essay clearly separates what is observed from how it is interpreted and presents young-earth and other views fairly, without mocking.
- **Sources and care:** Primary sources and Scripture are quoted exactly with their sources named; pages are neat and labeled.

Answer key

1. The coprolite is direct evidence of what was eaten; tooth shape only suggests what could be eaten. The giant panda (carnivore teeth, eats bamboo) or fruit bats.
2. A bigger egg needs a thicker shell to bear its weight, which slows oxygen passage and makes hatching harder; volume (oxygen need) grows faster than surface area.
3. $h \approx 4 \times 0.25 = 1.0 \text{ m}$; $SL \div h = 2.0$, at the boundary between walking and trotting (a fast walk).
4. Any two: whether all the animals were buried at one time (one layer), whether they are one species with mixed ages, whether bones were sorted or aligned by water, whether they built up over time, and whether independent evidence (parallel trackways, age groups) agrees.
5. Weight rises with the cube of size but bone and muscle strength only with the square, so huge animals cannot sprint as fast for their size. Hutchinson and Garcia (2002) calculated that running that fast would require leg muscles making up most of its body weight, which is impossible.
6. For: fast-growing fibrolamellar bone, rapid growth from growth rings, upright posture, bird-like air sacs, polar nesting or isotope body temperatures. Debate: apparent lack of respiratory turbinates, growth rates between reptiles and mammals (mesothermy), and differences between groups.
7. A pennaceous feather has a shaft and hooked vanes; a filament is a simple strand. Archaeopteryx has true pennaceous flight feathers.
8. Each line of arrested growth usually marks one year, so counting them estimates age at death. Early rings are destroyed as the marrow cavity expands, and some years may leave no ring.
9. Air-filled (pneumatic) vertebrae and a small, light head (also ligaments). Unsolved: the very high blood pressure needed to pump blood up to a raised head.
10. Its hollow crest held long air passages; CT scans and a 1997 computer model of the passages suggested a low, horn-like resonating call. Living relatives (birds and crocodilians) also suggest low or closed-mouth sounds.
11. Sign: the date and the evolutionary claim. Observed: a skeleton with true flight feathers, teeth, clawed fingers and a long bony tail in fine limestone. Christians: many young-earth creationists read it as a created bird with unusual features, buried rapidly (many say in the Flood); old-earth Christians accept the date, and differ on common descent.

DINOSAURS TRAIL D: DINOSAURS AND THE BIBLE

The fourth trail of the Dinosaurs track brings the dinosaurs and Scripture together: the land animals of the sixth day, Behemoth and Leviathan in the book of Job, the animals on Noah's Ark, the great fossil graveyards and the Flood, dragon legends around the world, the competing explanations of dinosaur extinction, how to read a museum sign, soft tissue and radiometric dating, and the fitted design of dinosaur bodies. Each stop has a primary source (from the King James Bible or a 1915 American Museum of Natural History handbook), a picture study, a project, a narration, practice problems and Scripture.

This is the  **Expert** level, written for ages 14 and up, at a high-school standard. Each stop takes 35 to 50 minutes. The student reads the core ideas and the primary source, works the project and the practice problems (including at least two challenge problems), and writes a one-paragraph narration that the parent keeps. The track is creation-friendly: God made the land animals, dinosaurs among them, on the sixth day, and the Flood is taught as history. Period names such as **Jurassic** and **Cretaceous** are taught as museum vocabulary, and dates in millions of years are labeled as interpretations. The  stops (D5, D7, D8, D9) include the box *What the sign says / What we observe / How Christians read it*. Other Christian views are named briefly and fairly, and no view is mocked.

Five stops earn the **Expert Badge, Dinosaurs and the Bible, part 1**, and ten stops earn part 2 and the **Trail D certificate**. The two badge quizzes at the end of the trail are optional; badges are earned by doing the stops and keeping the narrations.

BEFORE YOU BEGIN

- Read Genesis 1–9 and Job 38–42 in the King James Version, or be ready to read them alongside the stops.
- Be comfortable with fractions, percentages, unit conversion and simple exponents (halving), and know the difference between an observation and an interpretation (Trail B, Stop B10, is helpful).

MASTERY CHECKLIST

- ☐ I can explain from Genesis 1 why dinosaurs belong to the sixth day and why sea reptiles and pterosaurs belong to the fifth.
- ☐ I can weigh the hippopotamus, elephant and sauropod views of Behemoth and the crocodile, whale and marine-reptile views of Leviathan, using the text of Job.
- ☐ I can describe a dinosaur bonebed and explain how mainstream and creation geologists read it, naming what both agree on.
- ☐ I can sort a museum sign into observation, inference, reconstruction and framework claim, and name the three assumptions behind a radiometric date.
- ☐ I can state the young-earth, old-earth Christian and mainstream views of dinosaur extinction fairly, and explain one example of design in dinosaurs.

GO DEEPER: BOOKS, MUSEUM PAGES AND RESOURCES

- **Project Gutenberg: W. D. Matthew, Dinosaurs (1915)**
(<https://www.gutenberg.org/ebooks/19302>): Free text of the American Museum of Natural History handbook quoted in Stops D7, D8 and D9; good for comparing old and new museum displays.
- **National Park Service: Dinosaur National Monument** (<https://www.nps.gov/dino>): Photos and history of the Carnegie Quarry and its Wall of Bones (Stop D5).
- **American Museum of Natural History: Brontosaurus or Apatosaurus?**
(<https://www.amnh.org/explore/news-blogs/brontosaurus-apatosaurus>): The museum's own account of the 1905 mount, the wrong head and the 1995 remount (Stop D8).
- **Answers in Genesis: Dinosaurs** (<https://answersingenesis.org/dinosaurs/>): Free creation-friendly articles on dinosaurs and the Bible, Behemoth, the Ark and soft tissue; preview for your family.

4.1 “EVERY LIVING THING” ON DAY SIX

OBJECTIVES

- Read Genesis 1:20–31 closely and sort the creatures of days five and six into the Hebrew groups behind the King James words.
- Explain what “after his kind” means and why many creation biologists place the created kind near the level of the scientific family.
- Explain why dinosaurs belong with the land animals of day six, what that means for people and dinosaurs, and which arguments for it are strong and which are weak.

Warm-up. Write down twelve animals as fast as you can, and be sure to include a T. rex, a plesiosaur, a pterosaur, a whale, a bat and a turtle. Now sort your list into three columns: made to fill the waters, made to fill the sky, made to live on the land. Mark any animal you were not sure about with a question mark. By the end of the stop you should be able to place every one and give a reason.

Video slot. Video coming. Dinosaurs and the days of creation; what a biblical “kind” is; creation biology and baraminology explained. Search approved channels (for creation-friendly framing, Answers in Genesis, the Institute for Creation Research or Creation Ministries International once vetted; for dinosaur anatomy, the Natural History Museum London or the American Museum of Natural History); preview first.

KEY TERMS

kind (Hebrew *min*)

The word in Genesis 1 for a created group of living things that reproduce “after his kind.” It is not the same as the modern word “species.”

baramin

A word coined by the creation biologist Frank Marsh in 1941 from the Hebrew *bara* (created) and *min* (kind): a group of living things descended from one original created kind.

beast of the earth (Hebrew *chayyah*)

In Genesis 1:24–25, wild land animals, as distinct from “cattle” (Hebrew *behemah*, larger tame-type beasts) and “creeping things” (Hebrew *remes*, small animals that move low to the ground).

tanninim

The Hebrew word in Genesis 1:21 that the KJV translates “great whales”: great creatures of the sea. Elsewhere the KJV often translates the singular *tannin* as “dragon.”

dinosaur

A land reptile whose legs stand straight under the body, with a hip socket that is open in the middle. By definition, dinosaurs did not live in the sea or fly (unless birds are counted, as many scientists now do).

Fall

Adam and Eve's first sin and God's curse that followed (Genesis 3), which Romans 8:20-22 says brought the whole creation into "the bondage of corruption."

CORE IDEAS

Reading the text slowly. Genesis 1 has a clear shape. On days one to three God forms the spaces: light and darkness, the waters above and below, dry land and plants. On days four to six He fills them: lights for the sky, creatures for the waters and the air, and creatures for the land. Day five fills the seas and the sky with "great whales" (Hebrew *tanninim*, great sea creatures), every living creature that moves in the waters, and "every winged fowl." The Hebrew word for fowl, *oph*, means "flying thing"; Leviticus 11:19 lists the bat among the *oph*, so it is broader than our word "bird." Day six fills the land in three groups (Genesis 1:24): cattle, creeping things and beasts of the earth. Then, last of all, God makes man in His own image.

Where the dinosaurs fit. Scientists define a dinosaur by its skeleton: a reptile whose legs stood straight under its body, with a hip socket open in the middle. Every dinosaur in a museum was a land animal. That puts them in day six, among the "beasts of the earth." The great sea reptiles, plesiosaurs, ichthyosaurs and mosasaurs, are not dinosaurs at all; they belong with the creatures of the waters made on day five, perhaps among the *tanninim*. The pterosaurs were not dinosaurs either; as flying creatures, they belong with the *oph* of day five. So the whole "Age of Reptiles" on a museum wall corresponds, in a straightforward reading of Genesis, to two days of a single week, with Adam made on the same day as T. rex and Triceratops. This is the deepest difference between the museum's story and the Bible's, and every later stop on this trail comes back to it.

"After his kind." The phrase appears ten times in Genesis 1 (count them in the primary source and in verses 11-12 and 21). It tells us that living things were made to reproduce within boundaries. It does not say that no change happens inside a kind. Wolves, coyotes, dingoes and every breed of dog can interbreed, and creation biologists group them in one kind. Lions and tigers can produce "ligers," and horses and zebras "zorses." Because hybrid studies of this kind often join species and genera together but rarely cross the boundary of a family, many creation biologists place the created kind near the level of the scientific family. Applied to dinosaurs, this matters a great deal. Paleontologists have named roughly a thousand dinosaur species (the count changes every year, and some are known from a single bone), but Answers in Genesis estimates only about fifty families. That estimate is an interpretation, and creation biologists still debate where the lines fall.

Green herbs for meat. Genesis 1:29-30 gives plants as food to people and to "every beast of the earth." Many young-earth Christians read this to mean that no animal ate another before the Fall. Then what about T. rex's teeth? Two answers are often given. First, sharp teeth do not prove a meat diet: the giant panda has the skull and teeth of a meat-eater but lives on bamboo, and fruit bats have sharp teeth too. Second, after Adam's sin God cursed the ground (Genesis 3:17-18), and Romans 8:20-22 says the whole creation now "groaneth and travaileth in pain," so animal bodies and behavior may have changed. Other Christians

read verse 30 as a general statement of God's provision and do not think it rules out all predation. The text plainly says the original creation was "very good"; Christians differ on exactly what that included.

Strong and weak arguments. If dinosaurs were made on day six, then people and dinosaurs lived at the same time. Adam named "every beast of the field" (Genesis 2:19-20), and the next stops look at Behemoth, Leviathan and dragon legends. Good students also learn which arguments not to use. From the 1930s on, some claimed that dinosaur and human footprints lay side by side in the Paluxy River in Texas. Creation scientists themselves studied the tracks again, and in 1986 John Morris of the Institute for Creation Research urged Christians to stop using them as evidence. Answers in Genesis lists them among "arguments creationists should not use." Honesty about weak evidence is part of loving the truth.

Other Christian readings. This course teaches the young-earth reading: six ordinary days, a few thousand years ago, with the Flood explaining much of the fossil record. Some Christians read the days as long ages (the day-age view), some as a literary frame that arranges creation by topic (the framework view), and some accept the long ages of mainstream geology while holding firmly that God created. These brothers and sisters love the Bible too, and we do not mock them. But notice the reason many hold the young-earth view: the text says "evening and morning" for each day, and Exodus 20:11 grounds the seven-day week in the six days of creation. Whichever view a Christian holds, every dinosaur was made by God on purpose, and He saw that it was good.

PICTURE STUDY



The Creation of the Animals, Jacopo Tintoretto, c. 1550-1553 · Oil on canvas · Gallerie dell'Accademia, Venice

Wikimedia Commons · Public domain

Tintoretto painted this canvas for the Scuola della Trinità, a Venetian brotherhood, as one of a series of four scenes from Genesis. He shows God sweeping across the scene like a wind, and the creatures pour out ahead of Him in rushing lines. Tintoretto had never heard of a dinosaur; the first dinosaur was named nearly three hundred years later. But he understood Genesis 1 as a story of abundance: the waters, sky and land filling with life at God's word.

Look closely

- Find the three “zones” of the painting: water, sky and land. Which creatures are in each?
- Follow the direction of God's arm and of the lines of birds and fish. Where does the painting lead your eye?
- Look for creatures Tintoretto paired or grouped together. Which ones can you name?

Talk about it

1. Tintoretto shows the creatures of days five and six together in one scene. Is that faithful to Genesis 1? Why might an artist do it?
2. If you were painting day six today, which dinosaurs would you add, and where would you put them so the painting stays true to the text?

HANDS-ON: THE DAY FIVE, DAY SIX CHART

Make a chart that sorts real creatures, living and fossil, into the Hebrew groups of Genesis 1, using the primary source as your authority. Then try your hand at the hardest question in creation biology: where does one kind end and the next begin?

You will need

- A large sheet of paper or two notebook pages side by side
- The primary source in this stop (Genesis 1:24–31) and a Bible open to Genesis 1:20–23
- Pictures or a list of these 20 creatures: T. rex, Triceratops, Stegosaurus, Brachiosaurus, Velociraptor, plesiosaur, ichthyosaur, mosasaur, pterosaur (Quetzalcoatlus), sea turtle, crocodile, frog, bat, eagle, whale, mouse, horse, lion, earthworm, snake
- Colored pencils

Steps

1. Divide the chart into five columns: Day five: creatures of the waters (*tanninim* and “every living creature that moveth”); Day five: flying things (*oph*); Day six: cattle (*behemah*); Day six: creeping things (*remes*); Day six: beasts of the earth (*chayyah*).
2. Place all 20 creatures. For each one, write the phrase from Genesis 1 that justifies your choice.
3. Circle the creatures that are true dinosaurs. Check: are all of them in a day-six column?
4. Star any creature you found hard to place (frogs and crocodiles live both in water and on land). Write one sentence for each explaining your choice and admitting what the text does not settle.

5. **Kind challenge.** Look up the families of the five dinosaurs on your list (Tyrannosauridae, Ceratopsidae, Stegosauridae, Brachiosauridae, Dromaeosauridae). Write one sentence explaining why some creation biologists think each family may be one created kind, and one reason others might disagree.

Check your work

- All 20 creatures are placed, each with a phrase from the text.
- Every true dinosaur is in a day-six column, and the sea and flying reptiles are in day five.
- I can explain the difference between a species and a created kind.

FIELD NOTEBOOK

1. Copy the five Hebrew words *min*, *tanninim*, *oph*, *behemah* and *chayyah* with their meanings, and draw one small creature beside each.
2. Draw a simple timeline of the creation week, days one to seven, and mark where each of these belongs: sea reptiles, pterosaurs, dinosaurs, Adam.
3. **Narration (the parent keeps this).** Write one paragraph answering: On what day were the dinosaurs made, and how do you know? Use at least two phrases quoted from Genesis 1 and explain why the sea reptiles and pterosaurs belong to a different day.

Did you know? Richard Owen coined the word “Dinosauria” in 1842, when only three were known: Megalosaurus, Iguanodon and Hylaeosaurus. Owen was a firm opponent of Darwin’s theory, and he believed the dinosaurs showed the wisdom of a Creator. The Hebrew *tannin*, “great sea creature” in Genesis 1:21, is translated “dragon” in many other places in the KJV, such as Psalm 148:7 and Isaiah 27:1. Stop D6 returns to that word.

Primary source. *Genesis 1:24–31, King James Version (1611).*

24 And God said, Let the earth bring forth the living creature after his kind, cattle, and creeping thing, and beast of the earth after his kind: and it was so.
25 And God made the beast of the earth after his kind, and cattle after their kind, and every thing that creepeth upon the earth after his kind: and God saw that it was good.
26 And God said, Let us make man in our image, after our likeness: and let them have dominion over the fish of the sea, and over the fowl of the air, and over the cattle, and over all the earth, and over every creeping thing that creepeth upon the earth.
27 So God created man in his own image, in the image of God created he him; male and female created he them.
28 And God blessed them, and God said unto them, Be fruitful, and multiply, and replenish the earth, and subdue it: and have dominion over the fish of the sea, and over the fowl of the air, and over every living thing that moveth upon the

earth.

29 And God said, Behold, I have given you every herb bearing seed, which is upon the face of all the earth, and every tree, in the which is the fruit of a tree yielding seed; to you it shall be for meat.

30 And to every beast of the earth, and to every fowl of the air, and to every thing that creepeth upon the earth, wherein there is life, I have given every green herb for meat: and it was so.

31 And God saw every thing that he had made, and, behold, it was very good. And the evening and the morning were the sixth day.

Go deeper. Ken Ham, *The New Answers Book 1* (Master Books, 2006), chapters on dinosaurs and on what a “kind” is. Todd Charles Wood and Megan J. Murray, *Understanding the Pattern of Life* (Broadman & Holman, 2003), an introduction to baraminology for serious students. Answers in Genesis, “Arguments Creationists Should Not Use” (answersingenesis.org), for the Paluxy tracks and other cautions. Second video topic: “What is a created kind? Hybrids and the boundaries of kinds.”

Goes deeper in. Life Science, high-school Biology, the units on classification and on creation and design (coming soon); and Literature, for reading Genesis 1 as carefully crafted Hebrew narrative.

For families. Hebrew terms follow standard lexicons. The ten uses of “after his kind” are in Genesis 1:11, 12 (twice), 21 (twice), 24 (twice) and 25 (three times). Frank Marsh coined “baramin” in *Fundamental Biology* (1941). The figure of about fifty dinosaur families is from Answers in Genesis; other creation biologists give different counts. The Paluxy retraction is John D. Morris, “The Paluxy River Mystery,” *ICR Impact* (1986). This stop teaches the young-earth reading as the course position and names other Christian views briefly and fairly; Genesis 1:30 and predation is a point on which faithful Christians differ, so you may wish to share your own view.

PRACTICE

1. **EASY** On which day were the dinosaurs made, and on which day were the plesiosaurs and pterosaurs made? Give a reason for each.
2. **MEDIUM** Name the three groups of land animals in Genesis 1:24 and give the Hebrew word and one example for each.
3. **MEDIUM** Why do many creation biologists think a created kind is often near the level of the family, not the species?
4. **CHALLENGE** **Primary source.** Count how many times “after his kind” or “after their kind” appears in Genesis 1:24–25. Then explain what the repetition tells a careful reader about how God made the animals, and what it does *not* tell us.
5. **CHALLENGE** Paleontologists have named roughly 1,000 dinosaur species. If Answers in Genesis is right that these fall into about 50 families, and each family is one kind, how many species does the average kind contain? Name two reasons the real numbers might differ.

6. **MEDIUM** Why did creation scientists themselves ask Christians to stop using the Paluxy River “man tracks” as evidence? What does this teach about how to argue?

Make it a game · Kind Keepers. One player names a creature (living or fossil). The first player to call out the correct day *and* the correct Genesis group (waters, flying things, cattle, creeping thing or beast of the earth) scores a point; a bonus point goes to anyone who can add the Hebrew word. Hard cases (frog, crocodile, penguin, bat, sea turtle) are worth two points if the player can defend the answer from the text in one sentence.

Scripture. “And God saw every thing that he had made, and, behold, it was very good. And the evening and the morning were the sixth day.” (Genesis 1:31, KJV)

The same day that saw the dinosaurs made also saw Adam made. God looked at all of it together and called it “very good.” Every creature in a museum hall began as part of that good work.

Practice: answers

1. Dinosaurs: day six, because all dinosaurs were land animals, “beasts of the earth.” Plesiosaurs: day five, with the creatures of the waters. Pterosaurs: day five, with the flying things (*oph*).
2. Cattle (*behemah*), such as a horse or ox; creeping things (*remes*), such as a mouse or lizard; beasts of the earth (*chayyah*), wild animals such as a lion or a T. rex.
3. Because animals of different species and even different genera within one family can often interbreed (wolves and dogs; lions and tigers; horses and zebras), while crosses between families are rarely if ever known. Ability to hybridize suggests descent from one original kind.
4. Five times (twice in verse 24 and three times in verse 25). The repetition stresses order and boundaries: animals were made as distinct kinds that reproduce true to their kind. It does not tell us how much variation can happen within a kind, nor exactly where the boundary between kinds falls; those questions need careful study.
5. $1,000 \div 50 = 20$ species per kind on average. The numbers might differ because (1) many named species are based on scraps or juveniles and may be the same animal under different names, so the species count may be too high; and (2) some families may contain more than one kind, or some kinds may span more than one family, so the kind count is uncertain.
6. On closer study the supposed human prints did not hold up (many were eroded or partly filled dinosaur tracks), so in 1986 John Morris of ICR urged Christians to stop using them. It teaches that Christians should use only honest, well-tested evidence, and admit weak arguments, because truth matters more than winning.

4.2 BEHEMOTH (JOB 40)

OBJECTIVES

- Place the Behemoth passage in the argument of God’s speeches in Job 38–41 and say why God describes it to Job.
- List the clues of Job 40:15–24 and test them, clue by clue, against the hippopotamus, the elephant and a sauropod dinosaur.
- Write a reasoned conclusion that separates what the text says from what interpreters infer, and state how confident the evidence allows you to be.

Warm-up. Read Job 40:15–24 (the primary source in this stop) aloud once, slowly. Without looking anything up, draw the creature you picture, using only what the verses say. Label each part of your drawing with the verse number that gave it to you. Keep the drawing; you will compare it with three real animals.

Video slot. Video coming. Behemoth in Job 40: hippopotamus, elephant or sauropod? Hippos in rivers and reeds; sauropod tails and skeletons. Search approved channels (for creation-friendly framing, Answers in Genesis, the Institute for Creation Research or Creation Ministries International once vetted; for animals, National Geographic or the Natural History Museum London); preview first.

KEY TERMS

Behemoth

The great land creature of Job 40:15–24. The Hebrew is the plural of *behemah* (“beast”), probably an intensive plural meaning “the great beast” or “beast of beasts,” since the verbs about it are singular.

intensive plural

A Hebrew way of showing greatness by putting a noun in the plural while treating it as one thing, as in *Elohim* for God.

sauropod

A long-necked, long-tailed plant-eating dinosaur, such as Apatosaurus, Diplodocus or Brachiosaurus.

Hebrew poetry

Poetry built on parallelism (saying a thing twice in different words) and vivid images. Job 3–41 is poetry, so its pictures can be bold without being false.

hyperbole

Deliberate overstatement for effect, such as “he drinketh up a river.” It is a way of speaking truly about something very great.

theodicy

The question of how a good and all-powerful God can allow suffering. The book of Job answers it not with a theory but with God Himself.

CORE IDEAS

Why God talks about animals. Job has lost his children, his wealth and his health, and for thirty-five chapters he and his friends have argued about why. Then the LORD answers “out of the whirlwind” (Job 38:1). He does not explain Job’s suffering. Instead He asks question after question about the stars, the sea, the weather and the animals: the lion, the raven, the wild goat, the ostrich, the war horse, the hawk. Job answers that he will lay his hand on his mouth (40:4). Then God speaks a second time, and the climax of the whole speech is two creatures, Behemoth on land and Leviathan in the water. The point is plain: if Job cannot master these creatures, he cannot sit in judgment on their Maker.

What the word means. *Behemoth* is the plural of the ordinary Hebrew word *behemah*, “beast” or “cattle,” the same word used in Genesis 1:24. Yet every verb about it is singular: “he eateth,” “he lieth.” Most scholars therefore read it as an intensive plural, “the beast of beasts.” God also says something striking: “which I made with thee” (40:15). Behemoth was made as Job was made, by the same hand, and a young-earth reader notes that land animals and man were made on the same day. God tells Job to “behold” it, as if it were a real animal Job could go and look at, like the lion and the ostrich in chapter 39.

The clues. The passage gives about a dozen: it eats grass like an ox; its strength is in its loins and its belly muscles; it “moveth his tail like a cedar”; its bones are like tubes of bronze and bars of iron; it is “the chief of the ways of God” (Hebrew *reshit*, first or foremost); it feeds where the mountains bring forth food; it lies under shady trees and in reeds and marsh; a flooding river does not alarm it, though it be the Jordan; and no one can catch it with snares. Some clues are physical, some are about habitat and some are about rank.

Three candidates. Most modern commentaries say the **hippopotamus**. Hippos eat grass, lie in reeds and rivers, are enormously strong (large males weigh 1,500 to more than 3,000 kg) and are dangerous to hunt. Bones from Tel Qasile on the Yarkon River show hippos still lived in the coastal rivers of Israel in the 10th century BC. But a hippo’s tail is a short stub, about 35 to 50 cm long, nothing like a cedar. The translators of the 1611 King James Bible put a note in the margin: “or, the Elephant, as some think.” An elephant is the largest land animal living and eats plants, but its tail is thin and ropelike; some suggest “tail” means the trunk, though the Hebrew word normally means tail. Many young-earth writers propose a **sauropod**. A Diplodocus tail had about 80 vertebrae and stretched more than 13 m; a tail “like a cedar” fits it well, as does “chief of the ways of God” for the largest land animals ever made, and sauropod trackways show they walked near water.

Weighing the evidence honestly. Each view has a weak point. The hippo fails the tail clue unless “moveth his tail” is read in an unusual way. The elephant fails it unless “tail” means trunk. The sauropod fits the tail and the rank, but it raises a question: God names the Jordan as though Behemoth lived in Job’s part of the world, and no sauropod bones have been found in rock layers that creation geologists place after the Flood. A young-earth reader can

answer that fossils of animals that lived after the Flood are rare in general, and that Job is very old, perhaps from the time of the patriarchs. Some other scholars treat Behemoth as a symbolic chaos-monster drawn from the myths of the ancient Near East; but God says He made it, and the speech puts it beside real animals.

Reading poetry well. Job is Hebrew poetry, so “he drinketh up a river” is hyperbole, not a measurement. That does not make the creature imaginary; a psalmist can say mountains “skipped like rams” about a real event. Good readers neither flatten the poetry into a lab report nor dissolve it into myth. They ask what each image would have meant to Job.

The point God makes. Whatever Behemoth was, God draws the lesson in verse 19: “he that made him can make his sword to approach unto him.” Only the Maker can master this creature. Job ends by saying, “I abhor myself, and repent in dust and ashes” (42:6), and God restores him. The Behemoth passage is not a riddle for scholars first. It is a lesson in humility, given to a suffering man by the God who made both him and the beast of beasts.

PICTURE STUDY



Behemoth and Leviathan, Plate 15 of Illustrations of the Book of Job, William Blake, 1825 (published 1826) · Line engraving · Many impressions survive in museum collections, among them the Tate, London
Wikimedia Commons · CC0

William Blake (1757–1827) was an English poet, painter and engraver. Late in life he engraved twenty-one plates on the book of Job, cutting the pictures and the words of Scripture around their borders into copper himself. In this plate God shows Job and his friends the two great creatures. Blake’s Behemoth looks like a cross between a hippo and an elephant, with tusks. Notice how he puts the creatures in a circle below, like a world Job can look into but cannot enter.

Look closely

- Look at Blake’s Behemoth. Which features come from a hippo, which from an elephant and which from neither?
- Find God and find Job. Where is each placed, and what are their hands doing?
- Read any lettering you can make out in the border. Why would Blake engrave Scripture around the picture?

Talk about it

1. Compare Blake’s Behemoth with your warm-up drawing. Which clues from Job 40 did Blake follow and which did he leave out?
2. Blake drew in 1825, before the word “dinosaur” existed (1842). How might his picture have looked if he had seen a sauropod skeleton?

HANDS-ON: THE BEHEMOTH BRIEF

Lawyers write a “brief” that lays out the evidence for a position and answers the other side. Write a one-page brief on the identity of Behemoth, scored clue by clue from the primary source.

You will need

- The primary source in this stop (Job 40:15–24)
- A ruler and pencil, and a sheet of graph or lined paper
- Pictures or measurements of a hippopotamus, an African elephant and a sauropod (a museum page or library book)
- Your warm-up drawing

Steps

1. Make a table with one row for each verse from 15 to 24 and three columns: hippopotamus, elephant, sauropod.
2. In each box write +1 (fits well), 0 (neutral or unclear) or –1 (does not fit), with a three- to six-word reason. Treat hyperbole fairly: do not score “drinketh up a river” as a literal measurement.
3. Add up each column. Then circle the one clue you think should count most, and explain why in a sentence.
4. Write your brief in three paragraphs: (1) your conclusion and your level of confidence (sure, likely or possible); (2) your two strongest clues; (3) the strongest objection to your view and your honest answer to it.
5. Finish with one sentence on what God wanted Job to learn from Behemoth, which does not depend on the identification.

Check your work

- Every verse from 15 to 24 is scored for all three animals with a reason.
- My brief states a confidence level and answers the strongest objection.
- I quoted at least two phrases exactly from the KJV.

FIELD NOTEBOOK

1. Draw the three candidates side by side at the same scale (a man 1.8 m tall for comparison): a hippo about 4 m long, an African elephant about 3.5 m at the shoulder, a sauropod about 25 m long. Draw each tail carefully.
2. List the dozen clues of Job 40:15–24 in your own words, marking each P (physical), H (habitat) or R (rank).
3. **Narration (the parent keeps this).** Write one paragraph explaining why God described Behemoth to Job and what Job learned, then add your best identification of the creature with your reason.

Did you know? The word “behemoth” has entered English as a word for anything huge (“a behemoth of a truck”). Jewish writings from after the Old Testament, such as 2 Esdras and 1 Enoch, imagined Behemoth and Leviathan as two monsters set apart at creation, one for the land and one for the sea; these legends are not Scripture, but they show how early readers saw the pair as the greatest of creatures. Diplodocus is among the longest-tailed animals known, with some vertebrae near the tip so small they look like a whip.

Primary source. *Job 40:15–24, King James Version (1611).*

15 Behold now behemoth, which I made with thee; he eateth grass as an ox.
16 Lo now, his strength is in his loins, and his force is in the navel of his belly.
17 He moveth his tail like a cedar: the sinews of his stones are wrapped together.
18 His bones are as strong pieces of brass; his bones are like bars of iron.
19 He is the chief of the ways of God: he that made him can make his sword to approach unto him.
20 Surely the mountains bring him forth food, where all the beasts of the field play.
21 He lieth under the shady trees, in the covert of the reed, and fens.
22 The shady trees cover him with their shadow; the willows of the brook compass him about.
23 Behold, he drinketh up a river, and hasteth not: he trusteth that he can draw up Jordan into his mouth.
24 He taketh it with his eyes: his nose pierceth through snares.

Go deeper. Answers in Genesis, “Could Behemoth Have Been a Dinosaur?” (answersingenesis.org), for the sauropod view. A standard commentary on Job, such as Francis I. Andersen, *Job* (Tyndale Old Testament Commentaries, 1976), for the hippopotamus view and the structure of God’s speeches. William Blake’s Job engravings and the watercolors he made for them, viewable online in several museum collections (search “Blake Book of Job”). Second video topic: “Hippopotamus behavior in rivers and reeds.”

Goes deeper in. Literature, the high-school unit on Hebrew poetry and the book of Job (coming soon); and Life Science, the units on large mammals and reptiles.

For families. The 1611 KJV margin at Job 40:15 reads “or, the Elephant, as some think.” Hippo bones from Iron Age Tel Qasile (10th century BC) are reported by Israeli archaeozoologists. Hippo tail length and mass are typical figures from zoological references; the Diplodocus tail figure is approximate and varies by specimen. Verse 17 uses an old English word, “stones,” for the animal’s thighs or lower body; modern translations differ. The stop presents the hippo, elephant and sauropod views fairly and leaves the student to weigh them, while affirming that Behemoth was a real creature God made.

PRACTICE

1. **EASY** Where does the Behemoth passage come in the book of Job, and who is speaking?
2. **MEDIUM** “Behemoth” is a plural word, but the verbs are singular. What does that suggest?
3. **MEDIUM** Name one clue that fits the hippopotamus well and one that fits it poorly.
4. **CHALLENGE** **Primary source.** Verse 19 calls Behemoth “the chief of the ways of God.” Explain how each of the three views (hippo, elephant, sauropod) would interpret this phrase, and which view it fits best. Then quote the second half of the verse and explain why it matters more than the identification.
5. **CHALLENGE** A hippo’s tail is about 0.45 m long and a Diplodocus tail about 13 m. How many times longer is the Diplodocus tail? A cedar of Lebanon can grow 30 m tall with a trunk 2 m or more across. Which tail is closer to “like a cedar,” and what is one fair objection to pressing this clue too hard?
6. **MEDIUM** Some scholars say Behemoth is a mythical chaos-monster. Give two reasons from the text for reading it as a real creature.

Make it a game • Twenty Clues. One player secretly chooses a large animal, living or fossil. The others ask yes-or-no questions modeled on Job 40 (“Does it eat grass like an ox?” “Is its tail like a cedar?” “Does it lie in the reeds?”). Keep a tally: the group wins if it names the animal in twenty questions or fewer. Afterward, discuss which questions were most useful and why habitat clues are weaker than skeleton clues.

Scripture. “He is the chief of the ways of God: he that made him can make his sword to approach unto him.” (Job 40:19, KJV)

The greatest beast is still a creature. God shows Job a creature he cannot tame to show him a God he cannot judge, and then, in chapter 42, restores him. Strength belongs to the Maker before it belongs to anything He made.

Practice: answers

1. In Job 40, in the LORD’s second speech “out of the whirlwind,” near the end of the book. God Himself is speaking to Job.
2. That it is an intensive plural, meaning one creature of great size or rank: “the beast of beasts,” not a herd of animals.

3. Fits well: any of eating grass, lying in reeds and marsh, unafraid of a flooding river, great strength. Fits poorly: “he moveth his tail like a cedar,” since a hippo’s tail is a short stub.
4. Hippo view: the most dangerous or impressive animal Job knew. Elephant view: the largest land animal living. Sauropod view: the largest land animal ever created, the “first” or foremost in size. The phrase fits the sauropod most naturally if *reshit* means foremost in size, though all three can be read with it. The second half, “he that made him can make his sword to approach unto him,” teaches that only the Creator can master such a creature, so Job should trust God rather than judge Him.
5. $13 \div 0.45 \approx 29$ times longer. The Diplodocus tail is far closer to a cedar. A fair objection: the comparison may be about stiffness or strength rather than length (“he moveth his tail like a cedar” could mean he stiffens it like a cedar), and this is poetry, so a single image should not carry the whole identification.
6. Any two: God says “which I made with thee,” so it is a created animal; God tells Job to “behold” it as something he could see; it is described alongside real animals in chapters 38–39; its food, habitat and behavior (grass, reeds, willows, the Jordan) are ordinary and natural.

4.3 LEVIATHAN (JOB 41)

OBJECTIVES

- Find the five places Leviathan is named in the Old Testament and tell where it is described as a real creature and where it is used as a symbol.
- Test the clues of Job 41 against the crocodile, the whale and a marine reptile, including an honest look at the “fire” verses.
- Explain how the prophets used Leviathan imagery that their pagan neighbors also knew, and why that does not make the Bible a book of myths.

Warm-up. Look up Job 41:1 and read only the first question: “Canst thou draw out leviathan with an hook?” Then write a list of every way people today catch or control big animals: hooks, nets, harpoons, tranquilizer darts, cages. Next to each, guess whether it would work on the creature God describes. Read the rest of the chapter to check your guesses.

Video slot. Video coming. Leviathan in Job 41: crocodile, whale or sea reptile? Nile crocodile armor and behavior; the bombardier beetle’s chemical spray. Search approved channels (for creation-friendly framing, Answers in Genesis, the Institute for Creation Research or Creation Ministries International once vetted; for animals, National Geographic or the Smithsonian); preview first.

KEY TERMS

Leviathan

A great creature of the waters named in Job 3:8 (KJV margin), Job 41, Psalm 74:14, Psalm 104:26 and Isaiah 27:1. The Hebrew *livyatan* probably comes from a root meaning “to twist” or “coil.”

neesing

An old English word for sneezing (Job 41:18).

Ugarit

An ancient city on the coast of Syria (modern Ras Shamra), whose clay tablets, found from 1929 on, contain poems about a sea serpent called Lotan.

polemic

Writing that argues against another view. Some Bible passages use the imagery of pagan myths to declare that the LORD, not the pagan gods, rules the sea and its monsters.

bombardier beetle

A beetle that mixes two chemicals in a chamber in its body and sprays a hot, irritating jet, close to boiling, at attackers.

symbol

A real thing used to stand for something else, as a lion stands for strength or a serpent for the devil.

CORE IDEAS

Five appearances. Leviathan is named five times in the Old Testament. In Job 3:8 the KJV text reads “their mourning,” but its margin gives “leviathan,” which is the Hebrew word. In Job 41 God describes Leviathan in thirty-four verses, the longest description of any creature in the Bible. Psalm 104:26 says God made Leviathan “to play” in the sea where the ships go. Psalm 74:13–14 speaks of God breaking “the heads of leviathan” when He divided the sea. Isaiah 27:1 says the LORD will punish “leviathan the piercing serpent, even leviathan that crooked serpent; and he shall slay the dragon that is in the sea.” Notice that the first two passages describe a creature God made; the last two use Leviathan as a picture of God’s enemies.

The clues of Job 41. No hook, cord, barbed iron or fish spear can take it. Its scales are its pride, so tightly joined that no air comes between them. “His teeth are terrible round about.” Its sneezes flash with light; its eyes are “like the eyelids of the morning.” “Out of his mouth go burning lamps, and sparks of fire leap out,” smoke pours from its nostrils, and “a flame goeth out of his mouth.” Its neck is strong, its heart as hard as a millstone. Sword, spear, dart and armor fail against it; iron is straw to it. It makes “the deep to boil like a pot” and leaves a shining wake. “Upon earth there is not his like,” and it is “a king over all the children of pride.”

Three candidates. Most modern commentators say the **Nile crocodile**: interlocking armored scales, terrible teeth, eyes that rise from the water first like a sunrise, and a reputation in the ancient world as a beast spears could not stop. One weakness is that the Egyptians did in fact hunt crocodiles. Some older readers suggested a **whale**, since Psalm 104 puts Leviathan in the open sea with the ships; but whales have no scales and no terrible teeth all round. Many young-earth writers propose a great **marine reptile**, such as a pliosaur or mosasaur, armored, huge and at home in “the deep.” This fits the size and the sea, but no one can check the scales of a pliosaur, and it raises the same question as Behemoth: did such creatures survive the Flood into Job’s day?

The fire. No living animal breathes fire, so readers divide here. Some take verses 18–21 as poetic hyperbole: breath steaming in cool air, spray glittering in the sun, eyes flashing. Others point out that God made creatures with remarkable chemistry. The bombardier beetle mixes hydroquinone and hydrogen peroxide with enzymes in a hardened chamber and fires a jet near 100 °C; fireflies and many deep-sea animals make their own light. A creature with some such defense is not impossible. The honest answer is that we do not know, and that the passage is poetry, so we should hold any explanation loosely.

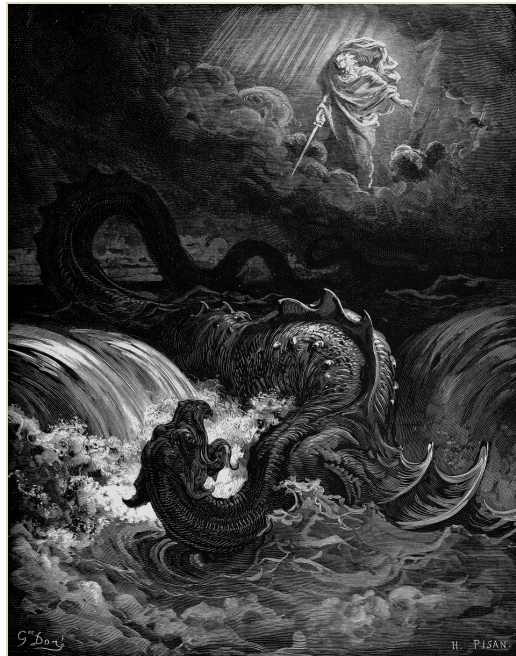
Leviathan and the neighbors’ myths. When the tablets from Ugarit were read, scholars found a poem about the storm-god Baal striking “Lotan, the fleeing serpent,” “the twisting serpent,” “the mighty one with seven heads.” The wording is strikingly like Isaiah 27:1. Some conclude that the Bible borrowed a myth. A better reading is that Isaiah and the

psalmist took a monster their neighbors feared, and even half-worshiped, and declared that the LORD made it, rules it and will slay it. Scripture uses real things as symbols all the time: a lion is a real animal (Judges 14) and also a picture of the devil (1 Peter 5:8). In the same way, Leviathan is a real creature in Job 41 and Psalm 104, and a symbol of chaos, of Egypt and finally of the serpent Satan in Psalm 74 and Isaiah 27.

Why God tells Job. The heart of the chapter is verses 10–11: “None is so fierce that dare stir him up: who then is able to stand before me? ... whatsoever is under the whole heaven is mine.” If Job dare not rouse Leviathan, how can he stand against Leviathan’s Maker? The last verse calls Leviathan king over the proud. Job, who had demanded a hearing, now sees his own pride, and repents.

Wonder, not terror. Psalm 104 adds a lighter note. The creature that terrifies sailors is, to God, something He made “to play.” The God of Job 41 is not anxious about His creation. He delights in it, and invites us to delight in it too.

PICTURE STUDY



The Destruction of Leviathan, Gustave Doré, 1865 · Wood engraving, for the illustrated French Bible (La Sainte Bible, Tours, 1866) · Published in Doré’s Bible; many prints in libraries and museums
Wikimedia Commons · Public domain

Gustave Doré (1832–1883) made more than two hundred engravings for a great French Bible published in 1866, and they became the most reproduced Bible pictures of the century. This one illustrates Isaiah 27:1, not Job 41. Doré shows Leviathan as a sea serpent and gives God’s victory to an angel. Compare it with Job 41: Doré chose the symbolic Leviathan of the prophets.

Look closely

- Trace the coils of the serpent. How does Doré make it look enormous?
- Where does the light come from in this picture, and what does it fall on?
- Look at the sea and the sky. How do they add to the struggle?

Talk about it

1. Doré's Leviathan has no legs and no armored scales. Which verses of Isaiah 27:1 support his picture, and which verses of Job 41 would call for a different one?
2. Why might an artist show an angel rather than God Himself slaying Leviathan?

HANDS-ON: CREATURE OR SYMBOL? TWO LEVIATHANS

Compare the Leviathan of Job and Psalm 104 with the Leviathan of Isaiah and Psalm 74, then test the "fire" verses scientifically by studying a real chemical defense.

You will need

- The primary source in this stop and a Bible open to Psalm 74:12-17, Psalm 104:24-26 and Isaiah 27:1
- Two sheets of paper
- A library book or museum web page on the bombardier beetle or on bioluminescent sea animals

Steps

1. On the first sheet make two columns: "Leviathan as a creature" and "Leviathan as a symbol." Copy at least three phrases into each, with references.
2. Under the columns, write two sentences: What signals in each passage tell you whether it is describing an animal or using a picture? (Look for the setting: creation and animals, or judgment and enemies.)
3. On the second sheet, write a short "field report" on the bombardier beetle: what two chemicals it mixes, where, how hot the spray is and what it is for. Draw the beetle and its chamber.
4. Below the report, write a paragraph: Does the beetle show that Job 41:19-21 could describe a real creature? Give the strongest point for and against, and end with what you think, held with fitting humility.

Check your work

- Both columns have at least three exact phrases with references.
- My beetle report names the chemicals and the temperature.
- My final paragraph gives a point on each side and does not claim more than the evidence shows.

FIELD NOTEBOOK

1. Draw Leviathan three ways in small panels: as a crocodile, as a whale and as a pliosaur. Under each, write the two Job 41 clues it fits best.
2. Copy Job 41:33–34 and underline the phrase that connects Leviathan with pride.
3. **Narration (the parent keeps this).** Write one paragraph explaining how Leviathan can be a real creature in Job 41 and a symbol in Isaiah 27:1 without the Bible contradicting itself.

Did you know? In 1651 the English philosopher Thomas Hobbes named his book on government *Leviathan*, picturing the state as a giant made of its citizens; its famous title page quotes Job 41 in Latin: there is no power on earth to be compared with him. An ancient Egyptian handbook on hieroglyphs, attributed to a writer called Horapollo, says that crocodile eyes stood for the sunrise, which some readers connect with “the eyelids of the morning.” The largest Nile crocodiles reach about 5 to 6 m in length.

Primary source. *Job 41:1-2, 12-21 and 31-34, King James Version (1611).*

1 Canst thou draw out leviathan with an hook? or his tongue with a cord which thou lettest down?

2 Canst thou put an hook into his nose? or bore his jaw through with a thorn?

...

12 I will not conceal his parts, nor his power, nor his comely proportion.

13 Who can discover the face of his garment? or who can come to him with his double bridle?

14 Who can open the doors of his face? his teeth are terrible round about.

15 His scales are his pride, shut up together as with a close seal.

16 One is so near to another, that no air can come between them.

17 They are joined one to another, they stick together, that they cannot be sundered.

18 By his neesings a light doth shine, and his eyes are like the eyelids of the morning.

19 Out of his mouth go burning lamps, and sparks of fire leap out.

20 Out of his nostrils goeth smoke, as out of a seething pot or caldron.

21 His breath kindleth coals, and a flame goeth out of his mouth.

...

31 He maketh the deep to boil like a pot: he maketh the sea like a pot of ointment.

32 He maketh a path to shine after him; one would think the deep to be hoary.

33 Upon earth there is not his like, who is made without fear.

34 He beholdeth all high things: he is a king over all the children of pride.

Go deeper. Answers in Genesis and Creation Ministries International articles on Leviathan and the bombardier beetle (answersingenesis.org, creation.com). John Day, *God's Conflict with the Dragon and the Sea* (Cambridge University Press, 1985), a

scholarly study of the Ugaritic parallels, for advanced readers. The Smithsonian National Zoo pages on crocodilians. Second video topic: “How the bombardier beetle’s spray works.”

Goes deeper in. Literature, the high-school unit on Hebrew poetry and the book of Job (coming soon); Life Science, reptiles and insects; and History, the ancient Near East and the discovery of Ugarit.

For families. Job 3:8 margin: the KJV margin gives “leviathan” for “their mourning.” The Ugaritic Lotan lines are from the Baal Cycle (KTU 1.5 i 1-3), in standard scholarly translation; the stop paraphrases rather than quoting a modern copyrighted translation. Bombardier beetle chemistry follows published studies (spray near 100 °C). The Horapollon note is offered as a curiosity; the text’s date and reliability are debated. The stop presents crocodile, whale and marine-reptile views fairly and treats the fire verses with humility. Isaiah 27:1 is read in the Christian tradition as pointing to the final defeat of Satan, “that old serpent” (Revelation 12:9; 20:2).

PRACTICE

1. **EASY** Name the five Old Testament passages that mention Leviathan.
2. **MEDIUM** Which two passages describe Leviathan as a real creature God made, and which two use it as a symbol of God’s enemies?
3. **MEDIUM** Give two clues from Job 41 that fit a crocodile and one that fits it poorly.
4. **CHALLENGE** **Primary source.** Verse 34 calls Leviathan “a king over all the children of pride.” Using the setting of the whole book, explain why God ends His speech with this line, and what Job does next.
5. **CHALLENGE** The Ugaritic poem calls Lotan “the twisting serpent” with “seven heads,” and Isaiah 27:1 calls Leviathan “that crooked serpent.” Give the borrowing explanation and the polemic explanation, and give one reason from Scripture that supports the polemic reading.
6. **MEDIUM** What does the bombardier beetle show, and what does it not show, about Job 41:19-21?

Make it a game • Canst Thou?. Take turns reading one “Canst thou...?” question from Job 41:1-7. The next player must answer in character as a hunter (“No, LORD, for...”) using a real fact about crocodiles, whales or sea reptiles, without repeating a fact already used. A player who cannot answer in ten seconds is out. The last hunter standing reads Job 41:10-11 aloud for everyone.

Scripture. “There go the ships: there is that leviathan, whom thou hast made to play therein.” (Psalm 104:26, KJV)

The creature no hook can take is, to its Maker, something He made to play. The God who rules Leviathan is not threatened by anything in His world, and He invites His people to look at it with wonder.

Practice: answers

1. Job 3:8 (in the Hebrew and the KJV margin), Job 41, Psalm 74:14, Psalm 104:26 and Isaiah 27:1.
2. Creature: Job 41 and Psalm 104:26. Symbol: Psalm 74:14 (God breaking its heads at the Red Sea, picturing Egypt) and Isaiah 27:1 (God slaying the serpent and dragon in the end).
3. Fit: any two of tight armored scales (verses 15–17), terrible teeth (14), eyes like the eyelids of the morning (18), weapons failing against it (26–29). Fits poorly: the burning lamps, smoke and flame (19–21); also, Egyptians did hunt crocodiles, so “canst thou draw out leviathan” is less absolute for a crocodile.
4. Job had demanded that God explain Himself, which was a kind of pride. God shows him a creature that rules over the proud and that Job cannot even approach; if Leviathan humbles the proud, how much more does its Maker? Job responds by confessing that he spoke of things too wonderful for him, and he repents (Job 42:1–6), after which God restores him.
5. Borrowing: Israel took over a Canaanite myth. Polemic: the prophets used imagery their neighbors knew in order to declare that the LORD, not Baal, rules the sea and will destroy what the pagans feared. Support: in Psalm 104:26 and Job 41 God says He made Leviathan, so it is His creature, not a rival god; and in Psalm 74 the imagery is tied to a real historical event, God dividing the sea at the Exodus.
6. It shows that God made at least one creature that produces a hot chemical spray, so a fire-like defense in a larger creature is not impossible. It does not show that Leviathan actually had such a defense, and it does not rule out reading the verses as poetic hyperbole.

4.4 DINOSAURS ON THE ARK?

OBJECTIVES

- Show from Genesis 6–7 which animals Noah was told to bring aboard and why that would include dinosaurs if they were alive at the time of the Flood.
- Calculate the Ark’s size from its dimensions in cubits and compare estimates of how many animals it carried.
- Explain the main objections (size, food, care) and the answers creation researchers give, and say which parts of those answers are Scripture and which are reasoned guesses.

Warm-up. Measure the length of your forearm from elbow to fingertip in inches or centimeters. That is your “cubit,” the measure Noah used. Now step off 300 of your cubits along a road or field (or multiply on paper). Write the answer in feet and in meters, and keep it for the project.

Video slot. Video coming. Noah’s Ark dimensions, stability and animal care; the Ark Encounter life-size ark in Kentucky. Search approved channels (for creation-friendly framing, Answers in Genesis and the Ark Encounter, the Institute for Creation Research or Creation Ministries International once vetted); preview first.

KEY TERMS

cubit

An ancient measure based on the forearm, from elbow to fingertip. The common cubit was about 18 in (45.7 cm); the Egyptian royal cubit was about 20.6 in (52.4 cm).

gopher wood

The wood God told Noah to use (Genesis 6:14). No one knows for sure what tree it was; the Hebrew word appears only here.

created kind

The original group of animals God made to reproduce “after his kind” (Genesis 1). Genesis 6:20 uses the same word for the animals that came to the Ark.

displacement

The weight of water a floating ship pushes aside, which equals the ship’s own weight with its cargo.

global Flood

The view that the Flood covered the whole earth (Genesis 7:19–23). Some Christians hold a regional-flood view instead.

juvenile

A young animal that is not yet full grown. Many creation researchers suggest God brought young adults, small but able to breed.

CORE IDEAS

What the text requires. God told Noah to bring “of every living thing of all flesh, two of every sort” (Genesis 6:19), and listed fowls, cattle and “every creeping thing of the earth after his kind” (6:20). Clean animals and birds came by sevens (7:2–3). The Flood killed “all in whose nostrils was the breath of life, of all that was in the dry land” (7:22). Fish, whales and sea reptiles were not taken aboard; air-breathing land animals were. Since every dinosaur was a land animal, a young-earth reading that places the dinosaurs alive at the time of Noah requires representatives of every dinosaur kind on the Ark. The text adds a detail that is easy to miss: the animals “shall come unto thee” (6:20). Noah did not have to hunt them down.

How big was the Ark? Three hundred cubits long, fifty wide and thirty high, with three decks (6:15–16). Using the common cubit of 18 inches, that is 450 × 75 × 45 feet (137 × 23 × 14 m), with a volume of about 1.5 million cubic feet (43,000 m³) and three decks with roughly 100,000 square feet of floor. The Ark Encounter in Williamstown, Kentucky, opened in 2016, used a longer cubit of 20.4 inches and built its ark 510 feet long. Its proportions matter too. In 1993 a team of Korean naval engineers led by S. W. Hong tested a model of the Ark’s shape and reported that its 6:1 length-to-width ratio was very stable in heavy seas, close to the proportions of modern cargo ships. In their 1961 book *The Genesis Flood*, John Whitcomb and Henry Morris compared the Ark’s volume to about 520 railroad stock cars.

How many animals? Not every species came, but every kind. John Woodmorappe’s 1996 study, *Noah’s Ark: A Feasibility Study*, assumed the kind was about equal to the genus and estimated some 16,000 animals. Researchers at Answers in Genesis, working since 2012 at the family level, estimate fewer than 1,400 kinds of land animals and at most about 6,700 animals. For dinosaurs, about fifty families would mean about a hundred dinosaurs, a tiny fraction of the passengers. These numbers are estimates built on the young-earth model, and the researchers say so.

The size problem. Didn’t a Brachiosaurus fill a deck by itself? Three facts help. First, most dinosaurs were not giants; many were the size of a dog, a sheep or a pony. Second, even the largest dinosaurs hatched from eggs no bigger than a cantaloupe or a football, and growth-line studies suggest the giant sauropods took many years to reach full size. Third, Genesis does not say the animals were adults. Woodmorappe and others suggest that God brought young adults, small enough to house and feed but old enough to breed after the Flood. That last point is a reasoned suggestion, not a statement of Scripture.

Food, water and work. Noah’s family numbered eight people, and they were aboard for about a year (Genesis 7:11 to 8:14). Woodmorappe worked through feeding, watering, ventilation and waste with tools a pre-industrial people could build: gravity-fed water troughs, sloped floors, dried and compressed fodder. Some have suggested that many animals slept more than usual, as some living animals do in hard conditions; this is speculation. The Bible does not tell us how Noah managed. It tells us that God commanded, God shut the door (7:16) and God “remembered Noah, and every living thing” (8:1).

Other Christian views. Some Christians, such as those at Reasons to Believe, hold that the Flood covered only the region where people lived, so the Ark carried only local animals and the dinosaurs were long gone. Young-earth Christians answer from the text: “all the high hills, that were under the whole heaven, were covered” (7:19); Peter says “the world that then was, being overflowed with water, perished” (2 Peter 3:6); and God promised never again to send such a flood (Genesis 9:11), a promise broken by every local flood if Noah’s was only local. Both sides affirm that the Flood truly happened.

Out of the Ark. When the waters went down, God said, “Bring forth with thee every living thing that is with thee ... that they may breed abundantly in the earth” (8:17). On the young-earth reading, the dinosaurs walked down the ramp with the rest. Why, then, are they gone? That question belongs to Stop D7.

PICTURE STUDY



Noah's Ark, Edward Hicks, 1846 · Oil on canvas · Philadelphia Museum of Art
Wikimedia Commons · CC0

Edward Hicks (1780–1849) was a Pennsylvania Quaker minister who supported his family by painting signs and coaches. He is best known for his many versions of *The Peaceable Kingdom*, based on Isaiah 11. In *Noah's Ark* he based the animals on popular prints of his day and painted them walking in calm pairs as storm clouds gather. Hicks never painted a dinosaur; only a handful had been named when he died.

Look closely

- Count the pairs of animals you can see. Which animals are near the front of the line and which are already at the ramp?
- Look at the sky. How does Hicks show that the Flood is coming?

- Look at the Ark. Is it shaped like a ship or like a box? How does it compare with Genesis 6:15–16?

Talk about it

1. Hicks shows the animals coming calmly in order. Which words in Genesis 6:20 support that picture?
2. If you added dinosaurs to this painting to match the young-earth reading, which ones would you add, how big would you paint them and why?

HANDS-ON: ARK ENGINEERS' REPORT

Work through the numbers like an engineer, using the primary source for the dimensions. Show your work.

You will need

- The primary source in this stop (Genesis 6:14–22)
- A calculator, paper and pencil
- Your warm-up cubit measurement
- Optional: a tape measure and chalk or stakes to mark out the Ark's width (75 ft) in a field or parking lot

Steps

1. Calculate the Ark's length, width and height in feet three times: with your own cubit, with the 18-inch common cubit and with the 20.6-inch royal cubit.
2. Using the 18-inch cubit, calculate the volume (length $\times$ width $\times$ height) and the floor area of three full decks (length $\times$ width $\times$ 3). Compare the floor area with an American football field including end zones (360×160 ft = 57,600 sq ft).
3. Suppose 100 dinosaurs, as young adults, needed an average of 100 sq ft each. What fraction of the total floor area is that? Then do the same for 6,700 animals at an average of 10 sq ft each.
4. Write a one-page report: your numbers, one thing the numbers show, and one problem the numbers cannot answer by themselves (for example, ventilation, food storage or care). Label which parts of your report rest on Scripture and which on assumptions.

Check your work

- I calculated the dimensions with three different cubits and showed my work.
- My report compares the floor area with a football field and gives the dinosaurs' share as a percentage.
- I labeled which parts rest on Scripture and which on assumptions.

FIELD NOTEBOOK

1. Draw the Ark to scale on graph paper (1 square = 15 ft) in side view and in cross-section with three decks. Draw a 6-ft man and a young sauropod about 15 ft long to the same scale.
2. Make a two-column list: "What Genesis says about the Ark" and "What researchers suggest." Put at least four items in each.
3. **Narration (the parent keeps this).** Write one paragraph answering: Were there dinosaurs on the Ark? Use the text of Genesis 6–7 and at least two numbers from this stop, and say clearly which parts of your answer are certain and which are reasoned guesses.

Did you know? Ark-shaped flood stories are found in many cultures. The best known outside the Bible is the Babylonian *Epic of Gilgamesh*, whose boat is a perfect cube, a shape that would spin and roll in the waves; the Ark's long box shape is far more seaworthy. The life-size ark at the Ark Encounter is one of the largest timber-frame structures in the world and includes displays of young sauropods and other dinosaurs in cages.

Primary source. *Genesis 6:14–22, King James Version (1611).*

14 Make thee an ark of gopher wood; rooms shalt thou make in the ark, and shalt pitch it within and without with pitch.

15 And this is the fashion which thou shalt make it of: The length of the ark shall be three hundred cubits, the breadth of it fifty cubits, and the height of it thirty cubits.

16 A window shalt thou make to the ark, and in a cubit shalt thou finish it above; and the door of the ark shalt thou set in the side thereof; with lower, second, and third stories shalt thou make it.

17 And, behold, I, even I, do bring a flood of waters upon the earth, to destroy all flesh, wherein is the breath of life, from under heaven; and every thing that is in the earth shall die.

18 But with thee will I establish my covenant; and thou shalt come into the ark, thou, and thy sons, and thy wife, and thy sons' wives with thee.

19 And of every living thing of all flesh, two of every sort shalt thou bring into the ark, to keep them alive with thee; they shall be male and female.

20 Of fowls after their kind, and of cattle after their kind, of every creeping thing of the earth after his kind, two of every sort shall come unto thee, to keep them alive.

21 And take thou unto thee of all food that is eaten, and thou shalt gather it to thee; and it shall be for food for thee, and for them.

22 Thus did Noah; according to all that God commanded him, so did he.

Go deeper. John Woodmorappe, *Noah's Ark: A Feasibility Study* (Institute for Creation Research, 1996), the most detailed study of animal care aboard the Ark. John C.

Whitcomb and Henry M. Morris, *The Genesis Flood* (1961), chapter 1. The Ark Encounter website (arkencounter.com), with pages on how many animals and how they were cared for. Second video topic: “How ship proportions affect stability.”

Goes deeper in. Arithmetic, units of measure, area and volume; Earth Science, the Flood unit; and History, the ancient Near East and flood traditions.

For families. Cubit lengths are standard estimates; the Ark Encounter uses 20.4 inches and opened on July 7, 2016. The Korean stability study is S. W. Hong et al., “Safety investigation of Noah’s Ark in a seaway,” *CEN Technical Journal* 8:1 (1994), from work at the Korea Research Institute of Ships and Ocean Engineering. Woodmorappe’s figure of about 16,000 animals assumes genus-level kinds; the figures of 1,398 kinds and at most 6,744 animals are from Answers in Genesis. The “about 520 stock cars” comparison is from Whitcomb and Morris. The regional-flood view is named fairly; this course teaches a global Flood. Ideas such as animals sleeping more than usual are labeled speculation.

PRACTICE

1. **EASY** Which animals did Noah take aboard, and which did he not need to?
2. **MEDIUM** **Primary source.** Using an 18-inch cubit, give the Ark’s length, breadth and height in feet.
3. **MEDIUM** Give three reasons creation researchers say dinosaurs would have fit on the Ark.
4. **CHALLENGE** Calculate the Ark’s volume (18-inch cubit) in cubic feet. If 100 young dinosaurs each needed a pen $10 \times 10 \times 10$ ft, what percentage of the Ark’s volume would they use?
5. **CHALLENGE** The Ark’s length-to-width ratio is 300:50. Simplify it, and explain why the Babylonian flood boat in the Epic of Gilgamesh, a cube, would be a poor design. Then name the 1993 study of the Ark’s stability and its finding.
6. **MEDIUM** Give one argument for the regional-flood view and two young-earth answers from Scripture.

Make it a game • Load the Decks. Draw three long rectangles for the three decks. Players take turns drawing an animal card (write 30 cards: 10 dinosaurs, 20 other animals, each with an estimated young-adult size: small, medium or large). Small animals go on any deck, medium on the lower two, large only on the lowest. Each player must also assign one task to one of Noah’s family (feeding, water, cleaning, repairs). The game ends when all cards are placed; discuss which choices made the Ark easiest to run.

Scripture. “Thus did Noah; according to all that God commanded him, so did he.” (Genesis 6:22, KJV)

Noah built a ship larger than anything he had seen, for a flood no one had ever seen, because God said so. Hebrews 11:7 calls this faith. The engineering questions are worth asking, but the heart of the story is a man who trusted God and obeyed.

Practice: answers

1. Air-breathing land animals and birds, two of every sort (and seven pairs of clean animals and birds). He did not need to take fish, whales or sea reptiles, since only "all that was in the dry land" died (Genesis 7:22).
2. $300 \times 1.5 = 450$ ft long; $50 \times 1.5 = 75$ ft wide; $30 \times 1.5 = 45$ ft high.
3. (1) Only kinds, not every species, were needed: perhaps about 50 dinosaur kinds, so about 100 animals. (2) Most dinosaurs were small to medium-sized. (3) God may have brought young adults, small but able to breed, and even the biggest dinosaurs hatched from small eggs.
4. $450 \times 75 \times 45 = 1,518,750$ cubic feet. $100 \text{ pens} \times 1,000 \text{ cubic feet} = 100,000$ cubic feet. $100,000 \div 1,518,750 \approx 0.066$, so about 6.6 percent of the volume.
5. $300:50 = 6:1$. A cube has no long axis, so it would spin and roll in the waves, while a long box resists rolling and turns its end into the waves. The study by S. W. Hong and Korean naval engineers found the Ark's proportions to be highly stable in rough seas, close to those of modern cargo ships.
6. Regional view: "all the earth" can mean the known world or the region where people lived. Answers (any two): "all the high hills, that were under the whole heaven, were covered" (Genesis 7:19); "the world that then was, being overflowed with water, perished" (2 Peter 3:6); God promised never again to send such a flood (Genesis 9:11), which local floods would break if Noah's was local; a regional flood would not require an Ark at all, since animals and people could migrate.

4.5 FOSSIL GRAVEYARDS AND THE FLOOD

OBJECTIVES

- Explain why most fossils require rapid burial, and describe four of the great dinosaur bonebeds with their numbers.
- Compare how mainstream geologists and creation geologists explain the same bonebeds, naming the observations both sides accept.
- Read Genesis 7:17–24 as history and explain how many creation geologists connect it to the rock record.

Warm-up. Think about what happens to a dead bird or squirrel left on the ground. Within days, what has eaten it or broken it down? Within a year, what is left? Write three sentences, then answer: what would have to happen to that animal for its skeleton to last long enough to become a fossil?

Video slot. Video coming. Dinosaur bonebeds and how fossils form; the Carnegie Quarry “Wall of Bones” at Dinosaur National Monument; the Cleveland-Lloyd Quarry; the Bernissart Iguanodons. Search approved channels (National Park Service, Royal Belgian Institute of Natural Sciences, Utah Geological Survey; for creation-friendly framing, Answers in Genesis, the Institute for Creation Research or Creation Ministries International once vetted); preview first.

KEY TERMS

bonebed

A layer of rock holding the bones of many animals together, often of one kind.

taphonomy

The study of what happens to a living thing between death and discovery as a fossil: decay, scavenging, transport, burial and mineral change.

sediment

Loose material such as mud, sand or volcanic ash laid down by water, wind or ice, which can harden into rock.

disarticulated

Describes a skeleton whose bones have come apart and been scattered, as opposed to articulated (still joined as in life).

formation

A named body of rock layers that can be mapped across a region, such as the Morrison Formation of the western United States.

catastrophism

The view that much of the rock record was shaped by sudden, large-scale events rather than only by slow, everyday processes.

CORE IDEAS

Fossils need fast burial. When an animal dies in the open, scavengers, insects, bacteria, sun and rain usually destroy it within months. In a long study of animals that died on the open plains of Amboseli in Kenya, Anna Behrensmeyer found that most bones left on the surface cracked and crumbled within about fifteen years. A good fossil needs the opposite: a body covered quickly by enough sediment to keep out scavengers and slow decay, and then minerals in groundwater to fill or replace the bone. Every paleontologist agrees on this. The question is how often, and how widely, such rapid burial happened.

Great graveyards. Some places hold bones by the thousand. At the **Carnegie Quarry** in Utah, found by Earl Douglass in 1909, a single sandstone layer has yielded nearly twenty fairly complete skeletons, and a wall left in place at Dinosaur National Monument still shows more than 1,500 bones of *Diplodocus*, *Camarasaurus*, *Stegosaurus* and others, jumbled together. The **Cleveland-Lloyd Quarry** in Utah has produced more than 12,000 bones from at least 74 dinosaurs, most of them *Allosaurus*. In 1878 coal miners at **Bernissart** in Belgium struck bones 322 m underground: about thirty fairly complete *Iguanodon* skeletons and parts of others, lying in clay that filled a deep pit. Near Hilda, Alberta, the **Hilda mega-bonebed** covers at least 2.3 square kilometers and holds the remains of an estimated few thousand *Centrosaurus*.

What we observe. In many bonebeds the bones are of one main kind, of several ages, and often broken and scattered, though some skeletons lie whole. They are usually in sandstone or mudstone laid by water, and some show signs of the bodies having floated or been dragged before burial. Many large dinosaur bonebeds lie in a few widespread formations: the Morrison Formation covers some 1.5 million square kilometers across thirteen U.S. states and parts of Canada.

The mainstream reading. Mainstream geologists explain each bonebed as a local disaster during a long history: a herd drowned crossing a river in flood, a drought that gathered animals at a shrinking water hole until they died and the next rains buried them, a mudflow, or a tropical storm surge across a coastal plain. David Eberth of the Royal Tyrrell Museum interpreted the Hilda bonebed as the result of storms that flooded a low coastal plain. On this view the rock layers above and below represent millions of years, with bonebeds as short, violent episodes inside that span.

The Flood reading. Creation geologists read the same rocks as mostly laid down in one year. Genesis 7 says the waters “prevailed exceedingly upon the earth” for 150 days and that every land creature outside the Ark died. Such a flood would bury enormous numbers of animals quickly and over whole continents, exactly what fossils require. Creation geologists point to the size of the formations, the many bonebeds in water-laid rock, the scarcity of erosion surfaces between layers and the near absence of soil horizons, roots and burrows in many sequences. Some suggest that dinosaur bonebeds high in the rock record formed late in the Flood year, as animals that had survived on remaining high ground were finally overwhelmed. Others debate where in the rocks the Flood begins and ends; creation geology is an active field, not a closed book.

Where the views meet. Notice how much both sides share. Both say bonebeds need rapid burial by water-borne sediment. Both see catastrophe, not slow everyday processes, in the bones. Since the 1980s mainstream geology itself has returned to catastrophes, from giant floods to asteroid impacts. The difference lies in the number and timing of the catastrophes: many local disasters over many millions of years, or one global Flood with its aftermath a few thousand years ago.

How to read a quarry wall. Standing before the Wall of Bones, a Christian student can say three true things: these creatures were made by God; they died suddenly and were buried fast; and God's Word records a judgment by water that would do exactly that. Peter warned that people would be "willingly ignorant" of that judgment (2 Peter 3:5-6). A bonebed is a sobering place, and also a reminder of the Ark and the God who saved.

PICTURE STUDY



Louis De Pauw supervising the reconstruction of an Iguanodon in the Chapel of Saint George, Brussels, Léon Becker, 1884 (showing work done in 1882) · Painting · Royal Belgian Institute of Natural Sciences, Brussels
Wikimedia Commons · Public domain

After the Bernissart find, the museum in Brussels needed a room tall enough to assemble the skeletons. It used the Chapel of Saint George in an old palace. Louis De Pauw, the museum's head preparator, led the work, hanging the bones from ropes and scaffolding to set them in position. Léon Becker, a Belgian naturalist and scientific artist, painted the scene in 1884. Today many of the Bernissart Iguanodons stand in a glass case in Brussels, some upright and some lying as they were found.

Look closely

- Find the ropes and scaffolding. How are the workers holding the skeleton up?
- Compare the size of the skeleton with the men. About how many times taller is it?

- Look at the posture. How does the skeleton stand, and where is the tail?

Talk about it

1. Today scientists think Iguanodon usually walked on all fours with its tail held level. Why might the 1880s team have mounted it standing upright like a kangaroo?
2. Some thirty Iguanodons came from one pit 322 m underground. Write one question a mainstream geologist and one question a creation geologist would want answered about how they got there.

Safety first. Boil chicken bones only with an adult, let them cool fully, and wash hands after handling them.

HANDS-ON: A BONEBED IN A BOX

Make a model bonebed with a sudden flood of sediment, then “dig” it and record what you observe before you interpret it.

You will need

- A clear plastic storage box or large jar
- Sand, soil, small gravel and fine clay or flour
- 20 small bones or bone stand-ins (chicken bones boiled clean with an adult, or pasta shapes)
- A pitcher of water, a ruler, a spoon and a soft brush
- Graph paper

Steps

1. Lay a thin layer of soil in the box and scatter the bones on it like animals on a riverbank.
2. Mix the sand, gravel, clay and water in a bucket into a thick slurry. Pour it quickly into the box from one end, as a flood surge. Let it settle overnight.
3. Sketch the side of the box: Do you see layers? Is coarse material at the bottom and fine at the top?
4. Dig carefully from the top with the spoon and brush. On graph paper, map where every bone lies and which way it points. Count how many are whole, broken, flat or upright.
5. Write two short paragraphs: first, only your observations; second, an interpretation. Then answer: What would be different if the bones had been buried slowly by a little sediment each year?

Check your work

- I mapped every bone on graph paper with its direction.
- I wrote my observations separately from my interpretation.
- I can explain why rapid burial is needed to make fossils.

FIELD NOTEBOOK

1. Draw a cross-section of a bonebed: rock layers above and below, a sandstone layer with jumbled bones, and labels for what you observe.
2. Make a table of the four bonebeds in this stop (name, place, main dinosaur, number of bones or animals).
3. **Narration (the parent keeps this).** Write one paragraph comparing how a mainstream geologist and a creation geologist explain a dinosaur bonebed. Name at least two observations they agree on and say exactly where they differ.

Did you know? On August 17, 1909, Earl Douglass wrote in his diary that he had seen eight tail bones of a Brontosaurus “in exact position.” He spent about fifteen years excavating the site. He hoped the bones in the quarry face would be left in place for visitors to see, and that is what was done: the Quarry Exhibit Hall at Dinosaur National Monument is built right over the bone-filled wall. In 1971 Polish and Mongolian scientists found a Velociraptor locked in combat with a Protoceratops, apparently buried in an instant, perhaps by a collapsing sand dune.

 **What the sign says / What we observe / How Christians read it.**  **What the sign says:** “These dinosaurs died about 150 million years ago, in the Late Jurassic, when a river in flood buried their bodies on a sandbar.” **What we observe:** more than 1,500 bones of several kinds of dinosaurs, many separated and jumbled, some still joined, buried together in one tilted layer of river-laid sandstone in the Morrison Formation, a formation that stretches across much of the western United States. The age is not printed on the rock; it comes from radiometric dating of volcanic ash in the formation, which assumes known starting amounts, constant decay rates and no gain or loss of atoms. **How Christians read it:** many young-earth Christians read the Morrison Formation and its bonebeds as laid down rapidly during Noah’s Flood, about 4,300 to 4,500 years ago, and treat “Jurassic” as a name for a set of rock layers, not an age. Other Christians accept the long ages and see local floods within them. All agree on what is observed: sudden death and rapid burial by water.

Primary source. *Genesis 7:17–24, King James Version (1611).*

- 17 And the flood was forty days upon the earth; and the waters increased, and bare up the ark, and it was lift up above the earth.
- 18 And the waters prevailed, and were increased greatly upon the earth; and the ark went upon the face of the waters.
- 19 And the waters prevailed exceedingly upon the earth; and all the high hills, that were under the whole heaven, were covered.
- 20 Fifteen cubits upward did the waters prevail; and the mountains were covered.
- 21 And all flesh died that moved upon the earth, both of fowl, and of cattle, and of beast, and of every creeping thing that creepeth upon the earth, and every man:
- 22 All in whose nostrils was the breath of life, of all that was in the dry land, died.
- 23 And every living substance was destroyed which was upon the face of the

ground, both man, and cattle, and the creeping things, and the fowl of the heaven; and they were destroyed from the earth: and Noah only remained alive, and they that were with him in the ark.

24 And the waters prevailed upon the earth an hundred and fifty days.

Go deeper. National Park Service, Dinosaur National Monument, “Quarry Exhibit Hall” (nps.gov/dino). Royal Belgian Institute of Natural Sciences, “The Bernissart Iguanodons at a glance” (naturalsciences.be). Andrew Snelling, *Earth’s Catastrophic Past* (Institute for Creation Research, 2009), a full creation geology text for advanced students. Second video topic: “How fossils form: rapid burial and permineralization.”

Goes deeper in. Earth Science, the units on rock layers, fossils and the Flood; and Life Science, the units on decay and decomposers.

For families. This is a ⏰ stop. Figures: Carnegie Quarry, found August 1909, about 1,500 bones in the exhibit wall (National Park Service); Cleveland-Lloyd, more than 12,000 bones and at least 74 individuals (Utah sources); Bernissart, 1878, 322 m deep, about thirty fairly complete skeletons (sources range up to 38 individuals); Hilda, described by Eberth, Brinkman and Barkas (2010). The Morrison Formation area is approximate. The “Fighting Dinosaurs” were found in 1971 by the Polish-Mongolian expedition. The Flood date of about 4,300–4,500 years ago follows the Masoretic chronology used by most young-earth writers. Creation geologists disagree among themselves about where the Flood boundaries lie in the rocks; the stop says so.

PRACTICE

1. **EASY** Why do almost all good fossils require rapid burial?
2. **MEDIUM** Name four dinosaur bonebeds from this stop and the main dinosaur in each.
3. **MEDIUM** Name two observations about bonebeds that both mainstream and creation geologists accept.
4. **CHALLENGE Primary source.** Genesis 7:20 says “Fifteen cubits upward did the waters prevail; and the mountains were covered.” Convert 15 cubits to feet and meters (18-inch cubit), and explain one common interpretation of what the number measures. Then list every group of creatures verse 21 says died, and explain why fish are missing from the list.
5. **CHALLENGE** The Cleveland-Lloyd Quarry has more than 12,000 bones from at least 74 dinosaurs. An adult Allosaurus skeleton has about 300 bones. How many bones would 74 complete skeletons contain, and what percentage of that total has been found? What does this suggest about the bodies before burial?
6. **MEDIUM** Sort each into observation or interpretation: (a) The Hilda bonebed covers at least 2.3 square kilometers. (b) The Centrosaurus died in a tropical storm 76 million years ago. (c) The Bernissart bones lay 322 m below the surface. (d) The Carnegie Quarry dinosaurs were buried during Noah’s Flood.

Make it a game · Wall of Bones. Draw a large “quarry wall” on paper and scatter 30 small bone shapes across it (or use pasta on a tray). One player is the guide, the others are visitors. Each visitor in turn points to a bone and makes one true observation about it (its direction, whether it is whole, what lies next to it). The guide may challenge any statement that is really an interpretation; a correct challenge earns the guide a point, a true observation earns the visitor a point.

Scripture. “For this they willingly are ignorant of, that by the word of God the heavens were of old, and the earth standing out of the water and in the water: Whereby the world that then was, being overflowed with water, perished:” (2 Peter 3:5–6, KJV)

Peter speaks of the Flood as real history, as real as creation itself, and warns against forgetting it on purpose. A bonebed is a place to remember both the seriousness of God’s judgment and His mercy in the Ark.

Practice: answers

1. Because an animal left in the open is quickly destroyed by scavengers, insects, bacteria and weather. Fast burial keeps these away and slows decay long enough for minerals to preserve the bones.
2. Carnegie Quarry, Utah (sauropods such as *Diplodocus* and *Camarasaurus*, with *Stegosaurus* and others); Cleveland-Lloyd Quarry, Utah (*Allosaurus*); Bernissart, Belgium (*Iguanodon*); Hilda mega-bonebed, Alberta (*Centrosaurus*).
3. Any two: the animals were buried rapidly; the burial was by water-laid sediment; many bones are broken, scattered or jumbled; many bonebeds contain mostly one kind of animal; they occur in widespread formations.
4. $15 \times 1.5 \text{ ft} = 22.5 \text{ ft}$, about 6.9 m. A common reading is that the water rose 15 cubits above the highest mountains, enough to clear them for the Ark, which itself was 30 cubits high and may have drawn about 15 cubits of water. Verse 21 lists fowl, cattle, beast, every creeping thing and every man. Fish are missing because the judgment fell on “all that was in the dry land” (verse 22); sea creatures were not the target, though many were also buried in the sediments.
5. $74 \times 300 = 22,200$ bones. $12,000 \div 22,200 \approx 0.54$, so about 54 percent. Many skeletons are incomplete and the bones are mostly disarticulated, which suggests the bodies had partly decayed, been scavenged or been broken apart and moved by water before final burial.
6. (a) observation; (b) interpretation (both the cause and the date); (c) observation; (d) interpretation (a young-earth reading of the evidence).

4.6 DRAGON LEGENDS WORLDWIDE

OBJECTIVES

- Describe dragon traditions from at least five cultures and compare what they share and how they differ.
- Explain what the KJV word “dragon” translates in Hebrew and why some uses probably mean a sea creature, a serpent or even a jackal.
- Evaluate three explanations for dragon legends (fossils, memories of living dinosaurs, fear of real animals), separating strong evidence from weak.

Warm-up. Without looking anything up, draw a dragon. Then list every feature you gave it (wings, fire, scales, horns, long tail, four legs, treasure, a cave). Put a check by each feature you think a real dinosaur or other real animal had. Keep the list; you will compare it with dragons from around the world.

Video slot. Video coming. Dragons in world cultures: the Ishtar Gate dragons of Babylon, Chinese dragons, Saint George, Beowulf; “dragon bones” and fossils. Search approved channels (Pergamon Museum, Museum of Fine Arts Boston, the British Library; for creation-friendly framing, Answers in Genesis, the Institute for Creation Research or Creation Ministries International once vetted); preview first.

KEY TERMS

tannin

A Hebrew word for a great creature of the sea or a serpent, translated “dragon” in many KJV verses (Psalm 148:7; Isaiah 27:1), “whale” in Genesis 1:21 and “serpent” in Exodus 7:9.

tan (plural tannim)

A similar-looking Hebrew word that most scholars think means “jackal,” an animal that howls in ruins. The KJV often translates it “dragons” too (Jeremiah 9:11; Malachi 1:3).

mushhushshu (sirrush)

The scaly, long-necked dragon on the glazed brick Ishtar Gate of Babylon, built under Nebuchadnezzar II about 575 BC.

legend

A traditional story handed down, often with a real person or event at its root but enlarged in the telling.

longgu

“Dragon bones,” fossil bones and teeth dug up in China and ground into traditional medicine for centuries; most were the bones of fossil mammals.

Golden Legend

A popular book of saints' lives compiled about 1260 by Jacobus de Voragine, which spread the story of Saint George and the dragon across Europe.

CORE IDEAS

Dragons everywhere. Almost every people has told stories of great serpent-like creatures. In Babylon the *mushhushshu*, a scaly beast with a long neck, a forked tongue, lion forelegs and eagle hind feet, marched in glazed brick along the Ishtar Gate that Nebuchadnezzar built about 575 BC; Daniel may have walked past it. The Greeks told of the serpent Python slain by Apollo and the dragon Ladon guarding golden apples. The Norse told of Fafnir guarding treasure and the world-serpent Jörmungandr. The Old English poem *Beowulf* ends with a fire-breathing dragon whose treasure is disturbed. In China the *long* is a wise, wingless rain-bringer and the emblem of the emperor. The Aztecs honored Quetzalcoatl, the feathered serpent, and Aboriginal Australians tell of the Rainbow Serpent.

Alike and different. Most of these creatures are reptile-like, large, linked with water or caves, and powerful. But they differ a great deal. Western dragons are usually evil, winged and fiery; Chinese dragons are usually good, wingless and watery. Some are snakes, some walk on four legs, some fly. So "the dragon" is not one creature described the same way everywhere. Any explanation must account for both the common core and the differences.

Dragons in the KJV. The word "dragon" appears about thirty-five times in the King James Bible, but it translates more than one Hebrew word. *Tannin* means a great sea creature or serpent: the "great whales" of Genesis 1:21, Aaron's rod that became a "serpent" in Exodus 7:9-10, and "the dragon that is in the sea" in Isaiah 27:1. A similar word, *tan*, is used for animals that howl in ruined cities ("a den of dragons," Jeremiah 9:11), and most scholars think it means jackals. Isaiah 30:6 speaks of a "fiery flying serpent," which some read as a venomous snake and others as a flying reptile. In the New Testament the great dragon is "that old serpent, called the Devil, and Satan" (Revelation 12:9). The 1611 translators chose "dragon" for creatures they could not identify with certainty, an honest choice in their day.

Explanation one: fossils. People have always dug up bones. The Chinese dug "dragon bones" for medicine for centuries; most turned out to be fossil mammals. The historian Adrienne Mayor argued in *The First Fossil Hunters* (2000) that Protoceratops skulls, weathering out of the Gobi on the old gold routes, inspired the Greek griffin. Other scholars have challenged her theory, noting that early griffin art does not match Protoceratops well. Fossils probably shaped some legends, but they cannot explain stories of living, moving dragons by themselves.

Explanation two: memories of real dinosaurs. Many young-earth Christians propose that people after the Flood saw dinosaurs and other great reptiles that survived for a time, and that dragon stories preserve memories of them, enlarged in the telling. They point to the long neck of the Babylonian *mushhushshu*, to winged serpents described by the Greek historian Herodotus near Arabia and Egypt, and to animals engraved on the brass of Bishop Richard Bell's tomb (1496) in Carlisle Cathedral, which some say resemble sauropods. Some proposed evidence is weak and should not be used: a carving at Ta Prohm in Cambodia

called a “stegosaurus” is more likely a rhinoceros or boar against a leafy background. If dinosaurs were made on day six and came off the Ark, people would have met them; the question is how much the legends really remember.

Explanation three: real animals we know. Others suggest that dragons combine the creatures people feared most: snakes, crocodiles, big cats and birds of prey. That explains some features (scales, venom, claws) but not the widespread long-necked, four-legged giant.

How a Christian historian weighs legends. A legend is not an eyewitness report, and it is not mere invention either. The wise reader asks what stays the same as a story spreads and what grows. Saint George was a real Christian soldier martyred about AD 303, but the dragon was added centuries later. A good student holds each explanation to evidence, admits uncertainty and remembers the dragon that matters most: Scripture says the ancient serpent is real and is defeated by Christ (Revelation 12:9-11).

PICTURE STUDY



Nine Dragons (detail), Chen Rong, 1244 · Handscroll, ink and touches of red on paper · Museum of Fine Arts, Boston (17.1697)

Wikimedia Commons · Public domain

Chen Rong (c. 1200–1266) was a Chinese official, poet and painter of the Southern Song dynasty, famous for his dragons. His *Nine Dragons* scroll is almost 15 m long; a viewer would unroll it slowly, a section at a time, watching dragons appear and vanish among clouds, waves and rocks. Chen is said to have painted with splashed ink, even smearing it with his cap, to make the mist. To Chinese viewers the dragon stood for rain, power and the hidden forces of nature.

Look closely

- Find the dragon's head. Look for horns, whiskers, teeth and eyes. What animals do these remind you of?
- Follow the body. Does it have wings? How many legs and claws can you see?
- Look at the clouds and water. How does Chen Rong make the dragon seem to appear out of the mist?

Talk about it

1. Compare this dragon with your warm-up drawing and with Saint George's dragon in European art. Which features are shared and which are different?
2. Does this dragon look like any dinosaur you know? Give an honest answer, with reasons, and say what that suggests about the "memory of dinosaurs" explanation.

HANDS-ON: THE DRAGON EVIDENCE GRID

Compare dragon traditions like a scientist and a historian together, and then test the three explanations against your data.

You will need

- Pictures of six dragons from different cultures (library books or museum pages): the Ishtar Gate *mushhushshu*, a Chinese dragon (this stop's picture), a Greek drakon on a vase, the Beowulf dragon, a Saint George dragon, Quetzalcoatl
- The primary source in this stop
- Large paper or a spreadsheet

Steps

1. Make a grid with the six dragons as rows and these columns: culture and date, body shape (snake or four-legged), wings, fire, neck length, home (water, cave, sky), good or evil.
2. Fill in every box from your sources. Mark any box you are unsure of with a question mark.
3. Count: Which features appear in four or more cultures? Which appear in only one or two?
4. Add a row for a sauropod, a crocodile and a large snake, filling in the same columns from what is known.
5. Write a half-page conclusion: Which explanation (fossils, memories of living dinosaurs, fear of known animals) best fits your grid? Which features does your favored explanation fail to explain? Use at least one KJV verse from the primary source in your answer.

Check your work

- My grid has six dragons and three real animals with every box filled or honestly marked "?".
- I counted which features are widespread.

- My conclusion names a weakness in my own favored explanation.

FIELD NOTEBOOK

1. Draw the Ishtar Gate *mushhushshu* from a museum photograph and label its four kinds of feet and body parts.
2. Copy the two Hebrew words *tannin* and *tan* with their meanings and one KJV verse for each.
3. **Narration (the parent keeps this).** Write one paragraph answering: Are dragon legends evidence that people once saw dinosaurs? Give the strongest evidence for, the strongest reason for caution and your own conclusion.

Did you know? The Ishtar Gate was excavated by German archaeologists from 1902 and rebuilt from its original glazed bricks in the Pergamon Museum in Berlin, where its dragons and bulls still march in rows. Chinese dragon bones led to real science: in 1899 a Chinese scholar is said to have noticed ancient writing on “dragon bones” bought as medicine, which led to the discovery of the oracle bones, the oldest Chinese writing. The scientific name of the pachycephalosaur *Dracorex hogwartsia* (2006) means “dragon king of Hogwarts,” because its spiky skull looked so dragon-like.

Primary source. *Five verses that use “dragon” in the King James Version (1611).*

Psalms 148:7 Praise the LORD from the earth, ye dragons, and all deeps:

Isaiah 27:1 In that day the LORD with his sore and great and strong sword shall punish leviathan the piercing serpent, even leviathan that crooked serpent; and he shall slay the dragon that is in the sea.

Isaiah 30:6 The burden of the beasts of the south: into the land of trouble and anguish, from whence come the young and old lion, the viper and fiery flying serpent, they will carry their riches upon the shoulders of young asses, and their treasures upon the bunches of camels, to a people that shall not profit them.

Jeremiah 9:11 And I will make Jerusalem heaps, and a den of dragons; and I will make the cities of Judah desolate, without an inhabitant.

Malachi 1:3 And I hated Esau, and laid his mountains and his heritage waste for the dragons of the wilderness.

Go deeper. Adrienne Mayor, *The First Fossil Hunters: Dinosaurs, Mammoths, and Myth in Greek and Roman Times* (Princeton University Press, 2000; new edition 2011), for the fossil explanation. Bill Cooper, *After the Flood* (New Wine Press, 1995), chapters on dragons, for the young-earth memory explanation. The Pergamon Museum (smb.museum) and the Museum of Fine Arts, Boston (mfa.org) collection pages. Second video topic: “The Ishtar Gate of Babylon.”

Goes deeper in. History, the ancient Near East (Babylon and Nebuchadnezzar) and medieval Europe (Saint George and Beowulf); Literature, *Beowulf*; and Art, Chinese ink painting.

For families. The KJV uses “dragon” or “dragons” about thirty-five times (counts vary slightly by edition and method). The Hebrew distinctions follow standard lexicons. The Ishtar Gate date (about 575 BC) and the Nine Dragons details (dated 1244; MFA Boston 17.1697) are from the museums. The 1899 oracle-bone story is traditional and often told about the scholar Wang Yirong; details are uncertain. Critiques of Mayor’s griffin theory include work by the paleontologist Mark Witton. The Bishop Bell brass and the Ta Prohm carving are discussed in creationist literature; the stop presents the first as debated and the second as weak evidence. No primary source was quoted from Herodotus because a verified public-domain text could not be checked word for word; it is summarized instead.

PRACTICE

1. **EASY** Name dragon traditions from five different cultures.
2. **MEDIUM** Give two ways Chinese dragons usually differ from Western dragons.
3. **MEDIUM** **Primary source.** Which of the five verses most likely use *tannin* (sea creature or serpent) and which most likely use *tan* (jackal)? Give a clue from each verse.
4. **CHALLENGE** Evaluate Adrienne Mayor’s theory that Protoceratops skulls inspired the griffin. State her evidence, one objection, and what the theory could and could not explain about dragon legends in general.
5. **CHALLENGE** Saint George was martyred about AD 303, the Golden Legend was compiled about 1260, and Paolo Uccello painted George and the dragon about 1470. How many years separate the martyrdom from the Golden Legend, and the Golden Legend from Uccello? What does this tell a historian about the dragon in the story?
6. **MEDIUM** Why should Christians not use the Ta Prohm “stegosaurus” carving as evidence?

Make it a game • Dragon or Dinosaur?. One player reads a description of a creature, either a real dinosaur or a dragon from a legend (“long neck, four legs, scaly, lives near rivers”; “wingless, whiskered, brings rain”). Others call “Dragon!” or “Dinosaur!” and must name which one. A bonus point goes to anyone who can say which features overlap. Make at least five cards of each kind before starting.

Scripture. “Praise the LORD from the earth, ye dragons, and all deeps:” (Psalm 148:7, KJV)

The psalmist calls even the dragons and the deeps to praise God. Whatever creatures stand behind the world’s dragon stories, Scripture places them under God as His creatures, called to praise Him, not as gods or rivals to be feared.

Practice: answers

1. Any five: Babylon (the *mushhushshu* of the Ishtar Gate), Greece (Python, Ladon), Norse (Fafnir, Jörmungandr), Anglo-Saxon England (the Beowulf dragon), medieval Christian Europe (Saint George), China (the *long*), Japan (*ryū*), the Aztecs (Quetzalcoatl), Aboriginal Australia (the Rainbow Serpent).

2. Any two: Chinese dragons are usually good and wise, Western dragons usually evil; Chinese dragons are usually wingless, Western ones winged; Chinese dragons are linked with water and rain, Western ones often with fire and caves; the Chinese dragon was an emblem of the emperor.
3. *Tannin*: Psalm 148:7 (“dragons, and all deeps,” paired with the sea) and Isaiah 27:1 (“the dragon that is in the sea”). *Tan*: Jeremiah 9:11 (“a den of dragons” in ruined Jerusalem) and Malachi 1:3 (“dragons of the wilderness” in wasted land), both of which fit jackals living in ruins. Isaiah 30:6 uses neither word; it speaks of a “fiery flying serpent.”
4. Evidence: Protoceratops skulls, beaked and frilled, weather out in the Gobi near ancient gold routes, and Greek writers placed griffins guarding gold in Central Asia. Objection: early griffin art does not match Protoceratops anatomy well, and griffin images may predate Greek contact with those routes. It could explain why people imagined monsters from strange bones; it could not by itself explain stories of living dragons that move, fly, fight and live in water.
5. $1260 - 303 = 957$ years; $1470 - 1260 = 210$ years. The dragon story appears nearly a thousand years after George’s death, so it is a later legend added to the life of a real martyr. A historian keeps the real person and his faithful death and treats the dragon episode as legend, not eyewitness history.
6. Because on close examination the plates along its back are most likely leafy background decoration, a common style at the temple, and the animal is more likely a rhinoceros or boar. Using doubtful evidence harms the credibility of good arguments and is not honest.

4.7 WHAT HAPPENED TO THE DINOSAURS? EACH VIEW

OBJECTIVES

- Describe the observations any explanation of dinosaur extinction must account for, including the boundary clay, iridium, shocked quartz and the Chicxulub crater.
- State the mainstream, old-earth Christian and young-earth Christian views fairly, each in its strongest form, with the weak points each must answer.
- Use a 1915 museum text to show how scientific explanations of extinction have changed, and explain why that calls for humility.

Warm-up. Write down every explanation you have ever heard for why the dinosaurs disappeared, even silly ones. Then sort them into three piles: “something that could be tested,” “something that could not be tested” and “not sure.” Keep the list to compare with the views in this stop.

Video slot. Video coming. Dinosaur extinction: the Chicxulub crater, the iridium layer, the Deccan Traps; the Alvarez hypothesis; dinosaurs after the Flood. Search approved channels (Natural History Museum London, Smithsonian, American Museum of Natural History; for creation-friendly framing, Answers in Genesis, the Institute for Creation Research or Creation Ministries International once vetted); preview first.

KEY TERMS

extinction

The dying out of every member of a kind or species, so that none remain alive anywhere.

iridium

A metal rare in the earth’s crust but more common in many meteorites. A thin clay layer enriched in iridium is found in many places at the level above which dinosaur bones are no longer found.

shocked quartz

Quartz grains crossed by sets of fine parallel lines, formed only under the enormous pressure of an impact or a nuclear blast.

Chicxulub crater

A buried impact crater about 180 km across under the Yucatán Peninsula of Mexico, identified as an impact structure in 1990–1991.

Deccan Traps

A huge series of lava flows in western India, more than a kilometer thick in places, which some scientists link to the dinosaurs’ extinction.

K-Pg boundary

The museum name for the rock level between the Cretaceous and Paleogene layers, above which dinosaur fossils (other than birds) are not found.

CORE IDEAS

What must be explained. Around the world, dinosaur bones are found in certain rock layers and not above them. At that level in many places lies a thin clay, a few centimeters thick or less, enriched in iridium and containing shocked quartz, tiny glass beads called spherules and, in some places, soot. Above it, the fossils include mammals, birds, crocodiles, turtles and frogs, but no non-bird dinosaurs, plesiosaurs, mosasaurs or pterosaurs. No dinosaur bones have been found with human tools or graves. Any honest explanation must account for all of this.

The mainstream view. In 1980 the physicist Luis Alvarez, his son the geologist Walter Alvarez and their colleagues reported the iridium layer at Gubbio in Italy and elsewhere and proposed that an asteroid about 10 km wide struck the earth. In 1990–1991 a buried crater about 180 km across was identified at Chicxulub in Mexico. Most geologists now say the impact, dated to about 66 million years ago, threw up dust and soot that darkened the sky, collapsed food chains and killed the dinosaurs within a short time. Some, notably Gerta Keller, have long argued that the eruptions of the Deccan Traps in India did most of the damage; many now think both played a part. The puzzle of who survived remains: why did crocodiles, turtles, frogs and birds come through when every other dinosaur did not?

Science changes its mind. In 1915 W. D. Matthew of the American Museum of Natural History wrote that the dinosaurs died out gradually through changing climate and competition from smarter mammals and birds (see the primary source). He also wrote that the dinosaurs' whole reign lasted about nine million years and ended about three million years ago, where museum signs today give about 165 million years for the reign and 66 million for the end. His explanation was the scientific consensus of its day, and it was replaced. That is not a reason to dismiss science; it is a reason to hold any explanation of the unobserved past with humility.

The old-earth Christian view. Many Christians accept the mainstream dates and the impact, and see God's providence in a long history: He governed even the asteroid and prepared the earth for the creatures that came after. They read Genesis 1 in one of the long-day or framework views named in Stop D1. This course teaches a different reading, but we can respect these believers and learn from their careful science.

The young-earth view. Young-earth Christians usually describe two stages. First, most dinosaurs died in Noah's Flood, buried in the sediments of the Flood year; that is why their fossils are so plentiful. Creation geologists debate where the boundary clay fits: many place it within the Flood, and some suggest Chicxulub was one of many impacts during that year. Second, the dinosaurs that left the Ark faced a changed world: new climates, the Ice Age that followed the Flood, scarce food, competition and, perhaps, human hunters. They dwindled and died out, as mammoths, giant ground sloths and moas did later. Dragon legends (Stop D6) may preserve memories of the last of them.

Each view's hard questions. The mainstream view must explain the selective survival and must rest its dates on assumptions about decay rates (Stop D9). The young-earth view must

explain why no dinosaur bones have been found in rock layers that creation geologists assign to after the Flood; its answer is that the surviving populations were small, lived only a few centuries and seldom fossilized, since fossils need rapid burial (Stop D5), and that post-Flood mammals such as mammoths left many fossils because they were far more numerous. Each side has answers; neither has answered every question.

Extinction in a groaning world. Whatever the timing, extinction is real and still happens. The dodo was gone by the late 1600s, and the last passenger pigeon, Martha, died at the Cincinnati Zoo in 1914. Romans 8 says the creation was “made subject to vanity” and groans, waiting for its deliverance. The end of the dinosaurs is one chapter of that groaning, and the God who holds “the soul of every living thing” in His hand (Job 12:10) has promised a renewed creation.

PICTURE STUDY



Agathaumas, Charles R. Knight, 1897 · Gouache on paper · American Museum of Natural History, New York (Museum Archives)

Wikimedia Commons · Public domain

Charles R. Knight (1874–1953) painted this horned dinosaur in 1897, one of his first dinosaur pictures, with advice and a rough sketch from the paleontologist Edward Drinker Cope. *Agathaumas* was named by Cope in 1872 from a partial skeleton found in Wyoming; it is now thought to be the same animal as *Triceratops* or a close relative, so the name is no longer used. Horned dinosaurs like this one are among the last dinosaurs found in the rock record before the boundary clay.

Look closely

- Look at the spikes along the back. Do horned dinosaurs in today’s museums have them?

- Find the horns and frill. How many horns can you see?
- Look at the setting. What does Knight suggest about where this animal lived?

Talk about it

1. Knight's picture was based on a partial skeleton and Cope's guesses. Which parts are observation and which are reconstruction?
2. Both this painting and Matthew's 1915 explanation were the best thinking of their day and were later revised. What does that teach about museum displays you see today?

HANDS-ON: THREE VIEWS, FAIRLY STATED

Write each view of dinosaur extinction in its strongest form, as its best defenders would, and then test each against the evidence.

You will need

- Three sheets of paper or index cards
- The primary source in this stop
- A highlighter

Steps

1. On each sheet, write one view as its own defender would: (1) mainstream impact and volcano view; (2) old-earth Christian view; (3) young-earth Flood and post-Flood view. Use the first person ("We think..."), at least 100 words each, with no mocking.
2. Make an evidence table with these rows: dinosaur fossils stop at one level; the iridium clay; shocked quartz; the Chicxulub crater; selective survival; no dinosaur bones with human artifacts; dragon legends; Genesis 1-9. For each view, mark whether it explains the item well, poorly or not at all.
3. Highlight, in Matthew's 1915 text, two statements that today's mainstream view has changed and one that it still holds.
4. Read your three statements aloud to a parent. Ask: "Would a defender of this view say I stated it fairly?" Revise any statement that sounds like a caricature.
5. Finish with a paragraph explaining which view this course holds and why, and the hardest question it must answer.

Check your work

- Each view is written fairly in its own voice, with no mocking.
- My table covers all eight rows for all three views.
- I identified what has changed since Matthew's 1915 explanation.

FIELD NOTEBOOK

1. Draw a column of rock layers with the boundary clay marked. Label what is found below it, in it and above it.

2. Make a timeline of explanations: Matthew (1915), Alvarez (1980), Chicxulub identified (1990–1991), and the young-earth two-stage view.
3. **Narration (the parent keeps this).** Write one paragraph answering: What happened to the dinosaurs? Explain the young-earth view in two stages, name one observation it explains well and one hard question it must answer.

Did you know? Luis Alvarez won the Nobel Prize in Physics in 1968, years before he turned to the dinosaur question. The Chicxulub crater was first noticed by geophysicists working for the Mexican oil company Pemex in the late 1970s, but it was not widely recognized as an impact crater until 1990–1991. The name comes from a small Maya village near the crater’s center.

 **What the sign says / What we observe / How Christians read it.**  **What the sign says:** “66 million years ago an asteroid struck Chicxulub, Mexico, ending the Age of Dinosaurs.” **What we observe:** dinosaur fossils stop at a certain level in the rock; at that level in many places is a thin clay with extra iridium, shocked quartz and glass spherules; a buried crater about 180 km wide lies under the Yucatán. The date comes from radiometric dating of the spherules and nearby volcanic material, assuming known starting amounts, constant decay rates and closed systems. **How Christians read it:** many young-earth Christians see the dinosaur layers as Flood deposits from about 4,300 to 4,500 years ago, with the crater possibly formed during the Flood year, and think the dinosaurs that left the Ark died out afterward; they treat “Cretaceous” as a name for rock layers, not an age. Other Christians accept the date and the impact. All agree on the boundary clay, the crater and the absence of dinosaur bones above that level.

Primary source. *W. D. Matthew, Dinosaurs, with Special Reference to the American Museum Collections (American Museum of Natural History, 1915), chapter III. Project Gutenberg eBook #19302.*

Their sway endured for a long era, estimated at nine millions of years, and about three times as long as the period which has elapsed since their disappearance. They survived vast changes in geography and climate, and became extinct through a combination of causes not fully understood as yet; probably the great changes in physical conditions at the end of the Cretacic period, and the development of mammals and birds, more intelligent, more active, and better adapted to the new conditions of life, were the most important factors in their extinction.

Go deeper. Walter Alvarez, *T. rex and the Crater of Doom* (Princeton University Press, 1997), the impact story told by one of its discoverers. Answers in Genesis, “What Really Happened to the Dinosaurs?” (answersingenesis.org), for the young-earth view. W. D. Matthew, *Dinosaurs* (1915), free at Project Gutenberg (eBook #19302). Second video topic: “Shocked quartz and how impact craters are identified.”

Goes deeper in. Earth Science, the units on rock layers, the Flood and the Ice Age; and Life Science, the units on ecology and extinction.

For families. This is a ⏰ stop. The Alvarez paper is L. W. Alvarez, W. Alvarez, F. Asaro and H. V. Michel, *Science* 208 (1980). The crater was identified by Hildebrand and others (*Geology*, 1991). The primary source was checked against Project Gutenberg eBook #19302; Matthew uses the old spelling “Cretacic.” His “three times as long” implies about three million years since the extinction. Martha the passenger pigeon died September 1, 1914. Young-earth creation geologists differ on where the K-Pg boundary falls relative to the Flood; the stop says “many.” All three views are stated fairly; the course holds the young-earth view.

PRACTICE

1. **EASY** Name three things found in the thin boundary clay at the level where dinosaur fossils stop.
2. **MEDIUM** Describe the two stages of the young-earth explanation of dinosaur extinction.
3. **MEDIUM** What is the “selective survival” puzzle, and which view must answer it?
4. **CHALLENGE** **Primary source.** Matthew says the dinosaurs’ reign lasted about nine million years and was “about three times as long as the period which has elapsed since their disappearance.” How many years ago did he think they died out? Compare his two numbers with today’s museum numbers (a reign of about 165 million years, ending 66 million years ago). By what factor has each number grown?
5. **CHALLENGE** The young-earth view must explain why no dinosaur bones are found in layers creation geologists assign to after the Flood. Give its answer, and then explain why woolly mammoths, which also lived after the Flood on this view, left many fossils.
6. **MEDIUM** Sort each into observation or interpretation: (a) A buried crater about 180 km across lies under the Yucatán. (b) An asteroid killed the dinosaurs 66 million years ago. (c) The last passenger pigeon died in 1914. (d) The dinosaurs that left the Ark died out in the Ice Age.

Make it a game • Defend the View. Write the three views on slips of paper. Each player draws one secretly and has one minute to defend it using only evidence from this stop. The others guess which view the player drew and then rate the defense from 1 to 5 for fairness and accuracy. A defense that mocks another view scores zero. Rotate until everyone has defended a view they do not hold.

Scripture. “In whose hand is the soul of every living thing, and the breath of all mankind.” (Job 12:10, KJV)

Every creature that has lived and died, the dinosaurs included, was in God’s hand. Extinction is part of a creation that groans under the curse, but nothing slips from the hand of the God who made it and will make all things new.

Practice: answers

1. Any three: extra iridium, shocked quartz, glass spherules, soot.
2. (1) Most dinosaurs died and were buried in Noah's Flood. (2) The dinosaurs that came off the Ark died out afterward in a changed world: new climates, the Ice Age, scarce food, competition and perhaps human hunting.
3. Why did crocodiles, turtles, frogs, birds and mammals survive the event that killed every non-bird dinosaur? The mainstream impact view must explain it, and it is still debated.
4. $9 \div 3 =$ about 3 million years ago. Reign: $165 \div 9 \approx 18$ times longer. Time since extinction: $66 \div 3 = 22$ times longer. Both numbers have grown roughly twentyfold in a century, which shows that dates for the unobserved past depend on the methods and assumptions of the time.
5. Answer: the dinosaurs leaving the Ark were few (perhaps about a hundred), their descendants may have lived only a few centuries in limited areas, and fossils require rapid burial, which was rare after the Flood. Mammoths, by contrast, multiplied into vast herds across the northern continents during the Ice Age, and many were buried in river silts, frozen ground and tar pits, so their remains are abundant.
6. (a) observation; (b) interpretation (cause and date); (c) observation (recorded history); (d) interpretation (a young-earth reading).

4.8 READING A MUSEUM SIGN

OBJECTIVES

- Sort the statements on a museum sign into four layers: observation, inference, reconstruction and framework claim.
- Tell the story of the Brontosaurus mount and its changing name, head and tail as a case study in how museum signs change.
- Rewrite a real museum sign so that each layer is clear, accurately and without mocking.

Warm-up. Find any dinosaur museum sign, from a visit, a museum website or a book (or use the sample in the  box). Copy it out word for word. Then, before reading further, put a check over every word or phrase you think someone actually saw or measured, and a question mark over every phrase you think is an explanation.

Video slot. Video coming. The Brontosaurus/Apatosaurus name story and the wrong-head mistake; Dippy the Diplodocus at the Natural History Museum, London; how museums build dinosaur mounts. Search approved channels (American Museum of Natural History, Natural History Museum London, Carnegie Museum of Natural History; for creation-friendly framing, Answers in Genesis or the Institute for Creation Research once vetted); preview first.

KEY TERMS

observation

A statement of what can be seen, measured or tested in the present: “This femur is 1.8 m long.”

inference

A conclusion drawn from observations by reasoning, often a strong one: “Its flat, worn teeth show it ate plants.”

reconstruction

An informed picture of something not preserved, such as skin color, sounds, behavior or missing bones.

framework claim

A statement that depends on a larger view of history, such as a date in millions of years or a claim about ancestry (“evolved from”).

cast

A copy of a fossil made in plaster, resin or another material. Many mounted skeletons are partly or wholly casts.

priority

The rule in scientific naming that when one animal has been given two names, the older name is used.

CORE IDEAS

A sign is a small sermon. Millions of people read museum signs every year, usually in a few seconds. A sign is short and speaks with the authority of the museum, and it mixes several kinds of statement without marking which is which. A careful reader learns to pull them apart. That is not hostility toward museums; it is good reading, and the best scientists do it too.

Four layers. Most signs contain four layers. **Observations:** the specimen number, which bones were found, where, in what formation, and measurements. **Inferences:** diet from teeth, posture from joints, speed from leg proportions; these can be very strong. **Reconstructions:** skin color, sounds, herds, nests, a painted background; these are informed guesses. **Framework claims:** “lived 150 million years ago,” “evolved from,” “ruled the earth for 165 million years.” These depend on a whole view of earth history, and no measurement on the bone produces them by itself. Labels such as “cast” or “model” tell you which parts are real fossil and which are copies.

A case study: Brontosaurus. In 1877 O. C. Marsh named a sauropod *Apatosaurus*; in 1879 he named a larger, more complete skeleton *Brontosaurus*, “thunder lizard.” In 1903 Elmer Riggs argued that the two were the same genus, so by the rule of priority the older name, *Apatosaurus*, should be used. Two years later, in 1905, the American Museum of Natural History unveiled the first mounted sauropod skeleton in the world, and called it *Brontosaurus*. No skull had been found with it, so the museum modeled one largely on *Morosaurus*, now called *Camarasaurus*, a sauropod with a short, boxy head (see the primary source). For seventy years signs, books and toys showed that head.

Corrections. W. J. Holland of the Carnegie Museum suspected early on that the true skull was long and low, like *Diplodocus*, and for years left his own mount headless rather than guess. In 1978 John McIntosh and David Berman confirmed that he was right. The Carnegie Museum replaced its head in 1979. The American Museum remounted its skeleton in 1995 with a new head, four more neck vertebrae and a tail lifted off the floor, since sauropod trackways show no tail drag. Then in 2015 a team led by Emanuel Tschopp studied dozens of sauropod skeletons and concluded that *Brontosaurus* was distinct after all. The name is back. One skeleton, three signs in a century.

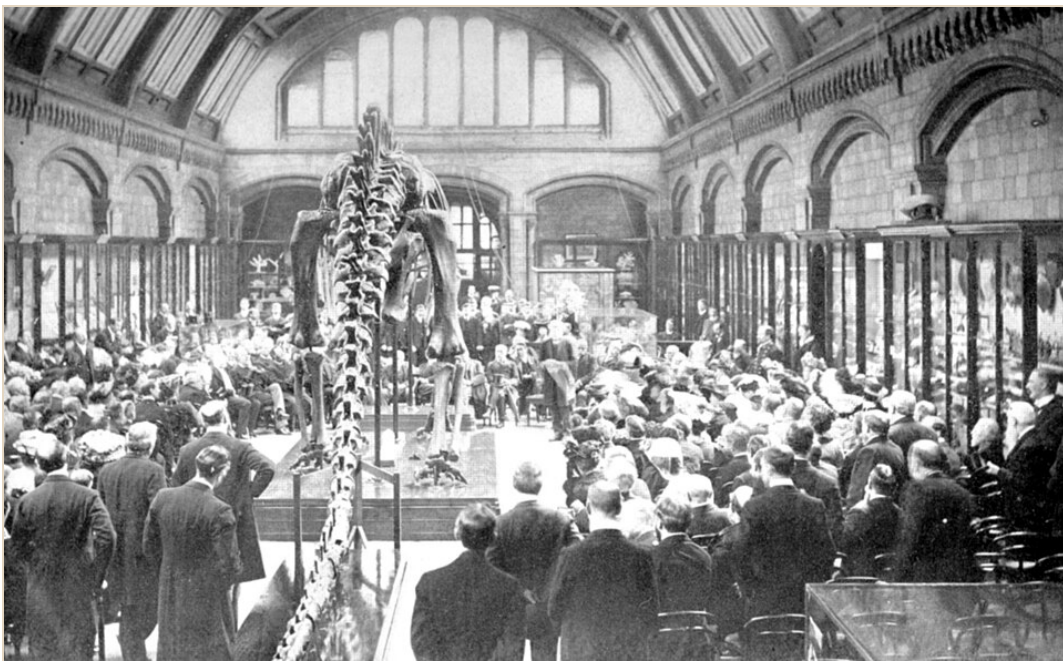
Another case: Dippy. On May 12, 1905, the Natural History Museum in London unveiled a plaster cast of the Carnegie *Diplodocus*, a gift from Andrew Carnegie, with its tail dragging on the floor. In 1993 the tail was lifted to curve over visitors’ heads. In 2017 Dippy left the great hall, replaced by a blue whale skeleton, and went on a tour of Britain. Each change was based on new evidence or new ideas, which is how good science works.

Reading the dates. The line most signs share is the date. “*Apatosaurus* lived about 150 million years ago” is not printed on the bones. It comes from radiometric dating of volcanic ash layers in the Morrison Formation, applied to the bone-bearing layers nearby, and it

assumes known starting amounts, constant decay rates and no gain or loss of atoms. Young-earth Christians read the same layers as Flood deposits about 4,300 to 4,500 years old. The observation, that these bones lie in the Morrison Formation, is shared; the date is a framework claim. Notice too that in 1915 the American Museum's own handbook dated the Morrison bones at "say eight million years" (Stop D9); today's sign says about 150 million.

Reading with grace. Proverbs 18:17 says a case seems right until someone examines it. The Christian reader examines, but with respect. Museum staff are often careful, honest scientists, and the specimens are real treasures. Don't sneer at a sign or argue with a docent. Read it accurately, give credit for the observations, name the framework claims calmly and ask good questions. That is how the Bereans read even the apostle Paul (Acts 17:11).

PICTURE STUDY



*Presentation of the first cast of Diplodocus to the Trustees of the Natural History Museum, London, Photographer unknown, 12 May 1905 · Black-and-white photograph · Natural History Museum, London
Wikimedia Commons · Public domain*

Andrew Carnegie, the Scottish-born steel magnate, paid for the excavation of a Diplodocus in Wyoming in 1899. When King Edward VII admired a sketch of it, Carnegie had a plaster cast made for London. It arrived in 36 crates, and on 12 May 1905 it was presented to the museum's trustees while Lord Avebury gave a speech. Casts were later given to museums in Berlin, Paris, Vienna, Bologna, St. Petersburg, La Plata, Madrid and Mexico City, so "Dippy" became the most widely seen dinosaur in the world.

Look closely

- Find the skeleton. Follow the neck and the tail. How are they held?

- Look at the people. How are they dressed, and what does that tell you about the occasion?
- Find the speaker. Why would a museum hold a ceremony for a copy of a skeleton?

Talk about it

1. In 1993 the museum lifted Dippy's tail off the floor. What evidence led to the change, and what does that tell you about the 1905 display?
2. This skeleton is a cast. Should a sign always say so? Why does it matter to a careful reader?

HANDS-ON: THE MUSEUM SIGN REWRITE

Take a real dinosaur museum sign and rewrite it so a reader can see every layer. Then write the sign the 1905 Brontosaurus should carry today.

You will need

- A real museum sign (copied from a visit, a museum website or a book) or the sample sign in the  box
- Four colored pencils
- The primary source in this stop
- Card stock for your final sign

Steps

1. Mark every phrase of your sign: underline observations, circle inferences, draw a wavy line under reconstructions and box framework claims.
2. Make a table with the four layers as columns and copy each phrase into the right column.
3. Rewrite the sign in 80 to 120 words. Keep every observation. Keep inferences but show the evidence ("Its worn teeth suggest..."). Mark reconstructions as such. Present the date as an interpretation and add one sentence giving the young-earth reading. Do not mock the original.
4. Now read the primary source. Make a list of what the 1905 American Museum handbook got right (observations), what it reconstructed and what it would need to correct today (name, head, tail, weight).
5. Write a new 80-word sign for the same skeleton as it stands today, using the same four layers. Letter both signs neatly on card stock.

Check your work

- Every phrase of the original sign is sorted into one of the four layers.
- My rewritten sign keeps all the observations and treats both views of the date fairly.
- My Brontosaurus sign mentions the name history, the head and the tail.

FIELD NOTEBOOK

1. Draw two sauropod heads side by side: the short, boxy Camarasaurus-style head of the 1905 mount and the long, low head of the 1995 remount. Label each with its date.
2. Make a timeline: 1877 Apatosaurus named; 1879 Brontosaurus named; 1903 Riggs; 1905 AMNH mount and Dippy; 1978 head confirmed; 1979 Carnegie correction; 1993 Dippy's tail lifted; 1995 AMNH remount; 2015 Brontosaurus revived.
3. **Narration (the parent keeps this).** Write one paragraph explaining the four layers of a museum sign, using the Brontosaurus story as your example, and say how a Christian should read a sign with both care and respect.

Did you know? The United States Postal Service issued a “Brontosaurus” stamp in 1989 and was criticized for using an outdated name; after 2015 the stamp was accidentally right again. The Carnegie Museum’s first Apatosaurus mount was displayed without a head for years because W. J. Holland refused to put on the wrong one. When Dippy left London’s great hall in 2017, the blue whale that replaced it was named “Hope.”

 **What the sign says / What we observe / How Christians read it.**  **What the sign says:** “*Apatosaurus*. Late Jurassic, 150 million years ago. This giant plant-eater roamed the floodplains of western North America in herds, using its whip-like tail to defend itself.” **What we observe:** a large sauropod skeleton, partly real bone and partly cast, from the Morrison Formation of Wyoming; teeth suited to stripping plants; a very long tail with small vertebrae at the tip; trackways of sauropods walking together in the same formation. The date comes from radiometric dating of volcanic ash in the formation and rests on assumptions about starting amounts, decay rates and closed systems. “Herds” and “whip-like defense” are inferences or reconstructions. **How Christians read it:** many young-earth Christians read the Morrison Formation as laid down during Noah’s Flood about 4,300 to 4,500 years ago and treat “Jurassic” as the name of a set of rock layers, not an age; they agree with the observations and accept many of the inferences. Other Christians accept the date. All agree on what the bones, teeth and tracks show.

Primary source. *W. D. Matthew, Dinosaurs, with Special Reference to the American Museum Collections (American Museum of Natural History, 1915), chapter V, describing the museum’s mounted Brontosaurus. Project Gutenberg eBook #19302.*

The Brontosaurus skeleton, the principal feature of the hall, is sixty-six feet eight inches long. (The weight of the animal when alive is estimated by W.K. Gregory at 38 tons). About one-third of the skeleton including the skull is restored in plaster modelled or cast from other incomplete skeletons. The remaining two-thirds belong to one individual, except for a part of the tail, one shoulder-blade and one hind limb, supplied from another skeleton of the same species. ... The modelling of the skull is based partly upon specimens in the Yale Museum, but principally upon the complete skull of *Morosaurus* shown in another case.

Go deeper. American Museum of Natural History, “Brontosaurus or Apatosaurus?” (amnh.org). Natural History Museum, London, “Diplodocus: this is your life” (nhm.ac.uk). Brian Switek, “Why Brontosaurus Still Matters,” *Smithsonian Magazine* (smithsonianmag.com). W. D. Matthew, *Dinosaurs* (1915), free at Project Gutenberg (eBook #19302); compare its chapters with a modern museum website. Second video topic: “How a dinosaur skeleton is mounted.”

Goes deeper in. Earth Science, the units on fossils, rock layers and dating; Literature, reading critically and the difference between fact and claim; and History, the great museums of the 1900s.

For families. This is a ⏸ stop. Name history: Marsh 1877 and 1879; Riggs 1903; Tschopp, Mateus and Benson, *PeerJ* (2015). The AMNH mount was unveiled in February 1905 and remounted in 1995 (AMNH). The correct skull was confirmed by Berman and McIntosh (1978); the Carnegie Museum replaced its head in 1979. Dippy was unveiled May 12, 1905, its tail raised in 1993 and moved from Hintze Hall in 2017 (NHM). The primary source was checked against Project Gutenberg eBook #19302; it prints “W.K. Gregory” without a space and the weight of 38 tons, far above modern estimates of roughly 15 to 25 metric tons. The sample sign is composed for teaching, in the style of real signs.

PRACTICE

1. **EASY** Name the four layers of a museum sign and give one example of each.
2. **MEDIUM** Why was the name Brontosaurus dropped in 1903, and why did it return in 2015?
3. **MEDIUM** What was wrong with the head on the 1905 Brontosaurus mount, and when was it corrected at the American Museum?
4. **CHALLENGE** **Primary source.** Sort five statements from Matthew’s text into observation or reconstruction, and identify the one estimate that has changed most. Then convert “sixty-six feet eight inches” to meters.
5. **CHALLENGE** In 1905 the American Museum’s Brontosaurus was about one-third plaster. If the mounted skeleton was 20.3 m long and the plaster was spread evenly, about how many meters of it were plaster? Then write a one-sentence label that would tell visitors honestly what they are seeing.
6. **MEDIUM** Your younger brother laughs at a museum sign and says, “That’s all lies.” How would you answer him, using this stop?

Make it a game · Layer Sort Relay. Write 20 statements from dinosaur signs on slips (a mix of observations, inferences, reconstructions and framework claims). Set four bowls at the far side of the room, labeled with the four layers. Two teams race to carry one slip at a time to the right bowl. At the end, check every slip together; any slip in the wrong bowl costs a point, and a team can win a point back by explaining why the slip was hard to sort.

Scripture. “These were more noble than those in Thessalonica, in that they received the word with all readiness of mind, and searched the scriptures daily, whether those things were so.” (Acts 17:11, KJV)

The Bereans listened eagerly and checked carefully, even when the apostle Paul was speaking. Reading a museum sign well is the same habit: an open mind, a careful search and a standard of truth, which for the Christian is God’s Word.

Practice: answers

1. Observation (“found in the Morrison Formation”); inference (“its teeth show it ate plants”); reconstruction (“greenish skin,” “lived in herds”); framework claim (“lived 150 million years ago,” “evolved from”).
2. In 1903 Elmer Riggs concluded that Brontosaurus and Apatosaurus were the same genus, so the older name, Apatosaurus (1877), had priority. In 2015 Tschoop and colleagues compared many sauropod skeletons and concluded that Brontosaurus differed enough to be its own genus again.
3. No skull had been found with the skeleton, so the museum modeled one mainly on Morosaurus (Camarasaurus), a short, boxy head. The true head was long and low, like Diplodocus. The American Museum replaced it in its 1995 remount.
4. Observations: the skeleton is sixty-six feet eight inches long (as mounted); two-thirds belongs to one individual; part of the tail, a shoulder blade and a hind limb came from another skeleton. Reconstructions: about one-third, including the skull, is restored in plaster; the skull is modeled on Morosaurus. The estimate that has changed most is the weight: Gregory’s 38 tons versus modern estimates of roughly 15 to 25 metric tons. $66\text{ ft } 8\text{ in} = 66.67\text{ ft} \times 0.3048 \approx 20.3\text{ m}$.
5. $20.3 \div 3 \approx 6.8\text{ m}$. Sample label: “About two-thirds of this skeleton is real fossil bone from one animal; the rest, including the skull, is modeled in plaster from other specimens.”
6. Explain that most of the sign is true observation about real bones, and much of the rest is careful inference. Only certain parts, such as the date or “evolved from,” are framework claims we read differently. We should read accurately, respect the people who work there, give credit for good work and calmly name what we disagree with, as the Bereans examined carefully (Acts 17:11).

4.9 SOFT TISSUE AND DATING

OBJECTIVES

- Summarize the soft-tissue and protein discoveries in dinosaur bone from 2005 onward, and the competing explanations for them.
- Explain how radiometric dating works, calculate with half-lives, and name the three assumptions every radiometric date rests on.
- Evaluate young-earth and mainstream arguments about dating fairly, including a weak point on each side.

Warm-up. A candle is burning on a table. It is now 10 cm tall, and you measure that it burns 2 cm every hour. How long has it been burning? Write your answer. Then write down everything you had to assume to get it. (Hint: how tall was it when it was lit?)

Video slot. Video coming. Mary Schweitzer and soft tissue in dinosaur bone; how radiometric dating works; half-life explained. Search approved channels (North Carolina State University, Smithsonian, the U.S. Geological Survey for dating basics; for creation-friendly framing, Answers in Genesis, the Institute for Creation Research or Creation Ministries International once vetted); preview first.

KEY TERMS

collagen

The main protein in bone, skin and tendon. Its amino-acid sequence can be read by mass spectrometry.

radioactive decay

The change of an unstable “parent” atom into a “daughter” atom, such as uranium-238 into lead-206 or potassium-40 into argon-40.

half-life

The time for half of the parent atoms in a sample to decay. Carbon-14: about 5,730 years; potassium-40: about 1.25 billion years; uranium-238: about 4.47 billion years.

closed system

A rock or mineral that has neither gained nor lost parent or daughter atoms since it formed, except by decay. Radiometric dating assumes this.

volcanic ash bed

A layer of volcanic ash in sedimentary rock. Its crystals (such as zircon or sanidine) are what radiometric dating usually measures; the fossils themselves are dated by their position near such beds.

contamination

Material from outside a sample, such as modern bacteria, carbon or handling residue, that can mix into it and change a test result.

CORE IDEAS

Soft tissue in a T. rex. In 2005 Mary Schweitzer and her colleagues reported in *Science* that when they dissolved the minerals from pieces of a T. rex thighbone (MOR 1125, from the Hell Creek Formation in Montana), stretchy, transparent, branching vessels remained, with small round structures inside and cell-like shapes called osteocytes in the bone. In 2007 a team led by John Asara read short amino-acid sequences of collagen from the same bone. In 2009 Schweitzer's team reported collagen from a duck-billed dinosaur, *Brachylophosaurus*, and sent samples to several laboratories to check; in 2017 another study confirmed the *Brachylophosaurus* collagen sequences. Other teams have since reported traces of original proteins or cell-like structures in other dinosaur fossils.

Why it surprised everyone. Proteins are long chains that fall apart over time, faster in warmth and water. Most scientists had taught that no original protein could last more than a few million years at most, let alone the 68 million years assigned to MOR 1125. Schweitzer has said she checked her results again and again before she believed them. The observation is now well supported. The argument is about what it means.

Two readings. Young-earth Christians say soft tissue and collagen fit much better with bones buried in the Flood about 4,300 to 4,500 years ago. Mainstream scientists propose ways tissue might last far longer. In 2014 Schweitzer's team showed that ostrich blood vessels soaked in a solution of iron from red blood cells stayed intact for two years, while those in plain water rotted within days; iron can cross-link proteins much as embalming fluid does. Others suggested that some of the "vessels" are bacterial films formed later, though the protein sequences argue against that for at least some samples. Schweitzer, who is herself a Christian, holds the old-earth view. Science continues, and both sides now cite her work.

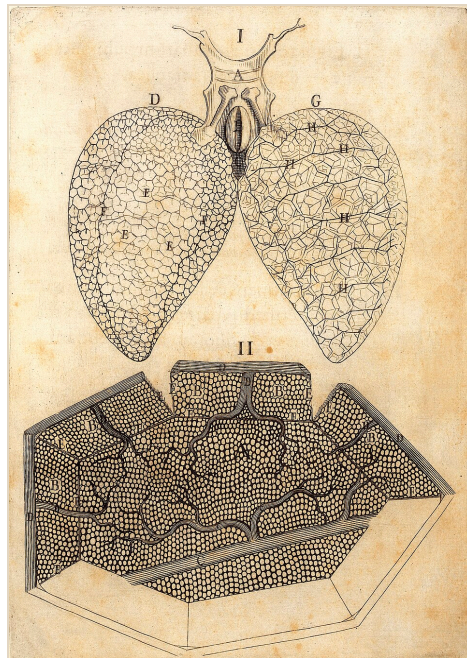
How radiometric dating works. A dinosaur bone is not usually dated directly. Geologists date crystals in volcanic ash beds above or below the bones. Inside a zircon crystal, uranium-238 decays to lead-206 with a half-life of about 4.47 billion years. Measure the ratio of lead to uranium, assume how much lead was there at the start, and calculate the time. After one half-life half the parent remains; after two, a quarter; after three, an eighth. Carbon-14, with a half-life of only 5,730 years, is not used for dinosaurs, because after about ten half-lives, some 57,000 years, too little would remain to measure.

Three assumptions. Every radiometric date rests on assumptions about the past: (1) **starting amounts**, how much daughter was present when the crystal formed; (2) a **closed system**, with no parent or daughter atoms gained or lost except by decay; and (3) a **constant decay rate** through all of history. Decay rates measured in laboratories are very steady under ordinary conditions, and geologists use cross-checks between methods. Young-earth researchers point out that the assumptions about the past cannot be directly observed. The RATE project of the Institute for Creation Research (2000–2005) argued that decay was greatly sped up during creation week or the Flood, citing helium still in zircon crystals; its own scientists admitted that such speeding would release enormous heat that they could not yet explain.

Honest problems on both sides. Young-earth writers point to dates that clearly fail, such as dacite from the 1986 lava dome of Mount St. Helens that gave a potassium-argon “age” of about 350,000 years in a 1996 study by Steven Austin. Mainstream geologists answer that the rock held older crystals and that the method is not suited to very young rocks. Some creation researchers have also reported carbon-14 in dinosaur bones; mainstream scientists answer that modern carbon easily contaminates fossils. Mainstream dating, for its part, must still explain the proteins. A fair student learns the strongest form of each argument before deciding.

Dates change. In 1915 the American Museum’s handbook said its Allosaurus bones from the Morrison Formation had been “buried for say eight million years” (see the primary source). Today’s signs say about 150 million. That growth does not prove today’s numbers wrong, but it shows that dates for the unobserved past are interpretations, built on methods and assumptions, and open to revision. Observations, such as a stretchy vessel under a microscope, stay put.

PICTURE STUDY



Engraved plate of a frog's lung, from De pulmonibus observationes anatomicae, Marcello Malpighi (plate engraved for his letters), 1661 · Engraving · Copies in historic medical libraries, including the Wellcome Collection, London

Wikimedia Commons · CC BY 4.0

In 1661 the Italian physician Marcello Malpighi (1628–1694) looked at the lung of a frog through an early microscope and saw what no one had seen before: tiny vessels, now called capillaries, linking the arteries and the veins. William Harvey had argued in 1628 that blood circulates, but could not see how it passed from arteries to veins. Malpighi published his discovery in two letters with engraved figures. More than three hundred years later, Mary Schweitzer looked through a microscope at branching vessels too, this time from inside a dinosaur bone.

Look closely

- Follow one vessel from where it is thickest to where it branches into the finest lines. How many times does it branch?
- Look for numbers or letters on the plate. What do you think they label?
- Compare this branching pattern with a tree, a river and a lightning strike. What do they share?

Talk about it

1. Malpighi reported only what he saw and let others test it. How is that like the way Schweitzer reported her vessels?
2. Why does the finest branching of blood vessels make soft tissue in a fossil so hard to explain over very long ages?

Safety first. Light candles only with an adult present, on a heat-safe surface away from paper and curtains, and never leave a flame unattended.

HANDS-ON: THE CANDLE CLOCK: TESTING ASSUMPTIONS

Use a burning candle as a model “clock” to see how a date depends on assumptions about the past, then do real half-life calculations.

You will need

- Two identical new candles, a ruler, a candleholder and matches (with an adult)
- A timer or clock
- Paper and a calculator

Steps

1. Measure a new candle. Light it with an adult and record its height every 15 minutes for one hour. Calculate the burn rate in cm per hour.
2. Have an adult secretly prepare the second candle: light it for an unknown time, perhaps blowing it out for a while or trimming it, then hand it to you. Measure its height.
3. Calculate how long it has burned, assuming it started at the full height of a new candle and burned at your measured rate. Then ask the adult what really happened. Which assumption failed: starting height, steady rate or no interference (closed system)?
4. **Half-life practice.** A sample starts with 1,000 parent atoms. Fill in a table showing parent and daughter atoms after 1, 2, 3, 4 and 5 half-lives. Then calculate: if 1/8 of the uranium-238 remains, how many years have passed?
5. Write a paragraph connecting the candle to radiometric dating: name the three assumptions and say which one young-earth researchers most often question, and which cross-checks mainstream geologists rely on.

Check your work

- I measured a real burn rate and calculated the second candle's time.
- My half-life table is correct for five half-lives.
- I named all three assumptions and connected each to the candle.

FIELD NOTEBOOK

1. Draw a microscope view of a branching vessel with small round structures inside. Label it "observation" and write two interpretations beneath it.
2. Draw a half-life graph: parent atoms (100, 50, 25, 12.5, 6.25) against half-lives (0 to 4).
3. **Narration (the parent keeps this).** Write one paragraph explaining what Mary Schweitzer found, how radiometric dates are calculated, and why the three assumptions matter for how Christians read the dates on museum signs.

Did you know? The T. rex thighbone was broken only because it was too heavy for a helicopter to lift in its plaster jacket, so the team split it, and fragments went to Schweitzer. Mass spectrometry, the method used to read the collagen, weighs fragments of molecules so precisely that it can tell which amino acids they contain. Malpighi's discovery of capillaries came only a few years after his country's scientists began using microscopes; he is called a founder of microscopic anatomy.

 **What the sign says / What we observe / How Christians read it.**  **What the sign says:** "This Tyrannosaurus lived 68 million years ago. Scientists were amazed to find soft tissue preserved in its bone." **What we observe:** flexible branching vessels, cell-like structures and collagen sequences from dinosaur bone, confirmed in more than one laboratory; volcanic ash beds in the same formations with measurable ratios of parent and daughter atoms. The 68-million-year date is calculated from those ratios, assuming known starting amounts, closed systems and constant decay rates. **How Christians read it:** many young-earth Christians see the soft tissue as strong evidence that the bones are thousands, not millions, of years old, buried in the Flood, and question the assumptions behind the dates. Mary Schweitzer, a Christian with an old-earth view, thinks iron helped preserve the tissue for millions of years. All agree on the observation: original soft material survives in some dinosaur bones.

Primary source. *W. D. Matthew, Dinosaurs, with Special Reference to the American Museum Collections (American Museum of Natural History, 1915), chapter IV, describing an Allosaurus skeleton from the Cope Collection. Project Gutenberg eBook #19302.*

Although collected by the crude methods of early days, it consisted of the greater part of the skeleton of a single individual, with the bones in wonderfully fine preservation, considering that they had been buried for say eight million years. They were dense black, hard and uncrushed, even better preserved and somewhat more complete than the two fine skeletons of Allosaurus from Bone-Cabin Quarry, the greatest treasures that this famous quarry had supplied.

Go deeper. Mary Schweitzer, “Blood from Stone,” *Scientific American* (December 2010), her own account. Brian Thomas, articles on dinosaur soft tissue at the Institute for Creation Research (icr.org), for the young-earth reading. U.S. Geological Survey, “Radiometric Time Scale” and related pages (usgs.gov), for how mainstream dating works. Second video topic: “How mass spectrometry identifies proteins.”

Goes deeper in. Earth Science, the dating unit; Life Science, high-school Biology, proteins and cells; and Arithmetic, exponents and halving.

For families. This is a ⏸ stop. Sources: Schweitzer et al., *Science* 307 (2005); Asara et al., *Science* 316 (2007); Schweitzer et al., *Science* 324 (2009); Schroeter et al., *Journal of Proteome Research* (2017); iron hypothesis, Schweitzer et al., *Proceedings of the Royal Society B* (2014); biofilm alternative, Kaye et al., *PLoS ONE* (2008). RATE results: Vardiman, Snelling and Chaffin, eds., *Radioisotopes and the Age of the Earth*, vol. 2 (ICR/CRS, 2005), including the acknowledged heat problem. Mount St. Helens: S. A. Austin, *CEN Technical Journal* 10:3 (1996). Half-lives are standard values. The primary source was checked against Project Gutenberg eBook #19302. Schweitzer has spoken publicly of her Christian faith. The stop presents both views fairly.

PRACTICE

1. **EASY** What did Mary Schweitzer’s team report in 2005, and from which dinosaur?
2. **MEDIUM** Name the three assumptions behind every radiometric date.
3. **MEDIUM** Why is carbon-14 not used to date dinosaur fossils in mainstream science, and why do some creation researchers test for it anyway?
4. **CHALLENGE** **Primary source.** In 1915 Matthew said the Morrison Allosaurus bones had been “buried for say eight million years.” Today’s museums give about 150 million years. By what factor has the estimate grown? Also, what words in the passage show Matthew did not regard his figure as exact?
5. **CHALLENGE** Potassium-40 has a half-life of about 1.25 billion years. A crystal contains one-quarter of its original potassium-40. (a) How many half-lives have passed? (b) How many years does that calculate to? (c) Name the assumption a young-earth researcher would most likely question, and the answer a mainstream geologist would give.
6. **MEDIUM** Give one argument from each side that the other side must answer.

Make it a game • Half-Life Countdown. Each player starts with 32 dried beans in a cup (parent atoms). Shake and pour; every bean that lands with its mark up (draw a dot on one side first) has “decayed” and moves to a second pile (daughter atoms). Count and record after each round. Who reaches one parent bean first? Afterward, use your table to ask: if a friend handed you a cup with 8 parent and 24 daughter beans, how many rounds would you say had passed, and what would you need to assume?

Scripture. “Where wast thou when I laid the foundations of the earth? declare, if thou hast understanding.” (Job 38:4, KJV)

God reminds Job that no human being saw the beginning. Our methods for dating the past are useful tools, but they rest on assumptions about times no one observed. The One who was there has spoken, and that is the surest starting point.

Practice: answers

1. Flexible, transparent, branching vessels and cell-like structures remaining after the minerals were dissolved from a T. rex thighbone (MOR 1125) from Montana.
2. (1) The starting amount of daughter atoms is known; (2) the sample has been a closed system, with nothing gained or lost except by decay; (3) the decay rate has been constant.
3. Its half-life is only about 5,730 years, so after about ten half-lives (some 57,000 years) too little would remain to measure; bones tens of millions of years old should have none. Some creation researchers test for it because any original carbon-14 would suggest the bones are thousands, not millions, of years old; mainstream scientists answer that what is found comes from modern contamination.
4. $150 \div 8 \approx 19$ times. The word “say” (“for say eight million years”) marks the figure as a rough estimate. The growth shows that age estimates for the unobserved past depend on the methods and assumptions in use and have changed greatly.
5. (a) One-quarter = $(1/2)^2$, so 2 half-lives. (b) 2×1.25 billion = 2.5 billion years. (c) A young-earth researcher would most likely question the constant decay rate (or the starting amount, or a closed system); a mainstream geologist would answer that decay rates measured in labs are extremely steady and that independent methods give consistent results.
6. Young-earth argument mainstream must answer: original proteins and soft tissue survive in dinosaur bone, though proteins were expected to break down within a few million years at most. Mainstream argument young-earth must answer: if radioactive decay was greatly sped up, the heat released would be enormous, as the RATE scientists themselves acknowledged.

4.10 FEARFULLY MADE: DESIGN IN DINOSAURS

OBJECTIVES

- Explain four examples of fitted design in dinosaurs: sauropod air-filled bones, hadrosaur teeth, the Parasaurolophus crest and dinosaur eggs and nests.
- State the design argument from Romans 1:20 and William Paley, and the main objection to it, fairly.
- Build and test a model of one dinosaur feature, and write a short design analysis of it.

Warm-up. Pick up a pencil and a drinking straw of about the same length. Which is lighter? Which is easier to bend sideways? Which would hold more weight if you stood it on end and pressed down? Write your guesses, then test them gently. Engineers and builders use hollow tubes for a reason, and so do many of God's creatures.

Video slot. Video coming. Sauropod air sacs and hollow vertebrae; hadrosaur dental batteries; the Parasaurolophus crest sound model; dinosaur eggs and nesting. Search approved channels (American Museum of Natural History, Natural History Museum London, Royal Tyrrell Museum, Smithsonian; for creation-friendly framing, Answers in Genesis, the Institute for Creation Research or Creation Ministries International once vetted); preview first.

KEY TERMS

pneumatic bone

Bone with internal air spaces connected to the lungs' air sacs, as in birds. Many sauropod and theropod vertebrae were pneumatic.

air sac

A thin, balloon-like extension of the breathing system. In birds, air sacs push air through the lungs in one direction, which is very efficient.

dental battery

Hundreds of teeth packed in columns in the jaw, with new teeth growing up to replace worn ones, forming one grinding surface, as in duck-billed dinosaurs.

resonating chamber

A hollow space in which air vibrates and makes sound louder or deeper, like the body of a guitar or the tube of a trumpet.

design argument

The argument that features of the natural world show purpose and point to a wise Designer (Romans 1:20).

natural selection

The process in which living things better suited to their surroundings survive and reproduce more. Creationists agree it happens within kinds; mainstream biology says it

explains the origin of all designs.

CORE IDEAS

“Clearly seen.” Paul writes that God’s “eternal power and Godhead” are “clearly seen, being understood by the things that are made” (Romans 1:20), and Job says to “ask now the beasts, and they shall teach thee” (Job 12:7). In 1802 William Paley opened his *Natural Theology* with a famous comparison: a man who finds a stone on a heath might think it had always lain there, but a man who finds a watch, with its parts fitted together for a purpose, knows it had a maker. Paley argued that living things show far more fitted design than any watch. Richard Owen, who named the dinosaurs, believed the same. Dinosaurs give us remarkable examples.

Light necks that breathe. A sauropod’s neck could be 9 to 15 m long. A solid neck that size would be impossibly heavy to hold up. But the neck vertebrae of sauropods were honeycombed with air spaces, connected, as in birds, to air sacs. In some sauropods air may have made up more than half the volume of a neck vertebra. The bones were built like the girders of a bridge: thin walls and struts where force runs, empty space elsewhere. And if sauropods breathed as birds do, air flowed in one direction through the lungs, an efficient design for a huge body. One system lightened the skeleton and served the lungs at once.

Teeth like a file. Duck-billed dinosaurs such as *Edmontosaurus* had dental batteries: hundreds of teeth stacked in columns, with up to several replacement teeth waiting under each working one. Together they formed a single grinding surface like a rasp, constantly renewed. In 2012 Gregory Erickson’s team found that hadrosaur teeth contained six kinds of tissue, two more than the teeth of horses, cows or elephants, which have four. The different tissues wore at different rates, keeping ridges sharp as the animal chewed tough plants. Erickson called them “walking pulp mills.”

A trumpet on the head. *Parasaurolophus* had a long, backward-curving crest. Inside, the nasal passages ran up through the crest and back down, a looped tube more than a meter long in adults. In 1997 scientists at Sandia National Laboratories built a computer model from CT scans of a skull and played air through it; it produced a deep, rumbling tone. Many paleontologists think the crest helped *Parasaurolophus* call to its herd, and juveniles with smaller crests would have sounded higher.

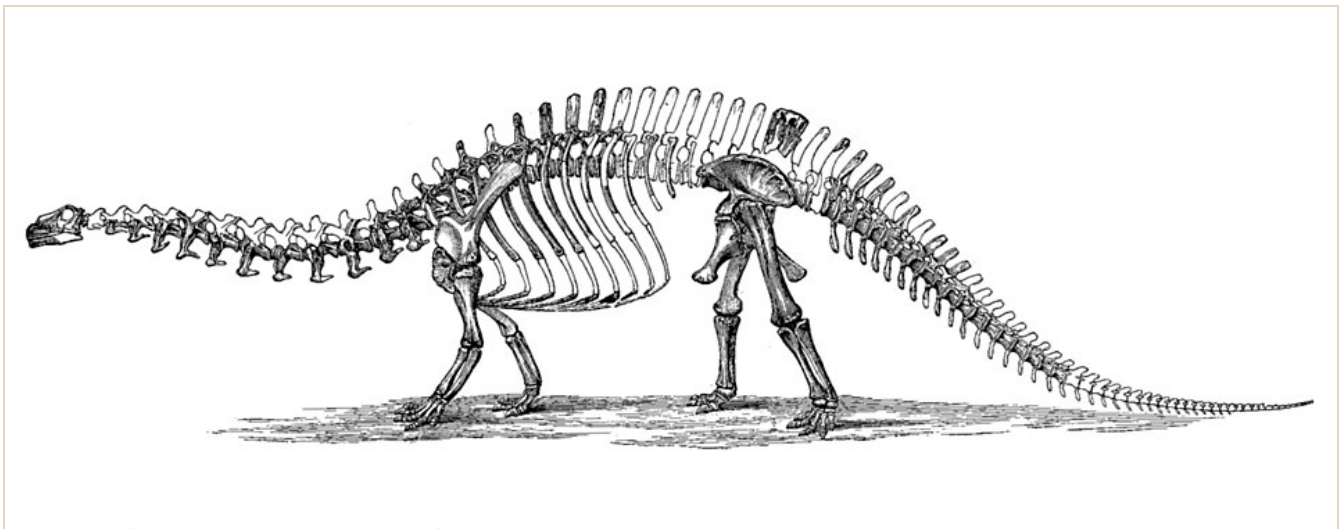
Eggs and parents. A dinosaur egg must let oxygen in and carbon dioxide out through thousands of tiny pores, but not so many that the embryo dries out. Eggshell structure varies by kind, matching nests that were buried, half-buried or open. In 1978 Jack Horner and Bob Makela were shown baby dinosaur bones in a Montana rock shop, owned by Marion Brandvold, who had found them; the trail led to a nesting ground with fossil babies whose leg bones were not yet strong enough to walk far, suggesting the parents fed them; Horner named the dinosaur *Maiasaura*, “good mother lizard.” Oviraptorid skeletons have been found sitting on their nests, arms spread over the eggs like brooding birds.

The objection, fairly stated. Mainstream biology answers that natural selection, working over long ages, produces the appearance of design without a designer. Creationists agree

that natural selection is real; it trims and adapts within kinds. But they argue that it cannot create new, coordinated systems such as an air-sac breathing system, where several parts must work together before any of them is useful; the biochemist Michael Behe called such systems “irreducibly complex” (1996). Christians also admit that not every feature looks ideal to us, and that in a fallen world (Romans 8:20-22) teeth and claws became weapons. The design argument does not prove every doctrine of the faith, but it points honestly to a Maker.

Fearfully made. David praised God because “I am fearfully and wonderfully made” (Psalm 139:14). The same God who knit David in the womb designed the sauropod neck and the hadrosaur tooth. To study a dinosaur carefully is to read one page of the book of creation, written by the God of Scripture.

PICTURE STUDY



Restoration of Brontosaurus, Othniel Charles Marsh (drawn under his direction), 1896 (a version of the restoration first published in 1891) · Printed plate · From Marsh, *The Dinosaurs of North America*, Sixteenth Annual Report of the United States Geological Survey (Washington, 1896)
Wikimedia Commons · Public domain

O. C. Marsh (1831-1899) of Yale first published a skeleton restoration of *Brontosaurus* in 1891, the first full skeletal drawing of a sauropod. This version appeared in his great 1896 report for the U.S. Geological Survey and became a model for mounts and paintings for decades. Marsh drew the bones from his specimens and filled in missing parts, including the head, which, like the 1905 museum mount (Stop D8), was based on the wrong kind of sauropod. Look past the errors to the engineering: the long neck, the arched back, the column-like legs.

Look closely

- Look at the neck vertebrae. Are they large or small compared with the back vertebrae? What would make a large vertebra light?
- Look at the legs. How are they built to hold great weight?

- Find the highest point of the back. How might the backbone work like a bridge between the front and back legs?

Talk about it

1. Marsh got the head wrong but drew the neck and legs well. What does this tell you about which parts of a reconstruction to trust most?
2. Choose one part of this skeleton and explain how its design fits its purpose, as an engineer would.

Safety first. Cutting tubing should be done by an adult or with an adult's help, on a cutting board, with the blade moving away from the body. Wash the hose end before putting your lips on it.

HANDS-ON: THE CREST TRUMPET AND A DESIGN DOSSIER

Build a simple model of the *Parasaurolophus* crest to hear how a longer tube makes a deeper sound. Then write a one-page design dossier on any dinosaur feature from this stop.

You will need

- A garden hose or vinyl tubing about 2 m long, and a kitchen funnel that fits one end
- Scissors or a utility knife (with an adult)
- A tape measure
- Optional: a free tuner or pitch app on a phone, used by a parent

Steps

1. Fit the funnel into one end of the tube as a bell. Buzz your lips into the other end, like a trumpet player. Listen to the pitch.
2. With an adult, cut the tube to 1.5 m, then 1 m, then 0.5 m, testing the sound each time. Record each length and whether the sound got higher or lower (or the note name from a tuner).
3. Compare: an adult *Parasaurolophus* crest held a looped tube more than a meter long; a juvenile's was much shorter. What would a herd of adults and young sound like?
4. Write a design dossier with four headings: *The problem* (what the animal needed), *The solution* (the feature), *How it works* (with a labeled sketch), *What it shows* (connect to Romans 1:20, and state fairly how a mainstream biologist would explain the feature).

Check your work

- I tested at least four tube lengths and recorded the results.
- I can explain why a longer tube makes a lower sound.
- My dossier has all four headings and states the other view fairly.

FIELD NOTEBOOK

1. Draw a cross-section of a sauropod neck vertebra showing the air spaces and thin struts, beside a solid bone of the same size. Label which is lighter and why.
2. Draw a hadrosaur dental battery: columns of teeth with replacement teeth underneath and the grinding surface on top.
3. **Narration (the parent keeps this).** Write one paragraph on one dinosaur feature that shows design. Describe how it works, connect it to Psalm 139:14 or Romans 1:20, and state the main objection to the design argument fairly in one sentence.

Did you know? Birds today have the same air-sac system that is inferred for sauropods and theropods; a bird's hollow bones are part of its breathing system. A hadrosaur could have had more than a thousand teeth in its jaws at one time, counting the replacements. Many sauropod eggs were round and only about 15 to 20 cm across, smaller than a soccer ball, though the adults that laid them weighed many tons.

Primary source. *Job 12:7-9 and Romans 1:20, King James Version (1611).*

Job 12:7 But ask now the beasts, and they shall teach thee; and the fowls of the air, and they shall tell thee:

8 Or speak to the earth, and it shall teach thee: and the fishes of the sea shall declare unto thee.

9 Who knoweth not in all these that the hand of the LORD hath wrought this?

Romans 1:20 For the invisible things of him from the creation of the world are clearly seen, being understood by the things that are made, even his eternal power and Godhead; so that they are without excuse:

Go deeper. William Paley, *Natural Theology* (1802), public domain and available free online; read chapter 1 on the watch. Answers in Genesis and the Institute for Creation Research articles on design in dinosaurs (answersingenesis.org, icr.org). Royal Tyrrell Museum (tyrrellmuseum.com) pages on hadrosaurs and their teeth. Second video topic: "How birds breathe: air sacs and one-way airflow."

Goes deeper in. Life Science, high-school Biology, the units on design in living things, breathing systems and teeth; Earth Science, fossils; and Arithmetic, for measuring and graphing the crest-trumpet results.

For families. Hadrosaur teeth: Erickson et al., *Science* (October 2012). Parasaurolophus sound model: Sandia National Laboratories with the New Mexico Museum of Natural History (1997). Maiasaura: Horner and Makela, *Nature* (1979), from a site found in 1978. Brooding oviraptorids: Norell et al., *Nature* (1995). Sauropod air spaces follow published work on pneumatic vertebrae; the "more than half" figure is hedged because it varies by species and bone. Michael Behe, *Darwin's Black Box* (1996). Paley's watch passage is summarized, not quoted, because a verified public-domain text could not be checked

word for word here. The design argument is presented with its main objection stated fairly.

PRACTICE

1. **EASY** What made sauropod necks light enough to hold up?
2. **MEDIUM** What is a dental battery, and what did Erickson's 2012 study find about hadrosaur teeth?
3. **MEDIUM** Summarize William Paley's watch argument and state the main objection to it.
4. **CHALLENGE** **Primary source.** Job 12:7-9 tells us to "ask now the beasts." Choose one dinosaur feature from this stop and write the "answer" it gives, in two or three sentences, connecting it to Romans 1:20. Then explain what Romans 1:20 says the creation reveals and what it does not reveal.
5. **CHALLENGE** In an air column closed at one end, the lowest note has a wavelength about four times the tube's length. Sound travels about 343 m/s. Estimate the frequency of the lowest note for a 1.2 m tube and for a 0.4 m tube (frequency = speed ÷ wavelength). What does this suggest about adults and juveniles?
6. **MEDIUM** What do creationists agree natural selection can do, and what do they argue it cannot do?

Make it a game · Engineer's Challenge. One player names a problem a dinosaur faced ("hold up a 12-meter neck," "chew tough plants all day," "call to the herd across a valley," "keep an egg from drying out"). The others race to sketch a solution in 60 seconds. Then reveal the real design from this stop and award points for the sketch closest to it. Finish by reading Psalm 139:14 together.

Scripture. "I will praise thee; for I am fearfully and wonderfully made: marvellous are thy works; and that my soul knoweth right well." (Psalm 139:14, KJV)

David looked at his own body and praised God. A careful look at a dinosaur skeleton can lead to the same praise: "marvellous are thy works." The study of creation is meant to end in worship of the Creator.

Practice: answers

1. Their vertebrae were full of air spaces connected to air sacs, as in birds, with thin walls and struts like the girders of a bridge.
2. A dental battery is hundreds of teeth stacked in columns with replacements growing up beneath, forming one grinding surface. Erickson's team found hadrosaur teeth had six kinds of tissue, more than the four in horse, cow or elephant teeth, wearing at different rates to keep the grinding surface sharp.
3. Paley said that a stone found on a heath might have lain there forever, but a watch, with parts fitted together for a purpose, must have had a maker; living things show far more fitted design, so they too must have a Maker. The main objection is that natural selection over long ages can produce the appearance of design without a designer.

4. Sample: The Parasaurolophus crest answers that God designed a looped tube more than a meter long to make a deep call that carried across a herd, a fitted solution showing wisdom. Romans 1:20 says the creation reveals God's "eternal power and Godhead," so that people are without excuse. It does not reveal the gospel, the name of Christ or the way of salvation; for those we need Scripture.
5. 1.2 m tube: wavelength ≈ 4.8 m; $343 \div 4.8 \approx 71$ Hz, a deep rumble. 0.4 m tube: wavelength ≈ 1.6 m; $343 \div 1.6 \approx 214$ Hz. Adults with long crests would call much lower than juveniles with short crests, so a herd could tell young from old by sound. (A real crest is curved and partly divided, so these are rough estimates.)
6. They agree it trims and adapts populations within created kinds (for example, beak sizes or color changes). They argue it cannot create new, coordinated systems in which several parts must all be present before any of them is useful, such as an air-sac breathing system.

TRAIL 4 BADGE QUIZZES

The badge quizzes are optional. The student answers in writing, in complete sentences, without notes; a parent checks the answers against the key. Four right out of five earns each badge. Badges and the certificate are earned by doing the stops and keeping the narrations, not by scores.

Badge quiz 1 (Stops 1–5)

1. On which day of creation were the dinosaurs made, and why do plesiosaurs and pterosaurs belong to a different day?
2. Name the three main candidates for Behemoth and the clue in Job 40 that most divides them.
3. How can Leviathan be a real creature in Job 41 and a symbol in Isaiah 27:1?
4. Using an 18-inch cubit, how long was the Ark, and give two reasons creation researchers say dinosaurs would fit aboard.
5. What do mainstream and creation geologists agree about dinosaur bonebeds, and where do they differ?

Badge quiz 2 (Stops 6–10)

6. The KJV word “dragon” translates more than one Hebrew word. Name two and their likely meanings.
7. Describe the young-earth explanation of dinosaur extinction in two stages, and name one observation in the boundary clay.
8. Name the four layers of a museum sign, and tell what was wrong with the 1905 American Museum Brontosaurus.
9. Name the three assumptions behind radiometric dating, and say what Mary Schweitzer found in 2005.
10. Explain one example of design in dinosaurs and connect it to Romans 1:20.

TRAIL CERTIFICATE: MY DINOSAURS AND THE BIBLE RESEARCH NOTEBOOK AND TRAIL D CERTIFICATE

Gather the work from this trail into one notebook with a cover: “Dinosaurs and the Bible: An Expert Research Notebook,” your name and the dates you started and finished.

Include all ten narrations, in order, as the heart of the notebook. Add your Behemoth Brief (Stop D2), your Ark Engineers’ Report (Stop D4), your Museum Sign Rewrite (Stop D8) and one design dossier (Stop D10).

Finish with a one-page essay, 400 to 600 words, answering: “How should a Christian read the dinosaur hall of a natural history museum?” Use at least three primary sources from the trail, state at least one view other than your own fairly, and separate observation from interpretation throughout.

When the notebook is complete, a parent reviews it with the rubric and signs the Trail D certificate.

- **Completeness:** All ten narrations are present, dated and titled, with the four named projects.
- **Use of sources:** Scripture and the 1915 primary source are quoted exactly and cited, and conclusions follow from the evidence.
- **Observation and interpretation:** The student consistently distinguishes what is observed from what is inferred or interpreted, especially with dates.
- **Fairness and clarity:** Other views are stated accurately and without mocking; the writing is clear, organized and free of careless errors.

Answer key

1. The sixth day, with the land animals, since all dinosaurs lived on land. Plesiosaurs were sea creatures and pterosaurs were flying creatures, so they belong with the creatures of the waters and the air made on the fifth day.
2. The hippopotamus, the elephant and a sauropod dinosaur. "He moveth his tail like a cedar" (Job 40:17): a hippo's tail is a short stub and an elephant's is thin, while a sauropod's was huge.
3. Scripture uses real things as symbols. In Job 41 and Psalm 104 Leviathan is a creature God made; in Isaiah 27:1 and Psalm 74 the same creature stands for God's enemies (Egypt, chaos, and finally Satan), just as a lion is a real animal and also a picture of the devil.
4. $300 \text{ cubits} \times 1.5 \text{ ft} = 450 \text{ ft}$. Reasons (any two): only kinds were needed, perhaps about fifty dinosaur kinds or about a hundred animals; most dinosaurs were small to medium-sized; God may have sent young adults, small but able to breed.
5. Both agree the animals were buried rapidly by water-laid sediment, often in catastrophe. They differ on the number and timing: many local disasters over millions of years, or mostly one global Flood a few thousand years ago.
6. *Tannin*, a great sea creature or serpent (Psalm 148:7; Isaiah 27:1), and *tan* (plural *tannim*), most likely a jackal living in ruins (Jeremiah 9:11; Malachi 1:3).
7. First, most dinosaurs died and were buried in the Flood; second, those that came off the Ark died out afterward in a changed world (climate, the Ice Age, scarce food, competition, perhaps hunting). Boundary clay: extra iridium, shocked quartz or glass spherules.
8. Observation, inference, reconstruction and framework claim. The 1905 mount had a head modeled on Morosaurus (Camarasaurus) instead of the long, low head of the real animal, and its tail dragged on the floor; both were corrected in 1995.
9. Known starting amounts, a closed system and a constant decay rate. Schweitzer found flexible, branching vessels and cell-like structures inside a T. rex thighbone after dissolving the minerals; later studies found collagen sequences.
10. Any one, for example: sauropod vertebrae full of air spaces linked to air sacs made a huge neck light and served efficient breathing; hadrosaur teeth with six tissues formed a self-sharpening grinding battery; the Parasaurolophus crest was a long tube for deep calls. Romans 1:20 says God's eternal power and Godhead are clearly seen in the things He has made.

DINOSAURS TRAIL E: SEA AND SKY REPTILES, AND THE ICE AGE

The fifth trail of the Dinosaurs track leaves the dinosaurs themselves to visit the creatures that lived beside them and after them: the ichthyosaurs, plesiosaurs and mosasaurs of the seas; the pterosaurs and the giant *Quetzalcoatlus* of the air; and then the great animals of the Ice Age, the woolly mammoth, the saber-toothed cat and the giant ground sloths, ending at the La Brea Tar Pits and with a museum display of the student's own. Along the way students meet Cuvier, Jefferson, the Peales and the scientists working today, and read the sources in which the first discoveries were reported.

This is the  **Expert** level, for ages 14 and up. Each stop takes 35–50 minutes and includes a full reading with real numbers and honest debates, a primary source where a public-domain text could be checked word for word, a picture study, a hands-on project, a written narration that the parent keeps, six practice questions (two of them challenge problems) and a “Go deeper” list. The track is creation-friendly: period names such as **Jurassic**, **Cretaceous** and **Ice Age** are taught as museum vocabulary, and every stop that gives a date carries the  box *What the sign says / What we observe / How Christians read it*, which sets out the mainstream reading and the young-earth reading fairly, mocking neither.

Stops 1–5 earn the **Sea and Sky badge**, and Stops 6–10 earn the **Ice Age badge** and the **Trail E certificate**. The badge quizzes at the end are optional. Stop E10 asks the student to build and present a museum display on one animal from the trail; that display, with the narrations, makes up the trail portfolio.

BEFORE YOU BEGIN

- Comfort with ratios, squares and cubes, and unit conversion (feet to meters).
- Trail B (Dinosaur Hunters) and the observation-and-interpretation idea from Stop B10 are helpful; a student new to the track should read one  box with a parent first.

MASTERY CHECKLIST

- ☐ I can describe the body plans of ichthyosaurs, plesiosaurs, mosasaurs and pterosaurs, explain how each swam or flew, and say why none of them was a dinosaur.
- ☐ I can explain the square-cube law and use it to discuss the size limits of flyers such as *Quetzalcoatlus*.
- ☐ I can tell mammoths from mastodons by their teeth, describe the main Ice Age animals of North America, and explain the La Brea predator trap.
- ☐ I can read a primary source critically, as with the Maastricht story or Jefferson's argument against extinction, separating facts, judgments and assumptions.
- ☐ I can write a museum label that separates observation from interpretation and present both the mainstream and the young-earth reading of a date fairly.

GO DEEPER: BOOKS, MUSEUM PAGES AND RESOURCES

- **Project Gutenberg** (<https://www.gutenberg.org>): Free full texts used on this trail: Hutchinson's *Extinct Monsters* (#42584), Lucas's *Animals of the Past* (#38013), Seeley's *Dragons of the Air* (#35316) and Rembrandt Peale's *Account of the Skeleton of the Mammoth* (#48915).
- **The Avalon Project: Jefferson's Notes on the State of Virginia** (https://avalon.law.yale.edu/18th_century/jeffvir.asp): Query VI contains Jefferson's discussion of the "mammoth" and his argument against extinction (Stops E6 and E8).
- **La Brea Tar Pits and Museum** (<https://tarpits.org>): Free pages, photos and videos on the pits, Project 23, dire wolves, saber-toothed cats and ground sloths (Stops E7-E9).
- **National Park Service: Pterosaurs in Big Bend** (<https://www.nps.gov/bibe/learn/nature/pterosaur.htm>): The story of *Quetzalcoatlus* and its discovery in Big Bend National Park (Stop E5).
- **Biodiversity Heritage Library** (<https://www.biodiversitylibrary.org>): Old plates and papers by Cuvier, Faujas, Collini and Tilesius, free to view, for picture studies and the Field Notebook.

5.1 ICHTHYOSAURS

OBJECTIVES

- Describe the ichthyosaur body plan (paddles, downturned tail, fin, huge eyes) and explain how each part fits life in open water.
- Explain the evidence that ichthyosaurs gave birth to live young, and why the size estimates for the largest kinds vary so widely.
- Weigh Cuvier's nineteenth-century description against what is known now, and tell apart the observation of shared shapes from two ways of explaining it.

Warm-up. Hold a ruler against your eye: a human eyeball is about 2.4 cm across. Now measure 26 cm on the ruler and draw a circle that wide on paper. That is the measured width of the eye of one ichthyosaur, *Temnodontosaurus*. What would an animal need eyes like that for?

Video slot. Video coming. Ichthyosaurs: Holzmaden fossils with skin outlines and embryos, the giant Ichthyotitan jaw from Somerset, and how dolphins, sharks and ichthyosaurs share a body shape. Search approved channels (Natural History Museum London, Smithsonian, PBS Eons with a parent; for creation-friendly framing, Answers in Genesis or Institute for Creation Research once vetted); preview first.

KEY TERMS

ichthyosaur

"Fish lizard": an air-breathing sea reptile with a dolphin-like body, four paddles and a tail fin. Not a dinosaur and not a fish.

sclerotic ring

A ring of small, overlapping bony plates inside the eye that held its shape. Ichthyosaurs, birds and many reptiles have one; mammals do not.

live birth (viviparity)

Bearing young alive instead of laying eggs. Fossil ichthyosaur mothers have been found with unborn young inside and even in the act of giving birth.

hyperphalangy

Having extra finger bones in each digit. Ichthyosaur paddles were packed with many small, rounded bones, making a stiff but slightly flexible fin.

tail bend

The sharp downward kink in the backbone near the end of an ichthyosaur's tail. The spine ran into the lower lobe of the fin; the upper lobe was soft tissue with no bone.

convergence

Similar shapes in animals that are not closely related, such as the streamlined bodies of sharks (fish), ichthyosaurs (reptiles) and dolphins (mammals).

CORE IDEAS

A reptile shaped like a dolphin. Ichthyosaurs were sea reptiles. They breathed air through nostrils set far back near the eyes, they had the skull and bones of reptiles, and yet in outline they looked astonishingly like dolphins or swordfish: a long narrow snout full of conical teeth, a streamlined body with no neck to speak of, two pairs of paddles, a triangular fin on the back and a crescent-shaped tail fin. The name *Ichthyosaurus*, “fish lizard,” was given in 1819 to the skeletons that Joseph and Mary Anning dug from the cliffs at Lyme Regis (Trail B, Stop B1). Hundreds of fine skeletons have since come from England and from Holzmaden in southern Germany, where some slabs even preserve a dark film outlining the body.

Clues in the soft outline. Early collectors found that most ichthyosaur tails had a sharp downward kink near the end and assumed the backbones had been broken after death. In the 1890s Bernhard Hauff, a quarry owner and preparator at Holzmaden, carefully exposed specimens with the body outline preserved and showed the truth: the spine bent down into the lower lobe of a two-lobed tail fin, and the upper lobe and the back fin were made only of soft tissue. In 2018 a team led by Johan Lindgren reported a *Stenopterygius* from Holzmaden with traces of smooth skin, a layer of what looks like blubber, and pigment suggesting a darker back and a paler belly, the same “countershading” seen in many fish and whales. The paddles were packed with extra finger bones, a stiff hydrofoil for steering, while the tail drove the animal forward.

Eyes as big as dinner plates. Ichthyosaurs had the largest eyes of any backboned animal known. A sclerotic ring of *Temnodontosaurus* shows an eyeball about 26 cm (10 in) across; *Ophthalmosaurus*, only about 4 m long, had eyes about 23 cm wide. Ryosuke Motani and colleagues argued in 1999 that eyes this large gathered enough light to hunt in deep, dim water, and that the bony ring helped keep the eye’s shape under pressure. Other evidence fits deep diving too: some ichthyosaur bones show damage like the bone death found in divers who surface too fast. Stomach contents show what they ate. Many skeletons hold the tiny hooks from the arms of squid-like belemnites, and fish scales are common.

Born in the sea. A reptile built like this could not crawl up a beach to lay eggs, and the fossils show it did not have to. Several Holzmaden mothers contain unborn young, and a few appear to have died while giving birth, with a baby partly out of the body tail-first, as dolphin calves are born, so that the newborn does not drown before it can reach the surface. A small, early ichthyosaur from China, *Chaohusaurus*, was described in 2014 with a baby coming out head-first, showing that not all kinds did it the same way. Fossils of mothers and unborn young buried together also tell us something about burial: they were covered quickly, before scavengers or rot could scatter them.

How big? Ichthyosaurs ranged from about 1 m to giants. *Shonisaurus*, Nevada’s state fossil, reached about 15 m, and *Shastasaurus sikanniensis* from British Columbia about 21 m. In May 2020, eleven-year-old Ruby Reynolds and her father, Justin, found a piece of an enormous jawbone on the beach at Blue Anchor in Somerset, England. In 2024 they joined the scientists who named it *Ichthyotitan severnensis* and estimated a length of about 25 m, close to a blue whale. Notice the honest difficulty: that estimate is scaled from a few jaw

pieces by comparison with smaller relatives. The bone is an observation; the 25 m is a careful, reasonable inference that could change when more of the skeleton turns up.

Reading the resemblance. When Georges Cuvier studied the first skeletons, he called the animal a puzzling mixture of dolphin, crocodile, lizard, whale and fish (see the primary source). Today we would say that sharks, ichthyosaurs and dolphins share a shape because water sets the same rules for all of them: drag rises steeply with speed, so a fast swimmer must be smooth, tapered and driven by a tail. Mainstream biologists call this convergent evolution, the same solution reached separately by unrelated lines. Creation biologists see the same Designer meeting the same engineering problem with three different kinds of creatures, each complete and suited to its life from the start. Both start from the same observation: three unrelated groups share one excellent design. Museum signs place ichthyosaurs in the “Triassic” and “Jurassic” and say they vanished from the record in the Cretaceous; here those are museum words for groups of rock layers, read in the box below.

PICTURE STUDY



The Sea-Dragons as They Lived, John Martin, 1840 · Mezzotint · Frontispiece to Thomas Hawkins, *The Book of the Great Sea-Dragons* (London, 1840)
Wikimedia Commons · Public domain

John Martin was famous for huge, gloomy paintings of Bible scenes such as the Flood and the fall of Babylon. In 1840 the fossil collector Thomas Hawkins asked him to picture the ichthyosaurs and plesiosaurs of Somerset and Dorset for the front of his book. The result looks more like a nightmare than a nature scene, and it shaped how the public imagined “sea-dragons” for a generation.

Look closely

- Find the ichthyosaur. Which features match the fossils (snout, eye, paddles) and which are guesses or mistakes (look at the tail, back and feet)?
- Notice the light. Where does it come from, and what does Martin want you to feel?
- Look at the plesiosaur's neck. Could a real neck bend like that?

Talk about it

1. Hawkins' skeletons had no soft outlines. What would Martin have drawn differently if he had seen the Holzmaden specimens with their tail fins and back fins?
2. Is it fair to judge Martin's picture by what was learned fifty years later? What can it still teach us?

HANDS-ON: THE FISH-LIZARD AUDIT

Test Cuvier's famous five-part description against the anatomy, and build a life-size eye to feel the scale.

You will need

- Poster board or a large paper plate, a compass or string and pencil, a ruler
- Scissors, glue, about 12-15 small rectangles of card
- A printed or library picture of an ichthyosaur skeleton (Natural History Museum or Holzmaden specimen)
- The primary source in the asides

Steps

1. Draw a circle 26 cm across on poster board and cut it out: the eyeball of *Temnodontosaurus*. Draw a 10 cm circle inside it for the pupil and iris area.
2. Glue overlapping card rectangles in a ring between the two circles to model the sclerotic ring. Beside it, draw a 2.4 cm circle for your own eye.
3. Read the primary source. Make a table with five rows (snout, teeth, head and breastbone, paddles, vertebrae) and three columns: "Cuvier compared it to," "What the skeleton shows," "Real relationship or only a resemblance?"
4. Fill in the table using the skeleton picture and this stop. For example, ichthyosaur vertebrae are short, deep discs like a fish's, but they belong to an air-breathing reptile.
5. Write two sentences under the table: what Cuvier got right by careful looking, and what he could not have known in his day.

Check your work

- My eye model is 26 cm across, with a ring of plates.
- My table has five rows and a judgment in each.
- I can explain the difference between a resemblance and a relationship.

FIELD NOTEBOOK

1. Draw an ichthyosaur in side view with its soft outline. Label the snout, sclerotic ring, nostril, front paddle, back fin, tail bend and the two lobes of the tail fin. Shade the parts that have no bone inside.
2. Make a three-column chart, "Shark / Ichthyosaur / Dolphin," with rows for group (fish, reptile, mammal), breathing, tail direction (side to side or up and down) and how the young are born.
3. **Narration (the parent keeps this).** Write one paragraph explaining how scientists know that ichthyosaurs gave birth to live young, and what those same fossils tell us about how quickly the animals were buried.

Did you know? Ichthyosaurs swung their tails from side to side, like sharks, not up and down like dolphins. That is why their tail fins stand upright. The first ichthyosaur skeleton from Lyme Regis was so strange that for several years it was shown and argued over as a kind of crocodile, a fish, or a link between them.

 **What the sign says / What we observe / How Christians read it.**  **What the sign says:** "Ichthyosaurs ruled the seas from about 250 to 90 million years ago, through the Triassic and Jurassic, and died out in the Cretaceous." **What we observe:** ichthyosaur bones are found in marine rock layers on every continent; in the layers museums call "Cretaceous," they become rare and then are not found in the higher layers. Many are beautifully complete, some with skin outlines, stomach contents and unborn young. The ages come from radiometric dating of volcanic layers elsewhere, matched by fossils, and rest on assumptions about steady decay rates, starting amounts and closed systems. **How Christians read it:** many young-earth Christians read these thick, fossil-packed sea deposits as laid down rapidly during the Flood year, which fits the quick burial needed to preserve a mother and her young with their outlines intact. Other Christians accept the long ages. Everyone agrees on the order of the layers and on the need for rapid burial at sites like Holzmaden.

Primary source. *H. N. Hutchinson, Extinct Monsters (London, 1892), Chapter III, "The Great Fish-Lizards." Project Gutenberg eBook #42584.*

The illustrious Cuvier, in his day, considered the fish-lizard to be one of the most heteroclite and monstrous animals ever discovered. He said of this creature that it possessed the snout of a dolphin, the teeth of a crocodile, the head and breast-bone of a lizard, the paddles of a whale or dolphin, and the vertebræ of a fish!

"Heteroclite" means irregular or made of mismatched parts.

Go deeper. Ryosuke Motani's ichthyosaur pages (University of California, Davis) and his article "Rulers of the Jurassic Seas," *Scientific American* (December 2000). Natural History Museum, London: the marine reptile gallery and pages on the Anning ichthyosaurs. Urweltmuseum Hauff, Holzmaden (museum website, with photographs of

skin-outline specimens). H. N. Hutchinson, *Extinct Monsters* (1892), free at Project Gutenberg. Second video topic: “How the Ichthyotitan jaw was found and measured.”

Goes deeper in. Life Science, high-school Biology, the units on classification and animal design (coming soon); Earth Science, the fossils and rock-layers units; and Arithmetic, ratios and scale.

For families. This stop has dates, so it carries the ⏰ box. Figures: *Temnodontosaurus* eye about 264 mm (Motani, Rothschild and Wahl, *Nature* 1999). Blubber and countershading in *Stenopterygius*: Lindgren et al., *Nature* 2018. Head-first birth in *Chaohusaurus*: Motani et al., *PLOS ONE* 2014. *Ichthyotitan*: Lomax et al., *PLOS ONE*, April 2024, with Ruby and Justin Reynolds as co-authors; the 25 m length is an estimate from jaw pieces. The 1819 naming is usually credited to Charles König of the British Museum. The primary source was checked word for word against Project Gutenberg #42584; Hutchinson is reporting Cuvier secondhand, which is worth noticing.

PRACTICE

1. **EASY** Name three ways an ichthyosaur was like a dolphin and two ways it was different.
2. **EASY** What is a sclerotic ring, and what does its size tell us about ichthyosaur eyes?
3. **MEDIUM** Why did early collectors think ichthyosaur tails were broken, and how did Bernhard Hauff show otherwise?
4. **MEDIUM** Give two pieces of fossil evidence that ichthyosaurs bore live young, and one reason live birth made sense for them.
5. **CHALLENGE** A *Temnodontosaurus* eye was about 26 cm across; a human eye is about 2.4 cm. (a) How many times wider was it? (b) If eyes were the same shape, about how many times greater was its volume? (c) Why does the light-gathering area matter more than the width for an animal hunting in dim water?
6. **CHALLENGE** Using the primary source, explain which of Cuvier’s five comparisons describe real relationships and which describe only resemblance. Then state the observation that both convergent evolution and common design start from, and how each explains it.

Make it a game · Shark, Fish-Lizard or Dolphin?. Write twelve features on cards (gills, lungs, hair at birth, sclerotic ring, upright tail fin, flat tail flukes, scales, live birth, extra finger bones, blowhole, cartilage skeleton, nostrils near the eyes). The leader draws a card and players call out which of the three animals have it; some have more than one. A correct call earns a point; the player who explains a tricky one (like live birth, which all three can show) earns two.

Scripture. “O LORD, how manifold are thy works! in wisdom hast thou made them all: the earth is full of thy riches.” (Psalm 104:24, KJV)

“Manifold” means many and varied. A reptile built for open ocean, with eyes for the deep and young born in the water, shows the variety and wisdom the psalmist praised.

Practice: answers

1. Alike (any three): streamlined body, long toothed snout, back fin, tail fin, flippers or paddles, gave birth to live young in the water, breathed air. Different (any two): it was a reptile, not a mammal; its tail fin was upright and swept side to side; it had a bony sclerotic ring in the eye; its paddles were packed with many extra finger bones; its spine bent down into the lower tail lobe.
2. A ring of bony plates inside the eye. Its size gives the size of the eyeball: in *Temnodontosaurus* about 26 cm across, the largest eyes known in any backboned animal.
3. The backbone bends sharply downward near the end of the tail, which looked like damage after death. Hauff's Holzmaden specimens preserved the dark body outline, showing that the spine ran into the lower lobe of a two-lobed tail fin whose upper lobe had no bones.
4. Mothers found with unborn young inside; a few found in the act of giving birth, most with the baby tail-first; a *Chaohusaurus* with a baby coming out head-first. Reason: with paddles instead of legs they could not crawl onto land to lay eggs, and tail-first birth keeps the newborn from drowning before it reaches the air.
5. (a) $26 \div 2.4 \approx 11$ times wider. (b) Volume grows with the cube: $11^3 \approx 1,300$ times. (c) The amount of light gathered depends on the area of the pupil, which grows with the square of the width (about $11^2 \approx 120$ times for an eye of the same proportions), so a big eye can form an image where a small eye sees almost nothing.
6. Only the lizard comparison points toward a real relationship: the ichthyosaur is a reptile, so its lizard-like head and breastbone reflect its true group, while the dolphin snout, whale-like paddles and fish-like vertebrae are resemblances of shape for the same job. The crocodile-like teeth are reptile teeth, but a crocodile is not its close relative. Shared observation: unrelated animals (fish, reptile, mammal) share a streamlined body, fins and tail. Mainstream biology explains this as convergent evolution, separate lines reaching the same solution over time; creation biology explains it as common design, one Creator applying the same good solution to the same problem in different kinds.

5.2 PLESIOSAURS

OBJECTIVES

- Compare the two plesiosaur body plans, the long-necked elasmosaurs and the big-headed pliosaurs, with real lengths and vertebra counts.
- Explain the four-flipper swimming problem and how a 2017 robot experiment helped answer it.
- Show how reconstructions go wrong and get corrected, using Cope's *Elasmosaurus* and the Harvard *Kronosaurus*.

Warm-up. Lie on your stomach and “swim” using only your arms, then only your legs, then all four limbs at once. Which felt strongest? Which was hardest to coordinate? Plesiosaurs were the only large animals ever known to swim with four equal flippers, and scientists argued for nearly two hundred years about how they did it.

Video slot. Video coming. Plesiosaurs: four-flipper swimming, the Southampton robot flipper experiment, elasmosaur neck posture and the *Polycotylus* mother with her unborn young. Search approved channels (Natural History Museum London, Natural History Museum of Los Angeles County, Smithsonian); preview first.

KEY TERMS

plesiosaur

A sea reptile with a broad, flat body, a short tail and four long, wing-like flippers. The name means “near to a lizard.” Not a dinosaur.

elasmosaur

A plesiosaur with an extremely long neck and a small head. *Elasmosaurus* had 72 neck vertebrae.

pliosaur

A short-necked plesiosaur with a huge head and powerful jaws, such as *Liopleurodon* or *Kronosaurus*; the top predators of their seas.

cervical vertebrae

The bones of the neck. Counting them is one of the main ways to tell plesiosaurs apart (people and giraffes both have seven).

underwater flight

Swimming by flapping flippers up and down like wings, as sea turtles and penguins do, instead of rowing them back and forth like oars.

gastrolith

A stone swallowed on purpose and kept in the stomach. Many plesiosaur skeletons contain piles of them; their use (ballast or grinding food) is still debated.

CORE IDEAS

A strange design. In 1821 Henry De la Beche and William Conybeare named *Plesiosaurus*, “near to a lizard,” from scattered bones, and Mary Anning’s nearly complete skeleton of 1823 showed the whole animal (Trail B, Stop B1). Nothing alive is built like it. The body was broad, flat and stiff, held rigid by a basket of ribs above and rows of belly ribs (gastralia) below. The tail was short. All the push came from four long flippers, each a paddle of many finger bones, shaped like a wing in cross-section. Like ichthyosaurs, plesiosaurs breathed air and were reptiles, but they were a separate group with a very different way of moving.

Two body plans. Plesiosaurs came in two broad shapes. The elasmosaurs carried tiny heads on astonishing necks. *Elasmosaurus platyrus* from Kansas was about 10 m long, more than half of it neck, with 72 neck vertebrae; *Albertonectes* from Canada had 76, the most of any known animal. At the other extreme were the pliosaurs, with short necks and enormous heads: the skull of *Kronosaurus* from Australia was over 2 m long, and its teeth were thick cones built for seizing large prey. Between them came many in-between forms. Fossil stomach contents include fish, squid-like belemnites and ammonites for the long-necks, and other marine reptiles for the biggest pliosaurs.

Mistakes and corrections. Plesiosaurs have taught paleontologists humility. In 1868 Edward Drinker Cope described *Elasmosaurus* and drew it with the head on the end of the tail, because he assumed the long part must be the tail. Joseph Leidy pointed out the error by 1870, and Cope tried to recall the printed copies (the rivalry it fed belongs to Stop B6). A century later, the great *Kronosaurus* skeleton mounted at Harvard in 1959 was built partly from plaster and was given too many vertebrae; it was displayed as about 12.8 m long, but later study suggests closer to 9–10 m. In both cases the bones were real; the errors lay in how incomplete material was put together. Correction came from more specimens and more careful comparison.

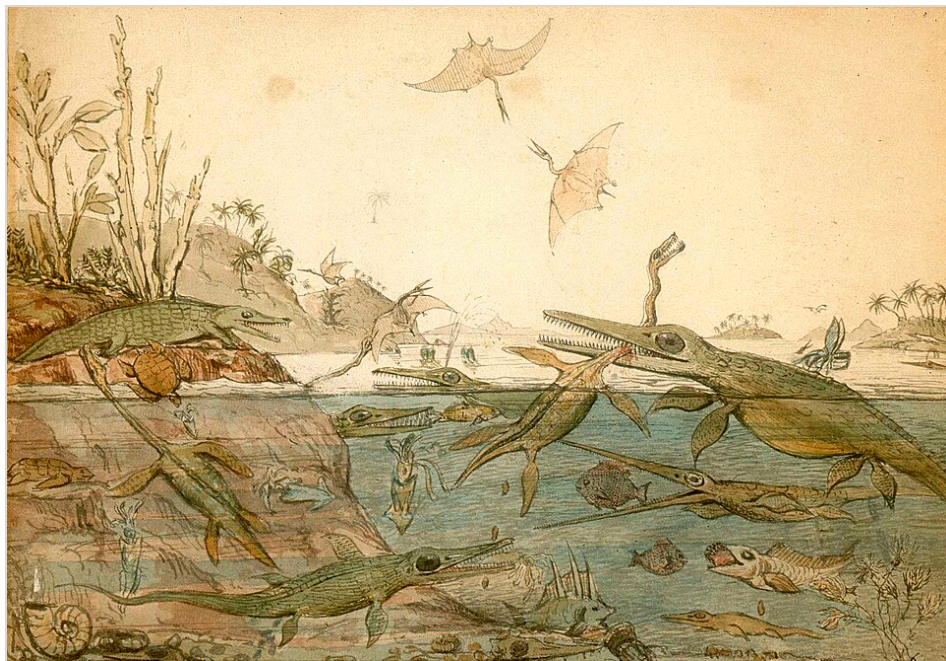
Four flippers. How did they swim? Some said they rowed like oars, others that they “flew” underwater like sea turtles and penguins, and a puzzle remained: why keep two pairs of big flippers when every other strong swimmer uses one pair or a tail? In 2017 a team led by Luke Muscutt at the University of Southampton built 3-D printed flippers scaled from fossils and drove them with a robot in a water tank. When the hind flippers beat in step with the front ones, catching the swirling wake the front flippers left behind, they produced up to about 60 percent more thrust and about 40 percent better efficiency than when they beat alone. Here a modern experiment tested an old idea about a body no one can watch alive.

Necks and babies. Old paintings show elasmosaurs holding their heads high above the water like swans. Studies of how the neck vertebrae fit together suggest otherwise. Each joint could bend only a little, so the neck could curve gently but was held mostly forward and somewhat down. Lifting the head high out of water would have been nearly impossible, since water no longer supports the weight. A long neck may have let the head approach schools of fish before the bulky body startled them. In 2011 Robin O’Keefe and Luis Chiappe described a *Polycotylus* from Kansas, found in 1987, with a single large unborn young inside, about a

third of the mother's length. One big baby, rather than many small ones, suggests that plesiosaur mothers may have cared for their young, as whales and dolphins do.

Legends and limits. Because their silhouette looks like a sea serpent, plesiosaurs are often linked with legends such as the Loch Ness monster. A careful student keeps the evidence separate: the neck posture argues against the classic swan-necked picture, Loch Ness is a fresh-water lake too small and cold to support a family of large reptiles, and no body or bone of a living plesiosaur has ever been found. Christians have good reason to be patient with real puzzles and slow to accept stories that lack evidence. Genesis says God “created great whales, and every living creature that moveth, which the waters brought forth abundantly” (Genesis 1:21); the Hebrew word translated “whales” is broad enough to include great sea creatures in general. Plesiosaurs were among the most unusual of them.

PICTURE STUDY



Duria Antiquior, a More Ancient Dorset, Henry De la Beche (lithograph by George Scharf), 1830 · Watercolor, printed as a hand-colored lithograph · Original watercolor at the National Museum Wales; prints in several museums
Wikimedia Commons · Public domain

Henry De la Beche, who helped name *Plesiosaurus*, painted this scene in 1830. It is one of the very first pictures of a whole ancient world built from fossils, and it is itself a primary source: it shows exactly what a leading geologist believed plesiosaurs looked like and how they lived, seven years after Mary Anning's complete skeleton.

Look closely

- Find the plesiosaurs. How are they holding their necks? Compare with what neck-joint studies suggest today.
- Look at one plesiosaur's flippers. Are they shown rowing, flapping or doing nothing?

- Find the plesiosaur at the surface. What is it doing, and does that fit with an air-breathing animal?

Talk about it

1. List two things De la Beche drew that fossils could show him and two things he had to imagine.
2. One plesiosaur is being bitten by an ichthyosaur. What kind of fossil evidence would prove or disprove that such fights happened?

HANDS-ON: BUILD A NECK: HOW FAR CAN 72 BONES BEND?

Model an elasmosaur neck and test how a neck of many stiff joints behaves.

You will need

- 72 pieces of rigatoni or penne pasta, or 72 large beads or cut drinking-straw pieces
- About 2 m of string or a pipe-cleaner chain
- A protractor, a ruler and tape
- A small ball of clay for the head

Steps

1. Thread the 72 pieces on the string, knotting so that they touch but can tilt slightly. Add the clay head at one end and tape the other end to a table edge.
2. Lay the neck flat and curve it as far as it will go sideways. Measure the angle between the first and last pieces with the protractor, or trace the curve on paper.
3. Hold the taped end level and try to lift the head straight up by pushing from the base only. What happens to the middle of the neck?
4. Work the math: if each of 72 joints could bend about 3° sideways, what is the greatest total curve? Compare it with your model.
5. Look at the *Duria Antiquior* picture again. Write a short “museum correction note” stating what you would change about the necks and why.

Check your work

- My model has 72 segments and a head.
- I measured or traced the greatest curve.
- I wrote a correction note using evidence.

FIELD NOTEBOOK

1. Draw an elasmosaur and a pliosaur from above, to the same scale (1 cm = 1 m). Label the head, neck, four flippers, gastralium and tail. Write the length and neck-vertebra count beside each.
2. Draw a flipper in cross-section like an airplane wing and add arrows for the water flowing over it.

3. **Narration (the parent keeps this).** Write one paragraph telling how scientists corrected one plesiosaur mistake (Cope's *Elasmosaurus*, the Harvard *Kronosaurus* or the swan neck), and what the correction teaches about the difference between bones and reconstructions.

Did you know? Some plesiosaur skeletons hold more than a hundred stomach stones. Scientists still debate whether they were ballast to help the animal stay underwater or tools for grinding hard-shelled food, and they may have done both. The Harvard *Kronosaurus* was blasted out of rock in Queensland, Australia, in 1932, and it took more than twenty-five years of preparation before it went on display.

Go deeper. Muscutt et al., "The four-flipper swimming method of plesiosaurs enabled efficient and effective locomotion," *Proceedings of the Royal Society B* (2017), with a readable summary on the University of Southampton site. Richard Ellis, *Sea Dragons: Predators of the Prehistoric Oceans* (2003). Natural History Museum of Los Angeles County: the *Polycotylus* mother and young on display. Second video topic: "How museums mount a marine reptile skeleton."

Goes deeper in. Life Science, high-school Biology, animal design and movement (coming soon); Earth Science, the fossils units; and Arithmetic, scale drawing and angles.

For families. No public-domain text excerpt could be checked word for word for this stop, so the 1830 picture serves as the primary source. Figures: *Elasmosaurus* about 10.3 m with 72 cervical vertebrae; *Albertonectes* 76 (Kubo, Mitchell and Henderson 2012). Harvard *Kronosaurus*: mounted 1959; the revised length follows McHenry's 2009 study and is still an estimate. Robot experiment: Muscutt et al. 2017 ("up to 60% more thrust and 40% higher efficiency"). *Polycotylus* embryo: O'Keefe and Chiappe, *Science* 2011. Cope's error and Leidy's correction are given briefly here; Stop B6 tells the Bone Wars. The 3° per joint figure in the project is an exercise value, not a measurement. No dates in years are given, so this stop has no ⏰ box.

PRACTICE

1. **EASY** What are the two main plesiosaur body plans? Name one example of each.
2. **EASY** What mistake did Cope make with *Elasmosaurus*, and who corrected him?
3. **MEDIUM** Why is the swan-like, head-high pose of elasmosaurs in old pictures probably wrong?
4. **MEDIUM** What did the 2017 robot flipper experiment find, and why does it help explain why plesiosaurs kept four flippers?
5. **CHALLENGE** *Elasmosaurus* was about 10.3 m long with a neck about 7 m long and 72 neck vertebrae. (a) What fraction of the body was neck? (b) What was the average length of each neck vertebra in cm? (c) If each joint bent at most 3° sideways, what was the greatest total sideways curve, and could the head reach back to touch its own flipper?
6. **CHALLENGE** *Polycotylus* was found with one large unborn young about a third of its mother's length. Explain what that observation is, what is inferred from it, and why one

large baby suggests something different from twenty small ones.

Make it a game • Four-Flipper Relay. Two players kneel one behind the other, the back player holding the front player's waist. Together they must "swim" across a rug by pulling with their arms in rhythm: front pulls, back pulls, front pulls. Try it out of rhythm, then in a steady alternating beat, and time both. Talk about why the rhythm mattered for plesiosaurs.

Scripture. "And God created great whales, and every living creature that moveth, which the waters brought forth abundantly, after their kind, and every winged fowl after his kind: and God saw that it was good." (Genesis 1:21, KJV)

The fifth day filled the seas with great creatures. Plesiosaurs, built unlike anything alive now, were part of a creation God called good.

Practice: answers

1. Long-necked, small-headed elasmosaurs (e.g., *Elasmosaurus*, *Albertonectes*) and short-necked, big-headed pliosaurs (e.g., *Liopleurodon*, *Kronosaurus*).
2. He put the head on the end of the tail. Joseph Leidy pointed out the error.
3. Neck joints allowed only small bends each, so the neck was held mostly forward and somewhat down; raising a heavy head and neck out of the water, where water no longer supports the weight, would have been nearly impossible.
4. Hind flippers beating in step with the front ones, using the front flippers' wake, gave up to about 60% more thrust and 40% better efficiency than beating alone. Four flippers working together were not wasteful but effective.
5. (a) $7 \div 10.3 \approx 0.68$, about two-thirds. (b) $700 \text{ cm} \div 72 \approx 9.7 \text{ cm}$. (c) $72 \times 3^\circ = 216^\circ$, more than a half circle, so the neck could curve well around to the side; whether the head could reach the flipper depends on where the flipper sits, but a gentle, broad curve is the key point: no single joint bent sharply.
6. Observation: a single large embryo skeleton inside an adult skeleton. Inference: plesiosaurs gave birth to live young, and this kind bore one big offspring at a time. Animals that produce one large young (whales, elephants, people) usually invest heavily and care for it after birth; animals that produce many small young usually leave them to chance. So one big baby suggests, though it does not prove, that plesiosaur mothers cared for their young.

5.3 MOSASAURS

OBJECTIVES

- Tell the history of the Maastricht skull and explain why it mattered to the idea of extinction.
- Describe the mosasaur feeding equipment (hinged jaws, second row of teeth) and the evidence for what mosasaurs ate.
- Evaluate a source that passes through three hands (Faujas, Mantell, Lucas) and compare it with modern archival research.

Warm-up. Play “telephone”: whisper a two-sentence story about a stolen treasure to one person, who whispers it to the next, and so on. Compare the last version with the first. The story of the first mosasaur skull reached English readers the same way, through three writers, and modern historians have found that some of it was never true.

Video slot. Video coming. Mosasaurs: the Maastricht skull in Paris, Tylosaurus from the Kansas chalk, mosasaur jaws and tail flukes. Search approved channels (Natural History Museum Maastricht, Sternberg Museum of Natural History, Smithsonian, PBS Eons with a parent); preview first.

KEY TERMS

mosasaur

“Meuse lizard”: a large sea-going lizard with four paddles and a finned tail, related to today’s monitor lizards and snakes. Not a dinosaur.

squamate

The group of scaly reptiles that includes lizards and snakes. Mosasaurs were squamates that lived in the sea.

inframandibular joint

A hinge partway along each half of the lower jaw that let a mosasaur’s jaw bow outward to swallow large prey.

pterygoid teeth

A second row of backward-curving teeth on the roof of the mouth, used to “walk” prey down the throat.

Niobrara Chalk

Soft white chalk layers in western Kansas, famous for mosasaurs, plesiosaurs, giant fish, sea birds and pterosaurs.

provenance

The history of who found, owned and moved an object. Good provenance is part of the evidence, and legal disputes often turn on it.

CORE IDEAS

The great animal of Maastricht. For centuries, men quarried soft limestone from tunnels under Mount Saint Peter (Sint-Pietersberg), outside the Dutch city of Maastricht on the river Meuse. In the 1760s and 1770s quarrymen began bringing out the jaws of a huge animal, and around 1780 the best skull of all appeared, more than a meter long with rows of sharp, curved teeth. A local army surgeon and collector, Johann Leonard Hoffmann, studied such fossils and wrote to scholars about them. The famous skull belonged to Theodorus Godding, a canon (a clergyman serving the cathedral chapter), who kept it at his country house on the hill. When French Revolutionary armies besieged and took Maastricht in 1794, the skull was found, reportedly after a reward of 600 bottles of wine was offered to the soldiers who could produce it, and carried to Paris as a prize of war. It is still in the national museum of natural history there.

Lizard, crocodile or whale? Scholars argued over what it was. Barthélemy Faujas de Saint-Fond, who had come with the French commissioners, thought it a crocodile. The Dutch anatomist Petrus Camper, who owned another Maastricht jaw, took it for a kind of toothed whale. His son Adriaan Camper restudied the bones and argued that it was a gigantic lizard, closest to monitor lizards, and Georges Cuvier agreed. In 1822 William Conybeare named it *Mosasaurus*, “lizard of the Meuse,” and Gideon Mantell later called the species *Mosasaurus hoffmannii* after the surgeon. The skull mattered beyond its size. Cuvier used it, with mammoths and ground sloths, to argue that whole kinds of large animals had disappeared from the earth. No one had ever seen a sea lizard of this size alive, and none was likely to be hiding in the well-traveled seas of Europe.

Sea lizards. Since then many kinds have been found, especially in the Niobrara Chalk of Kansas, where the Sternberg family and others collected hundreds of skeletons. Mosasaurs were long-bodied lizards with flippers instead of feet. *Tylosaurus* reached about 13 m, and estimates for the largest *Mosasaurus hoffmannii* run from about 12 m to more than 15 m, depending on which skull-to-body ratio is used. Well-preserved specimens reported in 2010 and 2013 showed a downturned tail with a crescent-shaped fin, like a shark’s turned upside down, small overlapping scales, and traces of dark pigment. Small mosasaur relatives have been found with unborn young inside, so they, too, gave birth at sea.

Built to swallow. Mosasaurs had remarkable feeding equipment. A joint partway along each half of the lower jaw let it bow outward, the two halves were loosely joined at the chin, and a second row of hooked teeth on the roof of the mouth gripped prey and ratcheted it down the throat, as snakes do today. Frederic Lucas compared this joint to the one in a cormorant’s bill. The evidence for what they ate is unusually direct: a Kansas *Tylosaurus* has the bones of a plesiosaur in its stomach region; others contain fish, sea birds, sharks and smaller mosasaurs. Ammonite shells with rows of round holes were long read as mosasaur bite marks. Some researchers argued in the 1990s that many such holes were made instead by limpets living on the shells; others answered that some sets match mosasaur tooth rows well. Both sides are looking at the same holes.

A story checked. The primary source tells the famous version: the surgeon Hoffmann dug out the skull, the greedy canon took it from him by a lawsuit, Hoffmann died without it, and the French justly took the “ill-gotten prize.” Notice how it reached Lucas’s readers in 1901: Lucas quoted Mantell’s English rendering of Faujas, who was one of the French officials who removed the fossil and had reason to make the removal look just. Research in Maastricht’s archives by the Dutch historian Peggy Rompen and others found that Godding was the rightful owner and that the lawsuit story is largely unsupported. Proverbs 18:17 is good advice for historians: the first account told often sounds right until someone checks it.

Museum words. Geologists later named the topmost stage of the Cretaceous rock layers the “Maastrichtian,” after the chalk of Mount Saint Peter. A museum sign may say that mosasaurs “ruled the seas until 66 million years ago.” As always, the observations are the bones and the layers they lie in; the dates are interpretations, read side by side in the box below. Mosasaurs are found in rocks on every continent, including Antarctica, sealed in fine chalk and limestone that often preserves even delicate scales.

PICTURE STUDY



The Great Fossil Animal of the Maastricht Quarries, Engraving after a drawing for Barthélemy Faujas de Saint-Fond, 1799 · Engraving · From Faujas de Saint-Fond, *Histoire naturelle de la montagne de Saint-Pierre de Maestricht* (Paris, 1799)
Wikimedia Commons · Public domain

Faujas published a large book on the fossils of Mount Saint Peter, and this plate shows the moment of discovery as he wished it to be remembered: lantern light, gentlemen in coats and quarrymen with tools around the great jaws in the tunnel wall. Like the text in the primary source, the picture is a reconstruction made years after the event.

Look closely

- Find the jaws in the rock. How big do they look compared with the men?

- Who is pointing, who is working and who is watching? What does the arrangement say about who mattered in the story?
- Look at the light and shadows. How does the artist make the moment feel important?

Talk about it

1. Faujas was part of the French party that took the skull to Paris. How might that affect the way he told and pictured the discovery?
2. What kinds of documents would a historian look for to check who really owned the skull?

HANDS-ON: THREE HANDS, ONE STORY: A PROVENANCE FILE

Build a file that traces the Maastricht skull from quarry to Paris, and mark which claims come from which source.

You will need

- The primary source in the asides
- Three colored pencils or highlighters
- A folder or two sheets of paper
- A cardboard model jaw (optional): two strips of card and two brass paper fasteners

Steps

1. Read the primary source aloud. In one color, underline every claim about events (finding, lawsuit, siege, hiding, removal). In a second color, underline words that judge people (“shrewdly,” “ill-gotten,” “precious”).
2. Make a provenance timeline with the dates from this stop: 1760s–1770s first jaws; about 1780 skull found; Godding keeps it; 1794 siege and removal; Paris; 1822 named *Mosasaurus*; 1829 *M. hoffmannii*.
3. In the third color, mark each step on your timeline as “confirmed by archives,” “reported by Faujas only,” or “disputed.” Use this stop’s core ideas and For families note.
4. Write a 100-word “corrected museum label” for the skull in Paris, giving owner, finder (if known), date and how it came to Paris, without the legend.
5. Optional: cut two card strips for a lower jaw half, join them in the middle with a brass fastener, and show how the hinge lets the jaw bow outward.

Check your work

- I marked events and judgments in different colors.
- My timeline has at least six dated steps, each marked confirmed, reported or disputed.
- My label is accurate and fair to both Hoffmann and Godding.

FIELD NOTEBOOK

1. Draw a mosasaur skull from the side and from below. Label the teeth, the intramandibular joint, the pterygoid teeth and the eye socket.
2. Draw a mosasaur in full, with the downturned tail fin. Beside it, sketch a shark tail and show how the two are mirror images.
3. **Narration (the parent keeps this).** Write one paragraph telling the story of the Maastricht skull as you now believe it happened, and explain in one sentence why the older version was believed for so long.

Did you know? Mosasaur fossils are found on every continent, including Antarctica. Kansas has been called one of the best places in the world to find them, because the soft Niobrara Chalk weathers into badlands where skeletons erode out. The Natural History Museum in Maastricht displays later mosasaur skeletons found in the same quarries, given local nicknames such as “Bèr” and “Lars.”

 **What the sign says / What we observe / How Christians read it.**  **What the sign says:** “Mosasaurs ruled the Late Cretaceous seas and died out with the dinosaurs 66 million years ago. The Maastrichtian Age is named after the rocks of Maastricht.” **What we observe:** mosasaur bones lie in marine chalk and limestone, often near the top of the rock layers that also hold the last dinosaur fossils; above those layers mosasaurs are not found. Stomach contents, scales and fins are sometimes preserved in fine sediment. The number of years comes from radiometric dating and assumes steady decay rates, known starting amounts and no gain or loss of atoms. **How Christians read it:** many young-earth Christians read these marine chinks and limestones as deposited during the Flood year, with mosasaurs among the sea creatures overwhelmed and buried as the waters rose over the continents. Other Christians accept the long ages. All agree on the bones, the layers and their order.

Primary source. *Frederic A. Lucas, Animals of the Past (New York, 1901), Chapter IV, “Rulers of the Ancient Seas,” quoting Faujas de Saint-Fond as rendered by Gideon Mantell. Project Gutenberg eBook #38013.*

Thus the story is told by M. Faujas St. Fond, as rendered into English, in Mantell's “Petrifactions and their Teachings”: “Some workmen, in blasting the rock in one of the caverns of the interior of the mountain, perceived, to their astonishment, the jaws of a large animal attached to the roof of the chasm. The discovery was immediately made known to M. Hoffman, who repaired to the spot, and for weeks presided over the arduous task of separating the mass of stone containing these remains from the surrounding rock. His labors were rewarded by the successful extrication of the specimen, which he conveyed in triumph to his house. This extraordinary discovery, however, soon became the subject of general conversation, and excited so much interest that the canon of the cathedral which stands on the mountain resolved to claim the fossil, in right of being lord of the manor, and succeeded, after a long and harassing lawsuit, in obtaining the

precious relic. It remained for years in his possession, and Hoffman died without regaining his treasure. At length the French Revolution broke out, and the armies of the Republic advanced to the gates of Maastricht. The town was bombarded; but, at the suggestion of the committee of savans who accompanied the French troops to select their share of the plunder, the artillery was not suffered to play on that part of the city in which the celebrated fossil was known to be preserved. In the meantime, the canon of St. Peter's, shrewdly suspecting the reason why such peculiar favor was shown to his residence, removed the specimen and concealed it in a vault; but, when the city was taken, the French authorities compelled him to give up his ill-gotten prize, which was immediately transmitted to the Jardin des Plantes, at Paris, where it still forms one of the most interesting objects in that magnificent collection."

"Savans" is an old spelling of savants, learned men.

Go deeper. Michael J. Everhart, *Oceans of Kansas: A Natural History of the Western Interior Sea* (2nd ed., 2017), and his website Oceans of Kansas. Biodiversity Heritage Library blog, "Fact or Fiction? Discovering the Mosasaur" (2015). Natural History Museum Maastricht (museum website). Frederic A. Lucas, *Animals of the Past* (1901), free at Project Gutenberg; read his jaw-mechanics paragraph in the same chapter. Second video topic: "Collecting fossils in the Niobrara Chalk."

Goes deeper in. History, the French Revolutionary Wars (coming soon); Life Science, high-school Biology, reptiles and classification; Earth Science, the fossils and rock-layers units.

For families. This stop has dates, so it carries the ⏰ box. The ownership history follows Peggy Rompen's archival research (summarized in the Biodiversity Heritage Library post listed above); exact discovery dates are uncertain, so the stop gives ranges. The 600 bottles of wine is a widely repeated report and is given as "reportedly." The skull was sent to Paris after the city fell in late 1794 and was in the museum there by 1795. Ammonite bite marks: Kauffman and Kesling 1960; the limpet alternative, Kase et al. 1998. Tail fin: Lindgren et al. 2010 (*Platecarpus*) and 2013 (*Prognathodon*). The primary source was checked word for word against Project Gutenberg #38013; straight quotation marks inside it are Lucas's. The war and siege are stated plainly without detail.

PRACTICE

1. **EASY** What does *Mosasaurus* mean, and which living animals are mosasaurs' closest relatives?
2. **EASY** Name two features of mosasaur jaws that helped them swallow large prey.
3. **MEDIUM** Why did the Maastricht skull matter to the debate about extinction?
4. **MEDIUM** Give one piece of direct evidence for what mosasaurs ate, and one piece that is disputed. Why is the second disputed?

5. **CHALLENGE** Using the primary source, list (a) three claims of fact, (b) three words or phrases that pass judgment, and (c) three reasons a historian should be cautious about this account. Then state what archival research found.
6. **CHALLENGE** A mosasaur skull is 1.6 m long. If one study says the skull was about one-tenth of total length and another says about one-eighth, what length does each give? What does the difference teach about size estimates?

Make it a game • Pass the Story. One player reads a 60-word true account of a fossil find and passes it on by memory to the next player, who must retell it to a third. The third writes it down. Compare with the original: score one point for each fact kept and lose one for each fact added. Then discuss: which kinds of details changed most, names, numbers or judgments?

Scripture. “He that is first in his own cause seemeth just; but his neighbour cometh and searcheth him.” (Proverbs 18:17, KJV)

The first version of a story, told by someone with a stake in it, can sound convincing until another witness examines it. Careful history, like careful science, hears the other side before deciding.

Practice: answers

1. “Lizard of the Meuse” (the river at Maastricht). Their closest living relatives are monitor lizards and snakes (squamates).
2. Any two: a hinge (intramandibular joint) in each lower jaw half that let it bow outward; loosely joined jaw halves at the chin; a second row of hooked pterygoid teeth on the roof of the mouth to ratchet prey inward.
3. It was a sea lizard far larger than any living lizard, and Cuvier used it, with mammoths and ground sloths, to argue that whole kinds of large animals had disappeared; such a creature was unlikely to be still living unseen in Europe’s well-known seas.
4. Direct: a *Tylosaurus* with plesiosaur bones in its stomach region (also fish, sea birds, sharks, smaller mosasaurs in others). Disputed: round holes in ammonite shells; some researchers think limpets made many of them, others that some rows match mosasaur teeth.
5. (a) Any three: workmen found jaws in a cavern; Hoffman supervised the extraction for weeks; the canon claimed it as lord of the manor; a long lawsuit; Hoffman died without it; the French spared the canon’s quarter; the canon hid it in a vault; it was taken to Paris. (b) “in triumph,” “precious relic,” “harassing,” “shrewdly,” “ill-gotten prize,” “magnificent.” (c) It passes through three writers (Faujas, Mantell, Lucas); Faujas was among the French who removed the fossil and had a motive to justify it; it was written years after the events; Lucas gives no documents. Archival research (Peggy Rompen and others) found that Godding was the rightful owner and that the lawsuit story is largely unsupported.
6. $1.6 \times 10 = 16$ m; $1.6 \times 8 = 12.8$ m. The same bone gives answers more than 3 m apart because each method assumes different body proportions taken from more complete relatives. The skull is the observation; the total length is an inference that depends on the assumption.

5.4 PTEROSAURS

OBJECTIVES

- Explain the pterosaur wing: the fourth finger, the membranes, the pteroid bone and the hollow bones, and compare it with bird and bat wings.
- Trace how the first pterosaur fossil was misread and then correctly identified (Collini 1784, Cuvier 1801-1809).
- Use trackways and bone studies to explain how pterosaurs walked and took off, and identify which ideas are still debated.

Warm-up. Spread your hand. Now imagine your ring finger growing longer than your whole arm, with a sheet of skin stretched from its tip back to your ankle. Your other three fingers stay small, with claws. That is a pterosaur's wing. Which finger would you have to fold to walk on your hands?

Video slot. Video coming. Pterosaurs: wing structure, pterosaur trackways, the quadrupedal launch, Pteranodon from the Kansas chalk. Search approved channels (Natural History Museum London, Smithsonian, American Museum of Natural History, PBS Eons with a parent); preview first.

KEY TERMS

pterosaur

“Winged lizard”: a flying reptile with wings of skin supported by one enormously long finger. Not a dinosaur and not a bird.

wing finger

The fourth finger of the pterosaur hand, made of four very long bones, which held the outer edge of the wing.

brachiopatagium

The main wing membrane, stretched from the tip of the wing finger to the body and hind limb, stiffened by fine fibers called actinofibrils.

pteroid

A small rod-like bone found only in pterosaurs, at the wrist, which supported a front membrane (propatagium) and helped control lift.

pycnofibers

Hair-like filaments covering the bodies of many pterosaurs, probably for insulation.

quadrupedal launch

The idea that pterosaurs took off by vaulting from all four limbs, pushing mainly with the strong forelimbs, rather than running on two legs.

CORE IDEAS

A third way to fly. God made three groups of backboned animals that truly fly by flapping: birds, bats and pterosaurs. Each does it differently. A bird's wing is made of feathers on a fused, three-fingered hand. A bat's wing is a membrane stretched between four long fingers. A pterosaur's wing was a membrane held almost entirely by one finger, the fourth, which in large kinds was longer than the rest of the arm. The other three fingers were short and clawed. Pterosaurs are not dinosaurs, though museums show them together; they are a separate group of reptiles. They ranged from the size of a sparrow (*Nemicolopterus*, about 25 cm across the wings) to giants with wingspans of about 10 m (Stop E5).

The first fossil. The first pterosaur ever described came from the fine limestone of the Solnhofen-Eichstätt district in Bavaria and sat in the natural history cabinet of the Elector Karl Theodor at Mannheim. In 1784 the cabinet's keeper, Cosimo Alessandro Collini, published it. He could not match it to any living animal and suggested it might be a sea creature using its long arms as paddles. In 1801 Georges Cuvier, working from Collini's drawing alone, recognized a flying reptile, and in 1809 he coined the name *Ptero-dactyle*, "wing finger." Others disagreed: in 1812 the German anatomist Samuel Thomas von Sömmerring argued it was a bat-like mammal. The primary source shows Harry Govier Seeley in 1901 summing up Cuvier's reasoning; Seeley himself thought pterosaurs were more bird-like than Cuvier allowed.

Built light. Pterosaur bones were hollow tubes with walls often only a millimeter or two thick, braced inside by struts and filled with air sacs connected to the lungs, as in birds. This made them light but strong for their size. Exceptional fossils from Solnhofen and Brazil preserve the wing membrane itself. It was not a loose flap like a bat's but a thin, layered sheet stiffened by countless fibers, with muscle and blood vessels inside, so the animal could tension and shape it in flight. A front membrane ran from shoulder to wrist, controlled by the pteroid bone, much like the slats an airplane extends to gain lift at low speed. Many pterosaurs had a fuzzy coat of pycnofibers. Some researchers reported in 2018 that some fibers were branched like simple feathers; others doubt it, and the question is open.

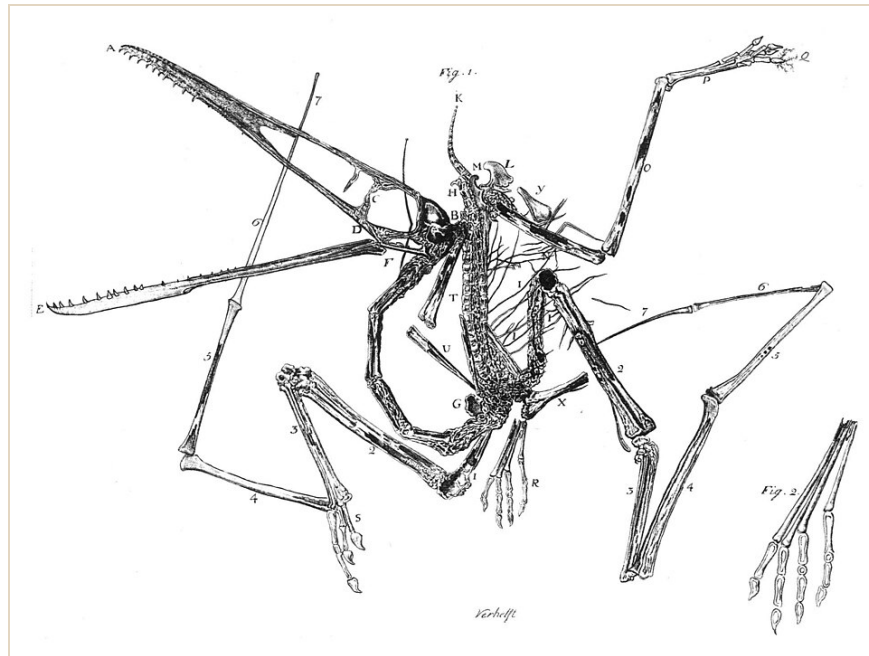
Two broad kinds. Earlier kinds, such as *Dimorphodon* (the first British pterosaur, found by Mary Anning in 1828) and *Rhamphorhynchus*, had long stiff tails, often ending in a vane, and many had needle-like teeth for catching fish. Later kinds, the pterodactyloids, had short tails, long necks and often spectacular head crests. *Pteranodon* from the Kansas chalk, named by O. C. Marsh in 1876, had a wingspan of about 6–7 m, no teeth at all, and a long backswept crest. Its bones are found in rocks laid down far from any shoreline of the time, and fish remains found with some specimens show it fed at sea.

Walking and taking off. For a century artists drew pterosaurs hanging like bats or waddling on two legs. Then trackways settled the walking question. Prints found in France, the western United States and elsewhere show small three-fingered handprints well outside the narrow footprints: pterosaurs walked on all fours, with the wing finger folded up out of the way. Taking off was harder to explain for big kinds. In 2008 Michael Habib, studying the strength of pterosaur limb bones, proposed that they vaulted into the air using the forelimbs,

which were much stronger than the hind limbs, the way a vampire bat leaps from the ground. Most researchers now accept a four-limbed launch, though details are still argued.

Design and debate. Pterosaurs show how much can be learned from bones and how much remains interpretation. Wing shapes, bone strength and trackways are observations; flight speed, color and how far they traveled are reasoned inferences. Mainstream scientists see the three kinds of flyers as flight evolving three separate times. Creation scientists see three different, complete designs, each with its own excellent engineering, made for life in the open sky (Genesis 1:20). Both can admire the same thing: a wing with almost no bone along its trailing edge that still carried an animal through the air.

PICTURE STUDY



The first described pterosaur fossil (Pterodactylus antiquus), plate from Collini's description, Engraving published by Cosimo Alessandro Collini, 1784 · Copperplate engraving · From the proceedings of the Electoral Palatine Academy, Mannheim; the fossil itself is in the Bavarian State Collection of Paleontology and Geology, Munich
Wikimedia Commons · Public domain

This is the drawing that Cuvier studied in Paris without ever seeing the real fossil. Collini's engraver drew exactly what was on the slab, which is why Cuvier could reason from it so well. The skeleton is small, about the size of a pigeon.

Look closely

- Find the skull, the neck and the very long finger bones. How many long bones make up the wing finger?
- Find the short fingers with claws. How many are there?
- Look for any sign of a wing membrane. Is there one in the drawing?

Talk about it

1. Collini guessed it was a sea animal. What in the drawing might have led him to think so?
2. Why is an accurate drawing of a specimen valuable even before anyone understands it?

HANDS-ON: WING LAB: BIRD, BAT AND PTEROSAUR

Build three paper wings on the same frame size and compare how each design is supported.

You will need

- Thin wooden skewers or straws (bones), tape and tissue paper or a plastic grocery bag (membrane)
- Paper feathers cut from card stock
- A ruler, scissors and a fan or hair dryer on cool
- The primary source in the asides

Steps

1. Read the primary source. Make four columns for the four designs Cuvier compared: gliding “Dragon” lizard (ribs), bird, bat and pterosaur. Under each, write how the flying surface is supported. You will build the last three.
2. Build a 40 cm bat wing: four skewers fanned from one “wrist,” with tissue membrane between them.
3. Build a 40 cm pterosaur wing: one long skewer for the wing finger, tissue running from its tip back to a skewer for the leg, and a short front skewer for the pteroid with a small front membrane.
4. Build a 40 cm bird wing: a short skewer “arm” with overlapping card feathers taped along it.
5. Hold each in front of the fan. Note which flutters, which holds its shape, and which you could fold. Write which design you think is best for a giant flyer and why.

Check your work

- I built all three wings at the same size.
- I recorded what happened to each in the airflow.
- I can explain Cuvier’s comparison in my own words.

FIELD NOTEBOOK

1. Draw a pterosaur forelimb and label upper arm, forearm, wrist, pteroid, three small clawed fingers and the four bones of the wing finger. Shade the propatagium and brachiopatagium different colors.
2. Draw a pterosaur trackway: two small three-fingered handprints outside two long footprints, repeated four times.
3. **Narration (the parent keeps this).** Write one paragraph explaining how the first pterosaur fossil was misread and then correctly identified, and what Cuvier noticed

that others had missed.

Did you know? The Solnhofen limestone that gave us the first pterosaur was quarried for printing stones (lithography) because it is so fine and even. The same quarries produced *Archaeopteryx* and dozens of beautifully preserved pterosaurs, some with wing membranes, throat pouches and webbed feet still visible.

Primary source. *H. G. Seeley, Dragons of the Air: An Account of Extinct Flying Reptiles (London, 1901), Chapter V, "Discovery of the Pterodactyle."* Project Gutenberg eBook #35316.

Cuvier defined this fossil from Solenhofen as distinguished by the extreme elongation of the fourth digit of the hand, and from that character invented for the animal the name Pterodactyle. He tells us that its flight was not due to prolongation of the ribs, as among the living lizards named Dragons; or to a wing formed without the digits being distinguishable from each other, as among Birds; nor with only one digit free from the wing, as among Bats; but by having the wing supported mainly by a single greatly elongated digit, while all the others are short and terminate in claws. Cuvier described the amazing animal in detail, part by part; and such has been the influence of his clear words and fame as a great anatomist that nearly every writer in after-years, in French and in English, repeated Cuvier's conclusion, maintained to the end, that the animal is a saurian.

"Saurian" means a reptile. The "Dragons" are the small gliding lizards of Southeast Asia (genus Draco).

Go deeper. Mark P. Witton, *Pterosaurs: Natural History, Evolution, Anatomy* (Princeton, 2013), well illustrated and readable. David M. Unwin, *The Pterosaurs: From Deep Time* (2006). H. G. Seeley, *Dragons of the Air* (1901), free at Project Gutenberg; compare his reconstructions with Witton's. American Museum of Natural History, "Pterosaurs: Flight in the Age of Dinosaurs" exhibition pages. Second video topic: "How a pterosaur took off."

Goes deeper in. Life Science, high-school Biology, flight and animal design (coming soon); Earth Science, fossils; and History, science in the age of Napoleon (Cuvier).

For families. Collini's description: 1784; Cuvier's identification as a flying reptile: 1801; the name *Ptero-dactyle*: 1809; Sömmerring's bat interpretation: 1812. *Pteranodon*: Marsh 1876. Quadrupedal launch: Habib, *Zitteliana* 2008. Branched pycnofibers: Yang et al., *Nature Ecology & Evolution* 2018 (debated). Wingspans are estimates. The primary source was checked word for word against Project Gutenberg #35316; Seeley spells Solnhofen "Solenhofen." No dates in millions of years are given, so this stop has no ⌚ box; "Jurassic" and "Cretaceous" on pterosaur labels are museum words for rock layers.

PRACTICE

1. **EASY** Which finger held up the pterosaur wing, and what does the name *Pterodactylus* mean?
2. **EASY** Name the three groups of backboned animals that fly by flapping, and say one way each wing is built.
3. **MEDIUM** How do trackways show that pterosaurs walked on all fours?
4. **MEDIUM** What is the pteroid bone, and what did it do?
5. **CHALLENGE** Using the primary source, list the four ways of supporting a flying or gliding surface that Cuvier compared, and give the reasoning that let him call the animal a reptile and not a bird or bat. Then explain why Seeley says writers “repeated Cuvier’s conclusion,” and what that suggests about authority in science.
6. **CHALLENGE** A *Pteranodon* had a wingspan of about 6.5 m. If each wing’s average width (chord) was about 0.5 m, estimate the total wing area. If it weighed about 35 kg, what is its wing loading in kg per square meter? Compare with a large bird of about 10 kg and 0.6 m² of wing.

Make it a game · Bird, Bat or Pterosaur?. The leader calls out a feature: “feathers,” “wing finger,” “three clawed fingers free,” “four long fingers in the wing,” “pteroid bone,” “hollow bones with air sacs,” “fur,” “teeth in some kinds,” “walks on folded wings.” Players flap like a bird, hang like a bat or crouch on all fours like a pterosaur. Some features fit two; whoever explains a double answer gets a bonus point.

Scripture. “And God said, Let the waters bring forth abundantly the moving creature that hath life, and fowl that may fly above the earth in the open firmament of heaven.” (Genesis 1:20, KJV)

The Hebrew word translated “fowl” means any flying creature, and the same word is used for flying insects elsewhere. Pterosaurs were among the most remarkable of the creatures that fly “in the open firmament of heaven.”

Practice: answers

1. The fourth finger. “Wing finger.”
2. Birds: feathers on a fused, three-fingered hand. Bats: skin stretched between four long fingers. Pterosaurs: skin held mainly by one very long fourth finger.
3. Pterosaur trackways show small three-fingered handprints set outside the hind footprints, in a regular four-footed pattern; the wing finger was folded up out of the way.
4. A rod-like wrist bone found only in pterosaurs that supported the front membrane (propatagium); by moving it, the animal could change the wing’s front edge to gain lift at low speed, like an airplane’s slats.
5. Four ways: ribs (gliding *Draco* lizards), a wing with fingers not distinguishable (birds), a membrane with only one finger free (bats), and a wing held mainly by one greatly lengthened finger with the rest short and clawed (pterosaur). The pattern matched none of the bird or bat designs, and the skull and skeleton were reptile-like, so he called it a saurian. Seeley says others repeated Cuvier because of his clear writing and great fame; authority can spread a

conclusion quickly, right or wrong, so each claim still needs to be checked against the specimens (here Cuvier was right that it was a reptile, though Seeley wanted to stress its bird-like features).

6. Area $\approx 6.5 \text{ m} \times 0.5 \text{ m} \approx 3.25 \text{ m}^2$. Wing loading $\approx 35 \div 3.25 \approx 11 \text{ kg/m}^2$. The bird: $10 \div 0.6 \approx 17 \text{ kg/m}^2$. The pterosaur's lower wing loading means it could fly slowly and soar easily on rising air, like a large seabird. (These are rough exercise figures; published estimates vary.)

5.5 QUETZALCOATLUS

OBJECTIVES

- Tell the story of the 1971 discovery in Big Bend National Park and explain why the wingspan estimate fell from about 15 m to about 10 m.
- Use the square-cube law to explain why size makes flight harder, and why mass estimates for *Quetzalcoatlus* range so widely.
- Compare the main ideas about how it fed and took off, and judge which evidence supports each.

Warm-up. Measure 10 m along a driveway, sidewalk or hallway with a tape measure. That is about the wingspan of *Quetzalcoatlus northropi*, nearly the same as a small four-seat airplane. Now stand at one end and imagine an animal with that wingspan standing up and looking you in the eye from about the height of a giraffe.

Video slot. Video coming. *Quetzalcoatlus*: the Big Bend fossils, the 2021 Society of Vertebrate Paleontology memoir, the quadrupedal launch and the giant-heron or stork feeding ideas. Search approved channels (University of Texas Jackson School of Geosciences, National Park Service Big Bend, Smithsonian, PBS Eons with a parent); preview first.

KEY TERMS

azhdarchid

A family of large, toothless pterosaurs with very long, stiff necks, long jaws and long legs. *Quetzalcoatlus* is the best-known member.

wingspan

The distance from one wing tip to the other with the wings spread. For incomplete fossils it must be estimated from the bones that survive.

square-cube law

When an object grows larger in the same shape, its area grows with the square of its length but its volume and weight with the cube. Big flyers get heavy faster than their wings get bigger.

terrestrial stalking

Hunting by walking on the ground and picking up small animals, as storks and ground hornbills do; the leading idea for how azhdarchids fed.

Javelina Formation

The rock layers in Big Bend National Park, Texas, deposited by rivers and on floodplains, where *Quetzalcoatlus* was found.

CORE IDEAS

A bone in an arroyo. In 1971 Douglas A. Lawson, a geology student at the University of Texas at Austin, was mapping rocks in Big Bend National Park for his master's thesis when he found a large bone weathering out of the side of a dry stream bed. He and his teachers, including Wann Langston Jr., returned and dug out parts of a wing: pieces of the upper arm, forearm, wrist and the long wing-finger bones. They were hollow, thin-walled and enormous. In 1975 Lawson announced the find in the journal *Science* as *Quetzalcoatlus northropi*. The name joins Quetzalcoatl, the feathered serpent worshiped as a god by the Aztecs and other peoples of ancient Mexico, with Jack Northrop, the American engineer who designed tailless "flying wing" airplanes.

Shrinking estimates. Lawson's first estimate gave a wingspan of about 15.5 m (51 ft), as wide as a fighter jet. That number spread through books and museums. Later workers compared the bones with more complete relatives and concluded that he had scaled from long-winged kinds like *Pteranodon*, while azhdarchids had relatively shorter wings. Most estimates now fall around 10–11 m. In 2021 the Society of Vertebrate Paleontology published a full set of studies on *Quetzalcoatlus*, decades after the find, based on the original bones and on hundreds of bones of a smaller species from another site in the park, now named *Quetzalcoatlus lawsoni*, with a wingspan of about 4.5 m. Their reconstruction gave *Q. northropi* a wingspan of about 10 m. The bones did not change; better comparisons did.

How heavy? Weight is harder still. Published estimates for *Q. northropi* range from about 70 kg to more than 500 kg, a spread of more than seven times. Light estimates came from treating it like a scaled-up glider of thin struts and air; heavier ones come from reconstructing the muscle needed to move such long bones, and from the strength its large limb bones would have needed. Many researchers today suggest roughly 200–250 kg, about the weight of three grown men, while the 2021 memoir suggested about 150 kg. This is a good example of honest uncertainty: the size of the skeleton is fairly well known, but its weight depends on assumptions about soft tissue that did not fossilize.

The square-cube problem. Why does weight matter so much? If a flyer is made twice as long in every direction, its wing area grows four times (2^2) but its weight grows eight times (2^3). Each square meter of wing must carry twice the load. That is why the largest flying birds today, such as the Andean condor or wandering albatross, weigh only about 10–15 kg, and why a 200 kg flyer seemed impossible to some. Donald Henderson argued in 2010 that the largest azhdarchids were too heavy to fly. Most researchers disagree, mainly because of the launch idea from Stop E4: with strong forelimbs, a giant pterosaur could vault into the air in a fraction of a second and then soar on rising air with little flapping, as condors do.

What did it eat? Early writers imagined *Quetzalcoatlus* skimming fish from the surface like a skimmer bird, or scavenging dinosaur carcasses like a vulture. Neither fits well. Its jaws were long and toothless, its neck long but stiff, and its legs long, and its bones are found in river and floodplain deposits, not sea deposits. In 2008 Mark Witton and Darren Naish proposed that azhdarchids were "terrestrial stalkers" that walked through open country picking up small animals, as storks and ground hornbills do. The 2021 studies described it as

walking and feeding like a giant heron. A simple test supports the ground-feeding idea: with legs and neck this long, its head could easily reach the ground while it stood on all fours.

Names and readings. A Christian student can learn the history behind a name without honoring the god it names, just as Paul could quote the inscription “To the unknown god” in Athens (Acts 17:23) while preaching the true God. The museum sign at Big Bend may say that *Quetzalcoatlus* lived “about 68 to 66 million years ago, at the very end of the Cretaceous,” alongside the giant sauropod *Alamosaurus*. As before, the bones and the layers are what we observe; the dates are interpretations, set out in the box below. What everyone agrees on is remarkable enough: an animal as tall as a giraffe once flew.

PICTURE STUDY



Otto Lilienthal in flight with his glider, Photographer unknown, 1894 · Black-and-white photograph · Many prints; the Otto Lilienthal Museum, Anklam, Germany, keeps his records
Wikimedia Commons · Public domain

No one painted *Quetzalcoatlus* before 1975, so this stop studies a different giant flyer. In the 1890s the German engineer Otto Lilienthal made around two thousand glides on wings of cloth stretched over willow ribs, with a span of about 7 m. He carefully studied how storks fly before he built them. He died in 1896 after a glider stalled and fell, and his work helped guide the Wright brothers.

Look closely

- Look at the wing frame. How are the ribs arranged, and what do they support?
- Where is Lilienthal’s body compared with the wings? How would he steer?
- Find the people on the ground. Why would he launch from a hill?

Talk about it

1. Lilienthal and his glider weighed about 100 kg together, with a span of about 7 m. Compare that with the size and weight estimates for *Quetzalcoatlus*. What does that suggest?
2. Why did Lilienthal study birds? What can engineers today still learn from flying animals?

HANDS-ON: CHALK THE GIANT AND TEST THE SQUARE-CUBE LAW

Draw *Quetzalcoatlus* life-size on pavement, then use sugar cubes to see why size makes flight harder.

You will need

- Sidewalk chalk and a 10 m tape measure (or string marked in meters)
- 27 sugar cubes or small building blocks
- Paper squares cut to fit one cube face
- A family member about 1.7–1.8 m tall for comparison

Steps

1. On a driveway or playground, chalk a straight 10 m line for the wingspan. Draw the wings as long triangles, widest near the body (about 1 m) and narrowing to points. Add a body about 1 m long, a neck about 2.5 m and a head about 2.5 m (estimates), pointing forward.
2. Lie down next to the drawing to compare. Take a photo from above if possible.
3. Build a 1-cube “flyer” and count its faces facing down (1) and its cubes (1). Then build a $2 \times 2 \times 2$ flyer: count the bottom faces (4) and cubes (8). Then a $3 \times 3 \times 3$: bottom faces (9), cubes (27).
4. Make a table: length, bottom area, weight (cubes), weight per unit of area. Write what happens to the load on each square of “wing” as the flyer grows.
5. Write two sentences: how could a giant flyer solve the square-cube problem? Use what you learned about hollow bones, a four-limbed launch and soaring.

Check your work

- My chalk drawing has a 10 m wingspan and labeled parts.
- My table shows weight per area rising as size grows.
- I can explain the square-cube law and one way pterosaurs dealt with it.

FIELD NOTEBOOK

1. Draw *Quetzalcoatlus* standing on all fours beside a giraffe and a person, to scale (1 cm = 0.5 m). Label head, neck, folded wing, hind legs and height.
2. Make a timeline of size estimates: 1975 (about 15.5 m), later revisions (about 10–11 m), 2021 (about 10 m). Write one reason estimates change.

3. **Narration (the parent keeps this).** Write one paragraph explaining why scientists agree fairly well on the size of *Quetzalcoatlus* but disagree widely on its weight, and how that affects the question of whether it could fly.

Did you know? A *Quetzalcoatlus* neck vertebra could be longer than a person's forearm, yet the neck had only about nine vertebrae, so it was long but quite stiff. A close relative from Romania, *Hatzegopteryx*, had an unusually broad, heavy skull and may have hunted larger prey. Big Bend National Park has a full-size replica of *Quetzalcoatlus* at its Fossil Discovery Exhibit.

 **What the sign says / What we observe / How Christians read it.**  **What the sign says:** “*Quetzalcoatlus* soared over Texas about 68 to 66 million years ago, near the end of the Cretaceous Period.” **What we observe:** its bones lie in the Javelina Formation, sandstones and mudstones laid down by rivers, near the top of the rock layers that hold dinosaur bones in Big Bend, along with bones of *Alamosaurus* and other animals. The dates come from radiometric dating of volcanic ash beds in the area and assume steady decay rates, known starting amounts and no gain or loss of atoms. **How Christians read it:** many young-earth Christians read these layers as deposited late in the Flood year, as moving water and sediment buried the animals of the land; a pterosaur, able to fly, might have been among the last overwhelmed. Other Christians accept the long ages. All agree on where the bones lie and in what layers.

Go deeper. Kevin Padian, Matthew Brown and others, eds., *Quetzalcoatlus* memoir, *Journal of Vertebrate Paleontology* 41, supplement 1 (2021), open access. National Park Service, “Pterosaurs in Big Bend” (nps.gov/bibe). University of Texas Jackson School of Geosciences, Vertebrate Paleontology Laboratory pterosaur pages. Mark P. Witton, *Pterosaurs* (Princeton, 2013), the chapter on azhdarchids. Second video topic: “The square-cube law and the limits of animal size.”

Goes deeper in. Arithmetic, powers, area and volume (the square-cube law) (coming soon); Life Science, high-school Biology, animal flight; and Earth Science, the fossils units.

For families. This stop has dates, so it carries the  box. Lawson, *Science* 187 (1975). Wingspan of about 10 m and mass of about 150 kg: Andres and Langston and companion papers in the 2021 memoir; other studies estimate about 200–250 kg (e.g., Witton and Habib 2010) or very different values (about 70 kg to over 500 kg overall). Flightless argument: Henderson 2010. Terrestrial stalking: Witton and Naish, *PLOS ONE* 2008. The chalk dimensions for neck and head are rounded estimates. The name honors an Aztec deity; the stop states this as history and adds a short Christian note. Lilienthal's glide count and the photographer's name are commonly given; the exact date and photographer of a given print may vary. No public-domain text source exists for a fossil found in 1971, so there is no primary-source aside.

PRACTICE

1. **EASY** Who found *Quetzalcoatlus*, where, and in what year?
2. **EASY** What two names are joined in *Quetzalcoatlus northropi*?
3. **MEDIUM** Why did the wingspan estimate drop from about 15.5 m to about 10–11 m?
4. **MEDIUM** Give two pieces of evidence for the “terrestrial stalker” idea.
5. **CHALLENGE** Suppose a pterosaur with a 6 m wingspan weighed about 35 kg. Using the square-cube law, estimate the weight of a pterosaur of the same shape with a 10 m wingspan. By how many times does the load on each square meter of wing increase?
6. **CHALLENGE** Mass estimates for *Q. northropi* range from about 70 kg to over 500 kg. Explain (a) which parts of the estimate are observations and which are assumptions, (b) why a light estimate makes flight easier to explain but may be less believable, and (c) what new fossil evidence would most narrow the range.

Make it a game • Bigger Is Heavier. Players take turns building “flyers” from blocks: $1 \times 1 \times 1$, $2 \times 2 \times 2$ and $3 \times 3 \times 3$. Each flyer must be held up by paper “wings” laid flat underneath it on two chairs’ edges (a sheet of paper bridging two books). How many sheets does each size need before the wings stop sagging? The player who predicts the right number before testing earns a point.

Scripture. “Doth the hawk fly by thy wisdom, and stretch her wings toward the south? Doth the eagle mount up at thy command, and make her nest on high?” (Job 39:26–27, KJV)

God asked Job whether he had taught the birds to fly. Engineers still struggle to explain how the largest flyers managed it. The wisdom behind flight is God’s, not ours.

Practice: answers

1. Douglas A. Lawson, a University of Texas geology student, in Big Bend National Park, Texas, in 1971.
2. Quetzalcoatl, the feathered serpent worshiped by the Aztecs, and Jack Northrop, designer of “flying wing” airplanes.
3. The first estimate scaled the bones using long-winged pterosaurs like *Pteranodon*; comparison with more complete azhdarchids showed they had relatively shorter wings, so the same bones gave a smaller span.
4. Any two: bones found in river and floodplain deposits, not sea deposits; long, stiff neck and long toothless jaws suited to picking food off the ground; long legs for walking; the head could reach the ground easily while standing on all fours; skim-feeding would have strained the jaw and neck.
5. Scale factor $10 \div 6 \approx 1.67$. Weight $\times 1.67^3 \approx \times 4.6$, so about $35 \times 4.6 \approx 160$ kg. Area $\times 1.67^2 \approx \times 2.8$. Load per square meter rises by $4.6 \div 2.8 \approx 1.67$ times. (This is close to some published estimates, but real animals did not keep exactly the same shape.)
6. (a) Observations: bone lengths, diameters and wall thickness. Assumptions: amount of muscle, size of air sacs, body width, wing membrane thickness. (b) A light animal needs less lift and power, so it flies easily on paper; but a body too thin may not hold the muscle needed

to move its large bones, and the size and strength of its limb bones suggest they bore real loads. (c) A more complete skeleton, especially the body, hip and breastbone with muscle attachment scars, or preserved soft tissue outlines.

5.6 WOOLLY MAMMOTHS

OBJECTIVES

- Describe the woolly mammoth's cold-weather design and how its teeth record diet and age.
- Tell mammoths and mastodons apart, and explain how that confusion shaped early American science, including Jefferson's.
- Explain what frozen carcasses show, set out the debated causes of the mammoths' disappearance, and read the Ice Age both as museum vocabulary and in a young-earth framework.

Warm-up. Put one hand in a bowl of ice water for ten seconds. Then put on a wool sock or mitten and try again. Mammoths had wool underneath, long guard hairs on top and a thick layer of fat under the skin. Which layer do you think did the most to keep them warm?

Video slot. Video coming. Woolly mammoths: the baby mammoth Lyuba, mammoth teeth versus mastodon teeth, frozen carcasses in Siberian permafrost, the Rouffignac cave drawings. Search approved channels (Field Museum, Smithsonian, Natural History Museum London, Royal BC Museum); preview first.

KEY TERMS

woolly mammoth

Mammuthus primigenius, an elephant about the size of an African elephant with long hair, small ears and long curved tusks, adapted to cold, dry grassland.

mastodon

A different, more distantly related elephant-like animal with low, cone-shaped tooth cusps for browsing twigs and leaves. Most of Jefferson's "mammoth" bones were mastodons.

lamellae

The thin plates of enamel that make up a mammoth molar, giving a flat grinding surface like a washboard, good for chewing grass.

permafrost

Ground that stays frozen all year. Mammoth carcasses with skin, hair and stomach contents have been found in the permafrost of Siberia and Alaska.

Ice Age

The museum name for a time when great ice sheets covered much of northern North America and Europe; also called the Pleistocene on museum signs.

mammoth steppe

The cold, dry grassland that stretched across northern Europe, Asia and Alaska during the Ice Age, unlike any large habitat today.

CORE IDEAS

Built for the cold. A grown woolly mammoth stood about 2.7–3.4 m at the shoulder and weighed perhaps 4–6 metric tons, about the size of an African elephant. Every part of it was suited to cold. Its ears were small and its tail short, cutting the surface where heat escapes. A flap of skin covered the tail opening. Its coat had a dense woolly underlayer and outer guard hairs that could reach about 90 cm long, and under the skin lay a layer of fat about 8–10 cm thick. A hump of fat over the shoulders stored energy for winter. Its tusks curved up and inward in a spiral and could exceed 4 m in old males; worn surfaces suggest they swept snow from grass. Studies of mammoth DNA have even found a version of the blood protein hemoglobin that releases oxygen well in the cold.

Teeth tell the story. A mammoth molar is a stack of thin enamel plates, as many as 20 to 30, bound with softer material; as it wears, the hard ridges stand up like a washboard for grinding tough grass. Mammoths, like elephants, had six sets of molars in a lifetime, each moving forward and replacing the one before, so a tooth's wear and position tell a mammoth's age. Mastodons, a separate group, had low, cone-shaped cusps for crushing twigs, leaves and branches. Georges Cuvier named the mastodon in 1806 from those “nipple-shaped” cusps. Mammoths grazed the mammoth steppe, a cold, dry grassland with herbs and sedges; the Berezovka mammoth, dug from the Siberian permafrost in 1901, still had grass and flowering plants between its teeth and in its stomach.

Jefferson's mammoth. In the 1700s Americans called any great bones from the Ohio valley the “mammoth,” or the *incognitum* (the unknown). Huge numbers came from Big Bone Lick in Kentucky. Thomas Jefferson collected them and in his *Notes on the State of Virginia* (1785) used them to answer the French naturalist Buffon, who had claimed that American animals were small and feeble. Read the primary source: Jefferson describes tusks, grinders and skeletons of “unparalleled magnitude.” Most of those bones were in fact mastodons, and true mammoths were also present in North America. Jefferson's point against Buffon was sound, but his name for the animal was mistaken, an error he could not have caught until Cuvier compared the teeth.

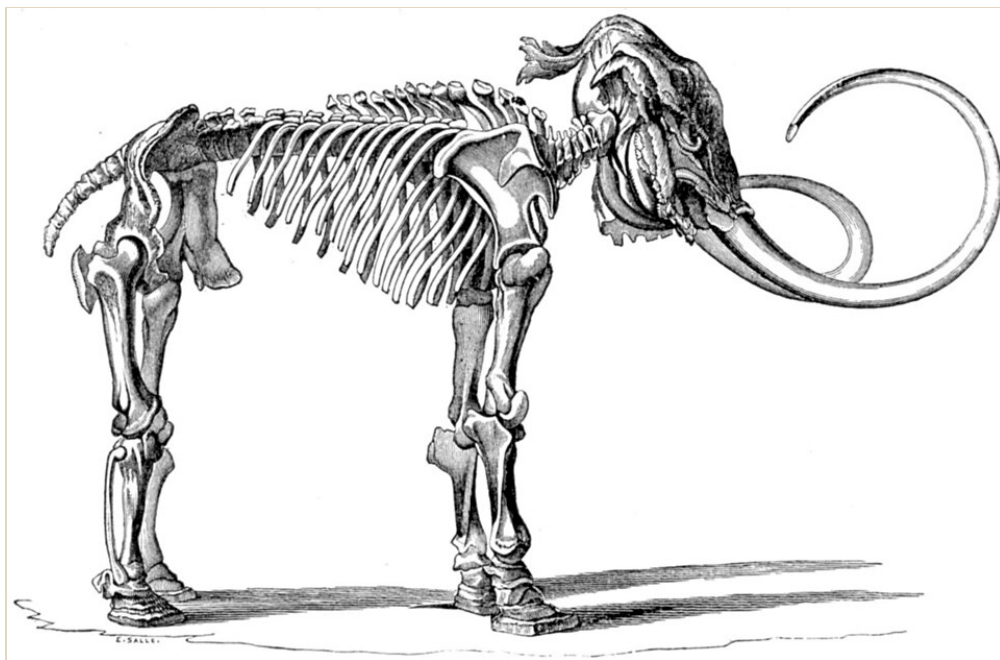
Frozen in Siberia. In 1799 an Evenk hunter named Ossip Shumachov found a mammoth emerging from a melting bank near the mouth of the Lena River. By the time the botanist Mikhail Adams reached it in 1806, wolves, bears and sled dogs had eaten much of the flesh, but he recovered the nearly complete skeleton, much of the skin and a quantity of hair, and brought them to St. Petersburg, where the skeleton was mounted, one of the first mammoth skeletons ever mounted. Since then many frozen mammoths have been found. In 2007 a reindeer herder on the Yamal Peninsula found “Lyuba,” a female calf about a month old, almost perfectly preserved, with her mother's milk still in her stomach. Such carcasses show that these animals were buried and frozen quickly, before they could rot; how that happened is still studied.

People and mammoths. Mammoths lived in Europe, Siberia and North America, where the larger Columbian mammoth ranged farther south. People of the Ice Age knew them well. They drew and engraved them on cave walls; the cave of Rouffignac in France is called the

“Cave of a Hundred Mammoths.” In what is now Ukraine they built round huts framed with mammoth bones and tusks. Spear points have been found with mammoth bones in North America. The woolly mammoth then disappeared from most of its range. Small groups held on longest on two islands: St. Paul Island in Alaska and Wrangel Island off Siberia, where by the standard radiocarbon chronology they lasted until about 4,000 years ago, when the pyramids of Egypt already stood.

Why did they disappear? Scientists still disagree. One side stresses climate: as the Ice Age ended, the dry mammoth steppe gave way to wet tundra, bogs and forest, and the mammoths’ food shrank. Another side stresses hunting by people, perhaps finishing off herds already under stress. Many think both mattered, and on small islands, lack of fresh water and inbreeding finished the last herds. Christians read this within the Bible’s history. Many young-earth creation scientists, such as the meteorologist Michael Oard, argue for one Ice Age after the Flood, caused by warm oceans (giving heavy snowfall) and volcanic dust (cooling summers), lasting perhaps several hundred years, with mammoths spreading out from the elephant kind that came off the Ark. The museum view counts many glacial advances over about 2.6 million years. Both views start from the same observations: moraines, ice-scraped rock, and frozen and buried mammoths.

PICTURE STUDY



The skeleton of the Adams mammoth, as mounted in St. Petersburg, Wilhelm Gottlieb Tilesius (drawing); engraved by E. Salle, 1815 · Engraving · From Tilesius’ description of the Adams mammoth for the Imperial Academy of Sciences, St. Petersburg; the skeleton is in the Zoological Museum, St. Petersburg
Wikimedia Commons · Public domain

The naturalist Wilhelm Gottlieb Tilesius described the Adams mammoth skeleton for the Russian Academy of Sciences and published this plate in 1815. It is one of the earliest scientific drawings of a whole mammoth skeleton, made when no one was yet sure how the

tusks or the back should look. Tilesius also drew the skin that still clung to the head and feet, evidence from the frozen carcass Adams had brought back from the Lena.

Look closely

- Look at the shape of the skull and the slope of the back from shoulders to hips. How is it different from an African elephant?
- Look at the tusks. Which way do they curve? Do they look as though they belong to the left and right sides correctly?
- Find the places where skin is still on the bones. Which parts of the body kept their skin?

Talk about it

1. Early mounts sometimes set mammoth tusks in the wrong sockets or the wrong direction. How could a scientist decide the right way without ever seeing a living mammoth?
2. Compare this engraving with a modern photograph of a mammoth skeleton. What has been learned since 1815?

HANDS-ON: GRINDER OR CRUSHER? A TOOTH LAB

Model a mammoth molar and a mastodon molar, test them on grass and twigs, and then judge Jefferson's evidence.

You will need

- Modeling clay or salt dough in two colors
- Toothpicks, a plastic knife and a ruler
- A handful of dry grass and a few small twigs
- The primary source in the asides

Steps

1. Mammoth molar: make a block of clay about $12 \times 6 \times 6$ cm. Press thin slices of the second color into it, standing on edge, about 5 mm apart, so the top shows many parallel ridges.
2. Mastodon molar: make a block the same size and add six to eight rounded, cone-shaped bumps on top, in pairs.
3. Let them dry or chill them. Rub grass between the mammoth tooth and a flat board, then between the mastodon tooth and the board. Do the same with twigs. Which tooth shreds grass best? Which crushes twigs?
4. Read the primary source. Jefferson mentions "grinders." Write what you would need to see on those grinders to decide whether they came from a mammoth or a mastodon.
5. Write a two-sentence verdict: was Jefferson right that the bones showed a very large American animal? Was he right to call it a mammoth?

Check your work

- My two molars clearly show ridges and cones.
- I tested both teeth on grass and on twigs and recorded what happened.
- My verdict separates what Jefferson got right from what he could not yet know.

FIELD NOTEBOOK

1. Draw a woolly mammoth in side view. Label the domed head, shoulder hump, small ear, trunk, spiral tusks, guard hairs, underwool and short tail, and write one sentence on how each part helps in the cold.
2. Draw a mammoth molar and a mastodon molar seen from above, side by side, and write their diets beneath.
3. **Narration (the parent keeps this).** Write one paragraph explaining how a frozen mammoth like the Adams mammoth or Lyuba helps scientists learn things bones alone cannot tell, and give two examples.

Did you know? Mammoth tusks grew throughout life and laid down growth layers, a little like tree rings. By slicing tusks and measuring chemical differences between the layers, scientists have traced where individual mammoths traveled, season by season. Siberian mammoth ivory, dug from melting ground and riverbanks, is still legally sold, and much more is found every year.

 **What the sign says / What we observe / How Christians read it.**  **What the sign says:** “Woolly mammoths roamed the Ice Age world from about 400,000 years ago; most died out about 10,000 years ago, and the last survived on Wrangel Island until about 4,000 years ago.” **What we observe:** mammoth bones, tusks and frozen carcasses in the uppermost loose sediments and permafrost of the north; cave drawings by people; carbon-14 measured in bone, hair and flesh. Radiocarbon dates assume that the amount of carbon-14 in the air was steady or can be corrected with calibration records; older dates also rely on the long-age reading of layers below. **How Christians read it:** many young-earth Christians place one Ice Age in the centuries after the Flood, with mammoths descended from the elephant kind on the Ark; they argue that carbon-14 ages beyond a few thousand years need adjusting because the Flood upset the earth’s carbon balance. Other Christians accept the conventional chronology. All agree that people saw living mammoths and that the last herds lived into the time of written history.

Primary source. *Thomas Jefferson, Notes on the State of Virginia (1785), Query VI, “A notice of the mines and other subterraneous riches; its trees, plants, fruits, &c.” The Avalon Project, Yale Law School.*

It is well known that on the Ohio, and in many parts of America further north, tusks, grinders, and skeletons of unparalleled magnitude, are found in great numbers, some lying on the surface of the earth, and some a little below it.

Go deeper. Adrian Lister and Paul Bahn, *Mammoths: Giants of the Ice Age* (rev. ed., 2007). Field Museum and Royal BC Museum pages on Lyuba (“Mammoths and Mastodons” exhibition). Thomas Jefferson, *Notes on the State of Virginia*, Query VI, on the Avalon Project; read the whole section answering Buffon. Michael J. Oard, *Frozen in Time: Woolly Mammoths, the Ice Age, and the Biblical Key to Their Secrets* (2004), for a young-earth reading. Second video topic: “How Lyuba the baby mammoth was found and studied.”

Goes deeper in. Earth Science, the Ice Age and glaciers units (coming soon); History, Thomas Jefferson and the early republic; Geography, Siberia and the Arctic.

For families. This stop has dates, so it carries the ⏳ box. Sizes, hair length and fat thickness are commonly cited ranges (Lister and Bahn). Mammoth hemoglobin: Campbell et al., *Nature Genetics* 2010. Adams mammoth: found 1799, recovered 1806, now in the Zoological Museum, St. Petersburg. Berezovka mammoth: excavated 1901. Lyuba: found 2007, Yamal Peninsula. Wrangel and St. Paul dates follow the standard radiocarbon chronology. The extinction causes are honestly debated, and both main views are given. The young-earth Ice Age model follows Oard; old-earth Christians hold the conventional view. The primary source was copied from the Avalon Project. The tusk question in the picture study is posed as a question, since early mounts varied; check the plate before discussing.

PRACTICE

1. **EASY** Name four features that helped the woolly mammoth live in the cold.
2. **EASY** How can you tell a mammoth tooth from a mastodon tooth?
3. **MEDIUM** What was found in the stomach of Lyuba, and what does it show?
4. **MEDIUM** Give the two main explanations for the disappearance of the mammoths, and one piece of evidence for each.
5. **CHALLENGE** Read the primary source. (a) What does Jefferson observe? (b) What did he conclude about these animals, and why did it matter to his argument with Buffon? (c) What did he not know that later research showed?
6. **CHALLENGE** A mammoth needed perhaps 150–200 kg of plant food a day. How many metric tons is that per year at 180 kg a day? If a herd of 15 mammoths fed in one valley for 30 days, how much food did they need? What does that suggest about the mammoth steppe compared with today’s Arctic tundra?

Make it a game • Mammoth or Mastodon? Make ten cards: grass-eater, twig-eater, ridged molars, cone-cusped molars, long woolly hair, found frozen in Siberia, found at Big Bone Lick, drawn in French caves, Jefferson’s “incognitum,” straighter tusks. The leader reads a card and players stomp (mammoth), shuffle (mastodon) or do both if it fits either. Explain any tricky ones.

Scripture. “Out of the south cometh the whirlwind: and cold out of the north. By the breath of God frost is given: and the breadth of the waters is straitened.” (Job 37:9-10, KJV)

Elihu reminds Job that frost and ice come from God’s hand. The mammoths lived in a world shaped by great cold, and that cold too was under His rule.

Practice: answers

1. Any four: small ears, short tail, flap over the tail opening, woolly underfur, long guard hairs, thick fat under the skin, fat hump, cold-adapted hemoglobin.
2. A mammoth molar has many thin enamel ridges (lamellae) on a flat grinding surface; a mastodon molar has rows of low, rounded cone-shaped cusps.
3. Her mother’s milk (and some dung, which calves eat to gain gut bacteria). It shows she was a young, nursing calf and that she was preserved quickly before decay.
4. Climate and habitat change: as the Ice Age ended, dry grassland became wet tundra, bog and forest (pollen and plant remains show the change). Human hunting: spear points found with mammoth bones, bone huts, cave art. Many scientists think both played a part.
5. (a) Tusks, grinders and skeletons of great size, found in great numbers on and just under the ground along the Ohio and farther north. (b) That America had a huge animal, the “mammoth,” larger than any in the Old World he knew; this answered Buffon’s claim that American animals were small and degenerate. (c) That most of these bones belonged to the mastodon, a different animal with different teeth (named by Cuvier in 1806), and that the animal was extinct, not living in the unexplored West.
6. $180 \times 365 = 65,700$ kg, about 66 metric tons a year. $15 \times 180 \times 30 = 81,000$ kg, about 81 metric tons. The mammoth steppe must have been far more productive than today’s wet, mossy tundra, which could not feed such herds; this is part of the habitat-loss argument.

5.7 SABER-TOOTHED CATS

OBJECTIVES

- Describe *Smilodon*: its species, size, sabers, gape and build, and explain why it was not a tiger.
- Explain the canine shear-bite and the evidence that *Smilodon*'s bite was weaker than a lion's but its neck and forelimbs stronger.
- Weigh the debate over whether healed injuries show that sabertooths lived in groups, and compare sabertooths in different animal families.

Warm-up. Open your mouth as wide as you can and have someone estimate the angle between your upper and lower teeth (about 40–50° for most people). A lion can open to about 65°. *Smilodon* could open to about 110° or more. Why would an animal with long sabers need to open so wide?

Video slot. Video coming. *Smilodon*: skulls and sabers at La Brea, how saber-toothed cats bit, *Homotherium* and *Thylacosmilus*. Search approved channels (La Brea Tar Pits and Museum, Natural History Museum of Los Angeles County, Smithsonian, PBS Eons with a parent); preview first.

KEY TERMS

Smilodon

“Knife tooth”: the best-known saber-toothed cat of the Americas, with upper canines up to about 18–28 cm long depending on species.

machairodont

A member of the saber-toothed branch of the cat family (Machairodontinae), separate from the branch that includes lions, tigers and house cats.

gape

How wide the jaws can open, measured as an angle. Sabertooths needed a very wide gape to clear their long canines.

canine shear-bite

The leading idea for how *Smilodon* killed: holding prey still with its forelimbs, then driving the sabers in with powerful neck muscles.

convergence

Similar features in unrelated animals. Saber teeth appear in true cats, in the cat-like nimravids and in the South American *Thylacosmilus*.

CORE IDEAS

Not a tiger. People often say “saber-toothed tiger,” but *Smilodon* was not a tiger, nor closely related to one. It belonged to a separate branch of the cat family, the machairodonts, with no

living members. It was first named in 1842 by Peter Wilhelm Lund, a Danish naturalist who spent years exploring the limestone caves of Lagoa Santa in Brazil and found bones of ground sloths, giant armadillos and great cats there. Three species are usually recognized. *Smilodon gracilis* was the smallest. *Smilodon fatalis*, the one found at La Brea, weighed roughly 160–280 kg, about the size of a large lion or tiger. *Smilodon populator* of South America was the giant, estimated at 220–400 kg, among the heaviest cats ever known.

The sabers. The upper canines of *S. fatalis* stood out about 18 cm below the gum; those of *S. populator* were longer, about 28 cm for the whole tooth including the root. They were flattened side to side, like a blade, with fine serrations in many specimens. A blade like that cuts deeply but can snap if twisted sideways against bone, and broken sabers are found in the fossil collections. To use them, *Smilodon* had to open its jaws to about 110° or more; the jaw joint and the bony anchor points of the jaw muscles were shaped to allow it. The body was built differently from a lion's too: very powerful forelimbs and neck, a heavy, robust skeleton and a short tail, more suited to ambush and grappling than to long chases.

How did it bite? In 2007 Colin McHenry and colleagues used computer models of skulls to compare *S. fatalis* with a lion of similar size. They found that its jaw muscles alone gave a bite only about one-third as strong as a lion's, but that its neck muscles, which drove the head downward, and its skull were built to handle large forces if the prey was held still. Their conclusion supported the canine shear-bite: the cat wrestled large prey down with its forelimbs and then drove its sabers into the throat with a downward push of head and neck, killing quickly. A lion, by contrast, holds on with a long crushing bite. The two cats solved the same problem in different ways.

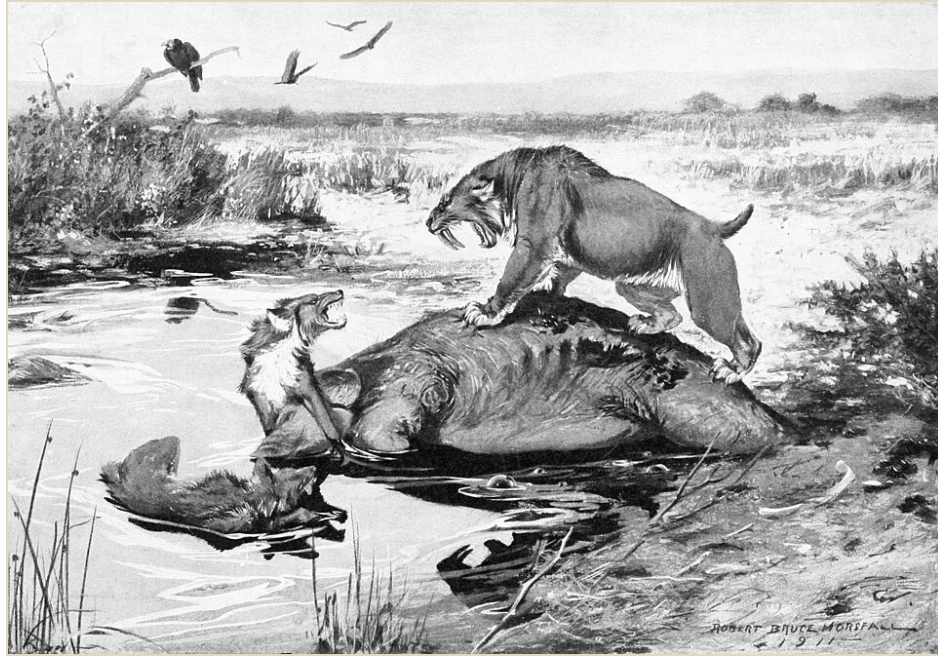
Alone or in groups? At La Brea, *Smilodon* is the second most common large mammal, after the dire wolf (Stop E9). Many skeletons show serious injuries that healed: crushed hips, broken legs, damaged spines. Some researchers argue that badly hurt cats could survive only if others shared their kills, which would mean they lived in groups, as lions do. Others reply that a healthy cat can live a long time on stored fat and that predators of many kinds recover from injuries alone; and that the predator-trap setting at La Brea, where many meat-eaters were drawn to struggling prey, could gather many cats whether they were social or not. This is an honest scientific disagreement, and both sides use the same bones.

Sabers more than once. Long blade-like canines appear in several unrelated groups. Besides *Smilodon*, there was *Homotherium*, the "scimitar cat," with shorter, broader sabers and long legs for running. The nimravids, cat-like but not true cats, had sabers too. Most striking is *Thylacosmilus* of South America, a meat-eater from a group related to marsupials, whose sabers grew all its life and were protected by a long flange of bone on the lower jaw. Mainstream biologists call this repeated convergent evolution. Creation biologists see it as the same good design used in several kinds; some have proposed that all true cats, sabertooths included, descend from one created cat kind, with *Thylacosmilus* belonging to a different kind altogether. Again, the observation is the same; the explanation differs.

Predators in God's world. *Smilodon fatalis* became California's state fossil in 1974. How should a Christian think about a creature built so plainly for killing? Genesis 1:30 gives

green plants as food to the animals at creation, and Isaiah pictures a coming peace when “the wolf also shall dwell with the lamb.” Many young-earth Christians therefore read predation as entering the world after the Fall, with animals like *Smilodon* living in the centuries after the Flood. Other Christians read predation as part of the created order from the beginning. Either way, Scripture also speaks of lions seeking “their meat from God” (Psalm 104:21): even in a fallen world, God feeds His creatures and holds the balance of life.

PICTURE STUDY



Smilodon, restoration for W. B. Scott's *A History of Land Mammals in the Western Hemisphere*, Robert Bruce Horsfall, 1913 · Pen-and-ink or wash illustration, printed as a halftone · From William Berryman Scott, *A History of Land Mammals in the Western Hemisphere* (New York, 1913)
Wikimedia Commons · Public domain

Robert Bruce Horsfall was a wildlife artist who drew restorations of extinct mammals for the Princeton paleontologist William Berryman Scott. Scott, an expert on fossil mammals, checked the restorations against the skeletons; the artist supplied the muscles, skin and fur by comparison with living animals, the same method careful artists use today.

Look closely

- Look at the length of the legs and tail. How does this cat's build differ from a cheetah's or a house cat's?
- Look at how far the sabers extend below the lower jaw when the mouth is closed.
- Find the shoulders and neck. Where would the strongest muscles be?

Talk about it

1. Did Horsfall give his cat a plain coat, spots or stripes? Can a skeleton tell an artist about coat color? What must the artist do instead?

2. If you were redrawing this cat today, what would you add or change because of the 2007 bite study?

HANDS-ON: GAPE AND SABER: A JAW MODEL

Build a hinged jaw and find out how wide it must open for long sabers to work.

You will need

- Two strips of stiff cardboard, about 25 cm × 6 cm (upper and lower jaw)
- A brass paper fastener for the hinge
- Card for teeth, scissors, tape and a protractor
- An apple or a ball of clay (the prey's neck)

Steps

1. Join the two jaw strips at one end with the paper fastener so they open like a mouth.
2. Cut and tape two 18 cm sabers (scaled to life size for *S. fatalis*) near the front of the upper jaw, pointing down. Add short lower canines to the lower jaw.
3. Open the jaw slowly. Use the protractor to find the smallest angle at which the tips of the sabers clear the lower teeth enough to fit around the apple. Record it.
4. Now replace the sabers with 6 cm lion-sized canines and repeat. Compare the two angles.
5. Try “biting” the apple by squeezing the jaws together, then by holding the jaw open and pushing the whole model straight down. Which method drives the sabers in more easily? Write how this connects to the canine shear-bite.

Check your work

- My model has working hinged jaws with life-size sabers.
- I measured and recorded both gape angles.
- I can explain why a downward push of the head worked better than a squeeze.

FIELD NOTEBOOK

1. Draw a *Smilodon* skull and a lion skull side by side, both with jaws open. Mark the gape angle on each (about 110° and 65°).
2. Make a chart of three saber-toothed animals: *Smilodon*, *Homotherium* and *Thylacosmilus*. For each give the group it belongs to, where it lived and one special feature.
3. **Narration (the parent keeps this).** Write one paragraph setting out both sides of the debate over whether *Smilodon* lived in groups, and say which side the evidence persuades you toward and why.

Did you know? Thousands of *Smilodon* individuals have been recovered from the La Brea Tar Pits, more than from anywhere else on earth, which is why so much is known

about how its bones grew and healed. Studies of the bones of young La Brea cats show that they grew quickly, much as lions and tigers do today, building thick, strong limb bones early in life.

Go deeper. Alan Turner and Mauricio Antón, *The Big Cats and Their Fossil Relatives* (1997), beautifully illustrated. Lars Werdelin, H. Gregory McDonald and Christopher A. Shaw, eds., *Smilodon: The Iconic Sabertooth* (Johns Hopkins, 2018), for advanced readers. La Brea Tar Pits and Museum, “Saber-toothed cat” pages (tarpits.org). Second video topic: “Comparing the skulls of lions and saber-toothed cats.”

Goes deeper in. Life Science, high-school Biology, predators and animal design (coming soon); Gardening & Animals, wild cats; Arithmetic, measuring angles.

For families. Lund named *Smilodon* in 1842. Mass ranges vary by study; those given are commonly cited (e.g., Christiansen and Harris 2005). Bite study: McHenry et al., *PNAS* 2007. For the social debate, see Carbone et al., *Biology Letters* 2009, and the replies to it. Growth study: Long et al., *PLOS ONE* 2017. The creation-biology proposal of a single cat kind is attributed generally to baraminology studies and stated as a proposal. Predation and the Fall is presented as the common young-earth reading with other Christian views noted. Hunting is described plainly without gore. No public-domain text source could be verified word for word for this stop, so there is no primary-source aside, and no dates in years are given, so there is no ⏳ box.

PRACTICE

1. **EASY** Why is “saber-toothed tiger” a misleading name?
2. **EASY** Who named *Smilodon*, when, and where did he find the bones?
3. **MEDIUM** Why did *Smilodon* need a gape of about 110° , and what risk came with long, thin sabers?
4. **MEDIUM** Name two animals other than *Smilodon* that had saber teeth, and say what that shows.
5. **CHALLENGE** McHenry’s team found *Smilodon*’s jaw-muscle bite was about one-third of a lion’s. A lion of similar size bites with about 1,000 N at the canines (an exercise figure). (a) What would *Smilodon*’s be? (b) Why does a weak bite not mean a weak killer? (c) What observations and what assumptions went into the study?
6. **CHALLENGE** Many La Brea *Smilodon* skeletons show healed, crippling injuries. State the argument that this shows group living, then give two objections. Which further evidence would help settle it?

Make it a game • Ambush!. One player is the *Smilodon* and hides behind furniture; the others are “bison” who must cross the room slowly to a “water hole” and back. The cat may pounce only within two steps of its hiding place and must tag with both hands (forelimbs) to catch. Discuss after: why was ambush, not a long chase, the better plan for a heavy, short-tailed cat?

Scripture. “The wolf also shall dwell with the lamb, and the leopard shall lie down with the kid; and the calf and the young lion and the fatling together; and a little child shall lead them.” (Isaiah 11:6, KJV)

Isaiah looks ahead to a peace in which predators no longer prey. The saber-toothed cat, built for the hunt, reminds us that this world is not yet what God has promised it will be.

Practice: answers

1. *Smilodon* was not a tiger or closely related to one; it belonged to a separate, extinct branch of the cat family, the machairodonts.
2. Peter Wilhelm Lund, a Danish naturalist, in 1842, from the caves of Lagoa Santa in Brazil.
3. Its long upper canines had to clear the lower jaw and fit around the prey before biting. Because the sabers were flattened like blades, a sideways twist against bone could snap them; broken sabers are found.
4. Any two: *Homotherium* (scimitar cat), nimravids (“false sabertooths”), *Thylacosmilus*. Saber teeth appear in unrelated groups (convergence), which mainstream biologists explain as separate evolution and creation biologists as common design.
5. (a) About $1,000 \div 3 \approx 330$ N. (b) *Smilodon* did not rely on squeezing; it pinned prey with strong forelimbs and drove the sabers in with powerful neck muscles pushing the head down, so most of the force came from the neck and body, not the jaw. (c) Observations: skull shape, size and bone thickness, and muscle attachment areas. Assumptions: muscle sizes and strength (soft tissue not preserved), the way the force was applied, and the material properties of the bone used in the computer model.
6. Argument: a cat crippled for weeks could not hunt, so it survived only because group members let it share kills, as lions do. Objections (any two): healthy cats can live off stored fat for a long time; solitary predators sometimes survive injuries by scavenging; La Brea’s predator trap gathers many meat-eaters at one place whether they were social or not; we cannot tell how long each injury kept the cat from hunting. Helpful evidence: brain size and structure compared with social cats, trackways showing several cats together, or several individuals of different ages found buried together outside a trap setting.

5.8 GIANT GROUND SLOTHS

OBJECTIVES

- Describe the main giant ground sloths (*Megatherium*, *Megalonyx*, the Shasta and Harlan's ground sloths) with real sizes, and explain how they fed and moved.
- Tell how the Madrid *Megatherium* and Jefferson's *Megalonyx* helped prove that whole kinds of animals had gone extinct.
- Analyze Jefferson's argument against extinction, separating its observations from its philosophical assumption, and compare it with what Scripture teaches.

Warm-up. Hang from a bar or a low branch with both hands for as long as you can. A tree sloth today spends most of its life hanging like that and weighs about as much as a house cat. Now imagine a sloth as tall as a giraffe when it stands up, too heavy to climb any tree. What would it do instead?

Video slot. Video coming. Giant ground sloths: *Megatherium* skeletons, Jefferson's *Megalonyx* claw, the Shasta ground sloth dung of Rampart Cave and sloth bones at La Brea. Search approved channels (Smithsonian, Academy of Natural Sciences of Drexel University, La Brea Tar Pits and Museum, Monticello); preview first.

KEY TERMS

ground sloth

Any of the large, extinct relatives of today's tree sloths that lived on the ground, from the size of a large dog to that of an elephant.

Megatherium

"Great beast": the giant ground sloth of South America, about 6 m long and up to about 4 metric tons, named by Cuvier in 1796.

Megalonyx

"Great claw": a North American ground sloth about 3 m long, named from bones described by Thomas Jefferson in 1797. The species is *Megalonyx jeffersonii*.

xenarthran

The group of mammals that includes sloths, anteaters and armadillos, with extra joints between the backbones of the lower back.

osteoderms

Small bony nodules set in the skin. Some ground sloths, such as Harlan's ground sloth, had a coat of mail of these under their hair.

extinction

The dying out of a whole kind of animal. Around 1800, giant sloths helped convince scientists that it really happens.

CORE IDEAS

Sloths on the ground. The two kinds of tree sloths alive today are slow, leaf-eating climbers of the Central and South American forests. Their extinct relatives were mostly ground-dwellers, and some were enormous. *Megatherium americanum* of South America was about 6 m long and perhaps 4 metric tons, as heavy as an elephant. It could rear up on its hind legs, braced by a massive tail, to pull down branches with its great clawed hands, reaching perhaps 4 m. In North America lived *Megalonyx jeffersonii* (about 3 m long and a metric ton), *Paramylodon harlani* (Harlan's ground sloth, common at La Brea) and the smaller Shasta ground sloth, *Nothrotheriops*. Their claws were so big that they walked on the outside edges of their hind feet and the knuckles of their hands.

The Madrid skeleton. In 1788 a huge skeleton was dug from the banks of the Luján River near Buenos Aires and shipped to Madrid, to the Royal Cabinet of Natural History. There Juan Bautista Bru, the cabinet's preparator, assembled it, one of the first fossil skeletons of an extinct animal ever mounted, and made careful drawings. Prints of the drawings reached Paris, and in 1796 the young Georges Cuvier, without seeing the bones, recognized that the animal was related to sloths, though gigantic, and named it *Megatherium*. Cuvier used it, with the mammoth, to argue that whole kinds of animals had once lived and now lived nowhere: extinction was real.

Jefferson's claw. At almost the same time, workers digging saltpeter in a cave in Greenbrier County, Virginia (now West Virginia), found large bones, including claws, and some were sent to Thomas Jefferson. In March 1797 Jefferson, then the new Vice President, presented a paper to the American Philosophical Society in Philadelphia describing a great clawed animal he named *Megalonyx*, "great claw." He thought it a giant lion, larger than the African lion. The anatomist Caspar Wistar, studying the same bones, saw that they resembled *Megatherium*, and by the early 1800s the creature was understood to be a ground sloth. In 1822 the French zoologist Anselme Desmarest named the species *Megalonyx jeffersonii*. It is West Virginia's state fossil.

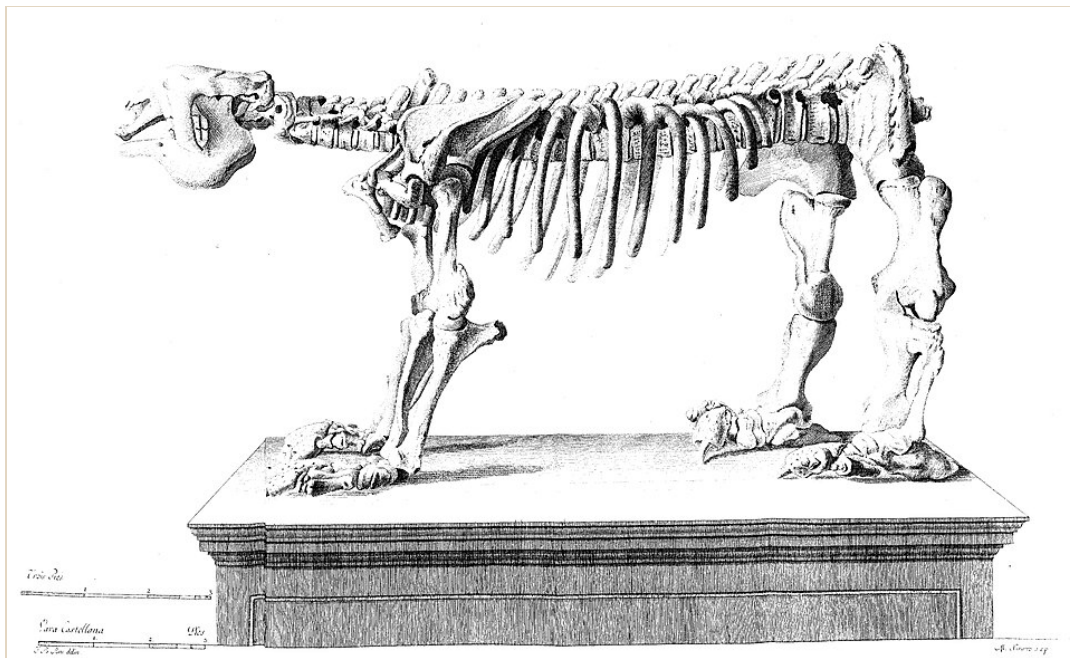
Jefferson's assumption. Jefferson hoped that *Megalonyx* and the mammoth might still live in the unexplored West, and he asked Lewis and Clark to note any animals there that might be rare or extinct. The reason appears in the primary source, written about the "mammoth": he believed that nature would never allow any "race" of animals to become extinct, or any link in "her great work" to break. This idea came from an old philosophy called the Great Chain of Being, which pictured creation as a ladder in which every rung must always be filled. It was a philosophical assumption, not an observation. Notice also that Jefferson speaks of "nature" and "her" work, not of the Creator; he rejected many Christian doctrines. Scripture nowhere teaches that every kind must survive. It teaches the reverse: that the whole creation "groaneth and travaileth in pain" (Romans 8:22) since the Fall, and the Flood itself destroyed vast numbers of creatures.

What they ate. Sloth dung tells the story directly. In dry caves of the American Southwest, such as Rampart Cave in the Grand Canyon, Shasta ground sloth dung piled up in thick layers, still recognizable, full of desert plants such as globemallow, Mormon tea and

saltbush. In 1976 a fire, probably set accidentally, smoldered in Rampart Cave for months and destroyed much of the deposit. Ground sloth teeth had no enamel and grew throughout life, suited to grinding tough plants. In 1832, at Punta Alta in Argentina, the young Charles Darwin dug out bones of *Megatherium*, *Myodon* and other giants and puzzled over why they had died out while smaller relatives survived.

An honest open question. Why did the giant ground sloths disappear? As with the mammoths, scientists debate changing climate and plant life, hunting by people, or both. In some places human tools or cut marks have been reported on sloth bones. Some ground sloths survived longest on Caribbean islands such as Cuba and Hispaniola, by the standard chronology into a time after they had vanished from the mainland. Christians may read their disappearance as part of the long story of a creation that is subject to death after the Fall, yet still under God's care. Jefferson's mistake is a good warning to every student: a strongly held assumption, however reasonable it feels, must give way to the evidence.

PICTURE STUDY



The skeleton of the Megatherium in the Royal Cabinet of Natural History, Madrid, Juan Bautista Bru (drawing); engraved by Manuel Navarro, Drawn about 1788–1789; published 1796 · Engraving · From José Garriga, *Descripción del esqueleto de un cuadrúpedo muy corpulento y raro* (Madrid, 1796); copy in the Biblioteca Nacional de España. The skeleton is in the National Museum of Natural Sciences, Madrid.
Wikimedia Commons · Public domain

Juan Bautista Bru, the preparator of the Royal Cabinet in Madrid, assembled the giant skeleton from Luján and made careful drawings of it. Prints of his drawings reached Paris, and from them, without seeing the bones, Georges Cuvier recognized a gigantic relative of the sloths and named it *Megatherium*. In 1796 the drawings were published in Madrid in this engraving. A picture, carefully made, carried the evidence across Europe.

Look closely

- Look at how the skeleton stands. How thick are the leg bones compared with the body?
- Find the feet and claws. How might an animal walk on claws this large?
- Compare the head with the body. Is the head big or small?

Talk about it

1. Cuvier identified this animal from drawings alone. What makes a drawing trustworthy enough for a scientist to use, and what are its limits?
2. What features of this skeleton would help an animal rear up and pull down branches?

HANDS-ON: JEFFERSON'S CLAW: TESTING AN IDENTIFICATION

Repeat the reasoning of 1797: compare a claw with possible owners, then test Jefferson's argument against extinction.

You will need

- Pictures (library or museum websites) of a lion paw skeleton, a tree sloth hand skeleton and the *Megalonyx* claw bones (Academy of Natural Sciences, Philadelphia, or Smithsonian)
- A ruler, paper and pencil
- Modeling clay (optional) for a life-size claw core, about 20 cm
- The primary source in the asides

Steps

1. Compare the three hand pictures. For each, note claw length compared with the finger bones, whether the claws retract (lions) or stay out (sloths), and how many claws are large.
2. Make a three-column table, "Lion," "Tree sloth," "Megalonyx." Decide which the *Megalonyx* claw most resembles and give two reasons.
3. Optional: model the *Megalonyx* claw core in clay at life size (about 20 cm along the curve; the horny sheath in life was longer).
4. Read the primary source. Write Jefferson's argument as three numbered steps: his premise, his evidence and his conclusion. Circle the step that is an assumption rather than an observation.
5. Write a short reply to Jefferson, as Cuvier might have, using the *Megatherium* and the mammoth as evidence.

Check your work

- My table compares three animals with at least three features each.
- I wrote Jefferson's argument in three steps and found the assumption.
- My reply uses real evidence, politely stated.

FIELD NOTEBOOK

1. Draw *Megatherium* standing upright against a tree with a person beside it to scale. Label the claws, tail, hind feet (walking on their sides) and head.
2. Make a timeline: 1788 (Luján skeleton), 1796 (Cuvier names *Megatherium*), 1797 (Jefferson's *Megalonyx*), 1822 (*M. jeffersonii* named), 1832 (Darwin at Punta Alta), 1976 (Rampart Cave fire).
3. **Narration (the parent keeps this).** Write one paragraph explaining what Jefferson thought *Megalonyx* was, why he expected it might still be alive, and what changed his contemporaries' minds.

Did you know? Jefferson's original *Megalonyx* bones are kept at the Academy of Natural Sciences of Drexel University in Philadelphia. In 2008 *Megalonyx jeffersonii* became the state fossil of West Virginia. At the Cueva del Milodón in southern Chile, explorers in the 1890s found ground sloth skin still covered with coarse hair and studded with bony nodules.

Primary source. Thomas Jefferson, *Notes on the State of Virginia* (1785), Query VI, "A notice of the mines and other subterraneous riches; its trees, plants, fruits, &c.," writing of the great bones he called the mammoth. *The Avalon Project, Yale Law School*.

Such is the oeconomy of nature, that no instance can be produced of her having permitted any one race of her animals to become extinct; of her having formed any link in her great work so weak as to be broken. To add to this, the traditionary testimony of the Indians, that this animal still exists in the northern and western parts of America, would be adding the light of a taper to that of the meridian sun.

"Oeconomy" is the old spelling of economy, meaning the ordered working of a system. A "taper" is a thin candle; the "meridian sun" is the sun at noon. Jefferson means that the Indian traditions add a little light to what he thinks is already as clear as noon.

Go deeper. Monticello (Thomas Jefferson Foundation), "*Megalonyx jeffersonii* fossils" encyclopedia page. Keith Thomson, *The Legacy of the Mastodon: The Golden Age of Fossils in America* (Yale, 2008). Martin J. S. Rudwick, *Georges Cuvier, Fossil Bones, and Geological Catastrophes* (1997), translated Cuvier documents including the *Megatherium* paper. Charles Darwin, *The Voyage of the Beagle*, Chapter V, free at Project Gutenberg. Second video topic: "How Megatherium fed."

Goes deeper in. History, Thomas Jefferson and the Lewis and Clark expedition (coming soon); Life Science, high-school Biology, extinction and classification; Literature, reading arguments (premise, evidence, conclusion).

For families. The primary source was copied from the Avalon Project. It comes from Jefferson's discussion of the "mammoth" (mostly mastodon) bones, written before the

Megalonyx find, but it states the belief that shaped his view of *Megalonyx* too; his 1797 memoir is not in the approved archives for this course, so it is described, not quoted. Dates: Luján skeleton 1788; Cuvier's *Megatherium* 1796; Jefferson's paper read March 1797; Desmarest's name 1822; Darwin at Punta Alta 1832; Rampart Cave fire 1976. Sizes are common estimates. Jefferson's religious views are stated plainly and without scorn. The Caribbean survival is given by the standard chronology without a number, so this stop has no ⏰ box.

PRACTICE

1. **EASY** What do *Megatherium* and *Megalonyx* mean?
2. **EASY** What animal did Jefferson first think *Megalonyx* was, and what was it really?
3. **MEDIUM** How do scientists know what the Shasta ground sloth ate?
4. **MEDIUM** Why did *Megatherium* matter to Cuvier?
5. **CHALLENGE** Using the primary source, put Jefferson's argument in the form premise, supporting testimony, conclusion. Identify which part is an assumption, explain where that assumption came from, and show how both the fossil evidence and Scripture answer it.
6. **CHALLENGE** A tree sloth weighs about 5 kg; *Megatherium* about 4,000 kg. (a) How many times heavier was *Megatherium*? (b) If both had the same body shape, by about how many times was *Megatherium* longer? (c) Why could it not climb trees, and how did it reach leaves instead?

Make it a game • Name That Bone. Gather pictures of ten claws or hand bones (lion, bear, tree sloth, anteater, eagle, mole, house cat, *Megalonyx*, *Megatherium*, human). Show one at a time without the name. Players guess the owner and must give one reason. A correct guess with a good reason scores two points; a correct guess alone scores one.

Scripture. "For we know that the whole creation groaneth and travaileth in pain together until now." (Romans 8:22, KJV)

Jefferson thought nature could never lose a single kind of animal. Paul teaches that creation since the Fall groans and suffers loss, waiting for the day God will make it new.

Practice: answers

1. *Megatherium*: "great beast." *Megalonyx*: "great claw."
2. A giant lion. It was a ground sloth.
3. From its preserved dung in dry caves such as Rampart Cave, which is full of identifiable desert plants such as globemallow, Mormon tea and saltbush.
4. It was a giant, clearly sloth-like animal unlike any living creature, too large to be overlooked if it still lived; with the mammoth, it helped him prove that extinction had happened.
5. Premise: nature never permits any kind ("race") of animal to become extinct or any link in its work to break. Testimony: Indian traditions say the animal still lives in the north and west. Conclusion: the animal still exists somewhere unexplored. The premise is an assumption, from

the philosophy of the Great Chain of Being, not an observation. Fossil evidence: *Megatherium*, mammoths and others had no living members anywhere, even as more of the world was explored, and Lewis and Clark found none. Scripture: nowhere promises every kind will survive; it teaches that creation groans under the curse since the Fall (Romans 8:22), and the Flood destroyed vast numbers of living things.

6. (a) $4,000 \div 5 = 800$ times. (b) Length scales with the cube root of mass: $\sqrt[3]{800} \approx 9.3$, so about 9 times longer. (c) No branch could hold 4 tons; it reared on its hind legs, braced by its massive tail, and pulled branches down with its clawed hands.

5.9 LA BREA TAR PITS

OBJECTIVES

- Explain what the La Brea asphalt seeps are, how they trapped animals and why the collection is so heavy with meat-eaters.
- Trace the history of the site from Native use and the Portolá expedition (1769) to the excavations of 1913–1915 and Project 23.
- Read radiocarbon dates on a museum sign critically, naming what is measured and what is assumed.

Warm-up. Spread a spoonful of honey or molasses on a plate and press a toy animal's feet into it. Lift it out. Now cover the honey with a thin layer of water and a few leaves and try again. Would you see the trap? That is how a pool of sticky asphalt, hidden under water and dust, could catch an animal the size of a bison.

Video slot. Video coming. La Brea Tar Pits: the Lake Pit, Pit 91, Project 23, the Fossil Lab, dire wolf skull wall. Search approved channels (La Brea Tar Pits and Museum / Natural History Museum of Los Angeles County, Smithsonian); preview first.

KEY TERMS

asphalt

Thick, sticky natural petroleum (often called “tar”) that seeps up to the surface at La Brea from the oil field below. *Brea* is Spanish for tar or pitch.

seep

A place where oil or asphalt slowly oozes up through cracks to the surface.

predator trap

A site where trapped plant-eaters attracted meat-eaters, which were trapped in turn, so meat-eaters greatly outnumber plant-eaters among the fossils.

taphonomy

The study of what happens to living things from death to discovery: how they died, were buried, broken, moved and preserved.

microfossil

A very small fossil, such as a seed, insect, snail or rodent tooth, recovered by washing and screening sediment.

radiocarbon dating

Estimating age from the amount of carbon-14 left in once-living material. It depends on assumptions about past carbon-14 levels and on clean samples.

CORE IDEAS

Asphalt in the city. In the middle of Los Angeles, beside Wilshire Boulevard, is a park where bubbles of gas rise through pools of black asphalt. The asphalt seeps up through cracks from the Salt Lake Oil Field far below. When it reaches the surface, the lighter parts evaporate and leave a thick, sticky residue. Native peoples of the region, including the Tongva and the Chumash farther up the coast, used asphalt from seeps for centuries to waterproof baskets and to seal the planks of their seagoing canoes. On August 3, 1769, the Spanish expedition of Gaspar de Portolá passed this way; its diarist, the Franciscan Fray Juan Crespí, recorded marshes of a pitch-like substance bubbling from the ground. The land later became the Rancho La Brea, and settlers dug asphalt to roof their houses.

Bones in the tar. Asphalt diggers found bones for decades and assumed they were from stray cattle. In 1875 the owner, Henry Hancock, gave a large canine tooth to William Denton, a visiting naturalist, who recognized it as belonging to a saber-toothed cat. Serious study began in the early 1900s. Scientists from the University of California, led by John C. Merriam, dug from 1906; in 1913 Hancock's son, G. Allan Hancock, gave the new Los Angeles County museum exclusive rights to excavate, and in about two years crews opened nearly a hundred pits and recovered hundreds of thousands of bones. In 1924 Hancock gave the land to the county as a park. In 2006, digging for a parking garage at the neighboring art museum uncovered sixteen new fossil deposits; they were boxed into 23 large crates and moved to the park for excavation. That work, called Project 23, has continued for years in public view.

How the trap worked. A pool of asphalt only a few centimeters deep can hold a large animal. On warm days the asphalt softens; covered by water, leaves or dust, it can look like solid ground or a drinking pool. A bison or horse that stepped in might stick fast. Its struggles would draw meat-eaters and scavengers, which could be caught in turn. This explains a striking fact: about 90 percent of the mammal remains are meat-eaters. The most common is the dire wolf, with more than 200,000 specimens, from thousands of individuals; the second is *Smilodon* (Stop E7). Coyotes, American lions, short-faced bears, eagles, condors and the giant extinct bird *Teratornis* are there too. Trapping did not need to happen often: a few large animals every several years, over many years, could build up the collection.

More than big bones. More than 3.5 million fossils from more than 600 species have come from La Brea: mammoths, mastodons, camels, horses, bison, ground sloths, birds, lizards, frogs, snails, insects, seeds, wood and pollen. Much of what is known about the local plants and climate comes from the tiny fossils washed out of the sediment by careful screening. In 2019 researchers used CT scans to find preserved pupae of leafcutter bees inside fossil nests. One partial human skeleton, a woman, was found in 1914; she is the only person known from the site. The bones are stained dark brown by the asphalt, which also soaked into them and helped preserve them; in some bones, proteins like collagen survive and can be tested.

Reading a jumble. La Brea bones are rarely found as whole skeletons. They are mixed, broken and scattered, a puzzle for taphonomy. Some show tooth marks from scavengers; some were moved by water or by the slow flow of asphalt; a few are worn as if rolled in a stream before they were trapped. Researchers must decide whether each pit records a single event or many over a long time, and whether bones belong together. This is careful detective work, and it shows why counting “specimens” (each bone) and counting “individuals” (each animal) can give very different numbers, as with the dire wolves above.

Dates on the sign. The museum states that the La Brea fossils range from about 50,000 to about 11,000 years old, with plant material younger still, based on many radiocarbon dates. Radiocarbon measures carbon-14 in collagen from bone, wood and seeds. Asphalt is itself made of ancient carbon and contaminates samples, so laboratories must clean it out thoroughly. The method assumes a known history of carbon-14 in the atmosphere, corrected by calibration records. Young-earth scientists accept that these animals lived after the Flood, during the Ice Age, but argue that the carbon balance of the world was different then, which would make older radiocarbon ages too high; they would place La Brea within a few thousand years. The box below sets out the two readings. Both agree that Los Angeles was once cooler and wetter, with forests of pine and cypress and herds of great animals moving through.

PICTURE STUDY



Rancho La Brea Tar Pool, Charles R. Knight, About 1931 (Field Museum mural series) · Oil on canvas mural · Field Museum, Chicago
Wikimedia Commons · Public domain

Charles R. Knight painted a series of 28 murals of the ancient world for the Field Museum. For this one he studied the La Brea fossils and pictured the Los Angeles valley long ago, with the saber-toothed cat *Smilodon*, the giant bird *Teratornis* and extinct horses gathered at a

pool of asphalt. He painted the trap the way the predator-trap idea describes it: plant-eaters at risk and meat-eaters drawn to the scene.

Look closely

- Find the saber-toothed cats, the great birds and the horses. Which are hunters and which are hunted?
- Look at the background. What plants and landscape did Knight show? How does it compare with Los Angeles today?
- Look at the surface of the pool. How has Knight shown that it is asphalt and not water?

Talk about it

1. Knight's painting makes the predator-trap idea easy to see. What observations at La Brea support this idea?
2. What parts of the scene had to come from imagination rather than fossils?

HANDS-ON: DIG A PIT: SPECIMENS, INDIVIDUALS AND A TRAP COUNT

Build a mini La Brea in a box, excavate it on a grid and learn why counting bones and counting animals are different.

You will need

- A shallow box or plastic tub, about 30 × 40 cm
- Sand or potting soil, mixed with a little dark cocoa powder (the "asphalt")
- Chicken bones (boiled clean) or pasta "bones" in three kinds and colors: wolf, cat and bison
- String and tape for a grid, a paintbrush, a spoon, a notebook

Steps

1. A parent or partner secretly buries "skeletons" in the tub: 6 wolves (5 bones each), 3 cats (5 bones each) and 1 bison (8 bones), mixed and scattered, some bones broken in two.
2. Lay a string grid over the tub in 10 cm squares and label them A1, A2 and so on. Excavate one square at a time with the spoon and brush, recording each bone's square and kind.
3. Count the specimens (all bones and pieces) for each kind. Then estimate the minimum number of individuals (MNI) for each kind by counting the most common single bone.
4. Compare: which kind has the most specimens? Most individuals? What percentage of individuals are meat-eaters?
5. Write a short "pit report" explaining how your results match the predator-trap idea, and one way your count could be wrong.

Check your work

- I excavated on a grid and recorded each find's square.
- I calculated both specimens and minimum individuals.
- My pit report explains the predator-trap pattern.

FIELD NOTEBOOK

1. Draw a cross-section of an asphalt seep: the oil field deep below, a crack, the sticky pool at the surface covered with water and leaves, and a trapped bison with a dire wolf approaching.
2. Make a bar graph of the La Brea mammal fossils: meat-eaters about 90%, plant-eaters about 10%. Label dire wolf and saber-toothed cat as the two most common.
3. **Narration (the parent keeps this).** Write one paragraph explaining how a pool of asphalt could trap far more meat-eaters than plant-eaters, and what the bones tell us about Los Angeles long ago.

Did you know? The name “the La Brea Tar Pits” says “the the tar tar pits,” since *la brea* already means “the tar.” The museum at the site was called the George C. Page Museum when it opened in 1977, and visitors can watch scientists cleaning fossils in its glass-walled Fossil Lab. Asphalt still bubbles up today, and park workers cone off fresh seeps on lawns and paths.

 **What the sign says / What we observe / How Christians read it.**  **What the sign says:** “The fossils of La Brea are from about 50,000 to 11,000 years ago, during the last Ice Age.” **What we observe:** bones, plants and insects soaked in asphalt; species no longer living in California; a mix that is about 90% meat-eaters; carbon-14 in cleaned bone collagen and wood. Radiocarbon ages assume a known history of carbon-14 in the atmosphere, corrected by calibration records, and complete removal of asphalt, which contains old carbon. **How Christians read it:** many young-earth Christians read La Brea as a record of the Ice Age after the Flood, within the last few thousand years, and argue that a disturbed carbon balance after the Flood makes older radiocarbon ages too high. Other Christians accept the standard dates. Everyone agrees that these animals lived after the great rock layers below them were laid down, and that the climate was cooler and wetter than today's.

Go deeper. La Brea Tar Pits and Museum website (tarpits.org), with pages on Project 23, the Fossil Lab and each common animal. John M. Harris, ed., *La Brea and Beyond: The Paleontology of Asphalt-Preserved Biotas* (Natural History Museum of Los Angeles County, 2015). Chester Stock, *Rancho La Brea: A Record of Pleistocene Life in California* (several editions from 1930), the classic museum guide. Second video topic: “How fossils are cleaned of asphalt in the La Brea Fossil Lab.”

Goes deeper in. Earth Science, petroleum and the Ice Age units (coming soon); Geography, California and the Los Angeles basin; History, the Spanish missions and the Portolá expedition.

For families. This stop has dates, so it carries the ⏳ box. Counts: “more than 3.5 million fossils” and “more than 600 species,” from the La Brea Tar Pits and Museum; dire wolves are the most common carnivore, saber-toothed cats second; about 90% of mammal specimens are carnivores. Portolá campsite and Crespí’s mention of the pitch: August 1769. Denton’s report of the saber tooth: 1875. University of California digs from 1906; county excavations 1913–1915; land donated 1924; Page Museum 1977; Project 23 from 2006. Leafcutter bee pupae: Holden et al. 2019. The radiocarbon range is the museum’s general figure. No public-domain text could be verified word for word for this stop (Crespí’s diary in English was published in 1927, and an exact text was not available), so there is no primary-source aside. The human remains are mentioned only plainly.

PRACTICE

1. **EASY** What is the “tar” at La Brea, and where does it come from?
2. **EASY** Which two meat-eaters are the most common fossils at La Brea?
3. **MEDIUM** Explain why about 90% of La Brea’s mammal fossils are meat-eaters.
4. **MEDIUM** What was Project 23?
5. **CHALLENGE** La Brea has more than 200,000 dire wolf specimens. If an average dire wolf skeleton found there is represented by about 50 recovered bones and pieces, about how many individuals is that? Suppose a count of the most common single bone also gives about 4,000. What does it mean when the two methods agree, and what would it mean if they did not?
6. **CHALLENGE** A museum label says a *Smilodon* bone is “28,000 years old (radiocarbon).” (a) What was actually measured? (b) Name two assumptions or corrections behind the number. (c) Why is asphalt contamination a special problem at La Brea? (d) How would a young-earth scientist read the same result?

Make it a game • Stuck!. Mark a few “asphalt pools” on the floor with paper hidden under a towel. One player, the bison, crosses the room; if they step on a hidden pool they are stuck and must stay. Others play wolves and cats who rush to the stuck bison, but anyone who steps on a pool is stuck too. After three rounds, count how many predators and how many plant-eaters were trapped.

Scripture. “And the vale of Siddim was full of slimepits; and the kings of Sodom and Gomorrah fled, and fell there; and they that remained fled to the mountain.” (Genesis 14:10, KJV)

The “slimepits” were pits of bitumen, natural asphalt, near the Dead Sea. Like La Brea, they were dangerous traps for anyone who rushed in carelessly. Scripture records real places and real substances.

Practice: answers

1. Natural asphalt, a thick, sticky petroleum, seeping up through cracks from the oil field below.
2. The dire wolf (most common) and the saber-toothed cat *Smilodon* (second).

3. One trapped plant-eater struggling in the asphalt attracted many predators and scavengers, which were trapped in turn; so each event added several meat-eaters for each plant-eater.
4. In 2006, digging for a parking garage at the neighboring art museum uncovered sixteen fossil deposits; they were packed into 23 large crates and moved to the park, where scientists have excavated them in public view.
5. $200,000 \div 50 = 4,000$ individuals. The two estimates match here, which gives some confidence; if they did not, it would show that bones are unevenly preserved or recovered, or that skeletons were broken into many pieces. "Specimens" count bones; "individuals" count animals, and they must not be confused.
6. (a) The ratio of carbon-14 to ordinary carbon in collagen extracted from the bone. (b) Any two: the amount of carbon-14 in the atmosphere when the animal lived (corrected by calibration records); a steady rate of decay; no carbon added or lost since death; complete cleaning of the sample. (c) Asphalt is petroleum, made of very old carbon with almost no carbon-14; any left in the sample makes the bone seem older. (d) That the animal lived after the Flood, in the Ice Age, and that the measured carbon-14 reflects a different carbon balance in the world then, so the true age is within a few thousand years.

5.10 BUILD A MUSEUM DISPLAY

OBJECTIVES

- Explain how Charles Willson Peale and his sons dug, assembled and displayed the first mounted fossil skeleton in America (1801–1802), and what they got right and wrong.
- Plan and build a museum display on one animal from this trail, with an object, a main label, an observation-and-interpretation panel and a Scripture panel.
- Write labels that are accurate, concise and honest about what is known, inferred and debated.

Warm-up. Think of the best museum display you have ever seen, in person or online. What made you stop and look? Was it the object, the label, a picture, something to touch? Write down three things. You are about to build a display of your own.

Video slot. Video coming. How museums mount fossil skeletons and write labels: behind the scenes at a fossil hall (the Smithsonian’s Deep Time hall, the Field Museum’s SUE remount), and Peale’s mastodon. Search approved channels (Smithsonian, Field Museum, American Museum of Natural History, Philadelphia museums); preview first.

KEY TERMS

specimen

A real object kept in a collection, such as a bone, shell or plant, usually with a catalog number and a record of where it was found.

cast (replica)

A copy made from a mold of a real specimen, often in plaster or resin. Most skeletons on display today are partly or wholly casts.

mount

A skeleton assembled in a lifelike pose on a frame (armature) of metal. Old mounts drilled iron through the bones; modern mounts hold them in cradles.

label

The written text beside an object. A good label tells what the object is, why it matters and what we know, in few words.

provenance

The recorded history of where a specimen was found and who has owned it. Without it, a fossil loses much of its scientific value.

interpretation

An explanation of what the evidence means. A good display makes clear which statements are observations and which are interpretations.

CORE IDEAS

The first mount. In June 1801 the Philadelphia painter and museum keeper Charles Willson Peale traveled to the farm of John Masten near Newburgh, New York, where huge bones had been dug from a marl pit. He paid \$200 for the bones already found and \$100 more for the right to dig. With his son Rembrandt and a crew, he built a great wooden wheel, turned by men walking inside it, to drive a chain of buckets that drained the flooding pit. Over weeks of cold, muddy work, described in the primary source, they recovered most of one skeleton, then searched nearby sites for more. Back in Philadelphia, with help from the anatomist Caspar Wistar, they assembled two skeletons, carving missing pieces in wood or modeling them from matching bones. One went on display in Peale's museum at Philosophical Hall late in 1801; Rembrandt took the other to London in 1802.

Right and wrong. Read Rembrandt Peale's words in the primary source: "Nothing is imaginary, and what we do not unquestionably know, we leave deficient." That is an admirable rule. The Peales said plainly that some parts were copies made from real bones, and they left the top of the head and the end of the tail missing rather than guess. Yet the same pamphlet called the animal a "carnivorous" beast, and in London the tusks were set pointing downward, like the fangs of a walrus, to suit that idea. The animal was a mastodon, a plant-eater, and its tusks curved up. Careful method protected the Peales from some mistakes but not from all. Every display mixes evidence with judgment, and an honest display shows which is which.

What a display is for. A museum display tells a true story using a real object. It has layers: the object itself (a specimen, cast or model); a main label of perhaps 50 to 100 words that a visitor can read in a minute; smaller labels for details; pictures, maps or diagrams; and sometimes something to touch. The best displays answer three questions a visitor brings: What is it? How do we know? Why does it matter? They also anticipate a wrong idea and correct it, as a sign might say, "Not a dinosaur: a flying reptile." Good museums revise displays as knowledge grows; the Field Museum remounted SUE the T. rex in 2018 to add the belly ribs, and many mounts have been rebuilt as posture studies changed.

Writing honest labels. Throughout this track you have practiced telling observations from interpretations. A label should do the same plainly. "This jaw is 1.6 m long" is an observation. "This mosasaur was about 15 m long" is an inference and should say "estimated." "This bone is 28,000 years old" is an interpretation that depends on a method and its assumptions. Good labels use active verbs and concrete numbers, avoid exaggeration ("the most terrifying predator ever"), credit the finder and preparer, and give a source. A display on a 🕒 topic should include a small box like the ones in this trail: *What the sign says / What we observe / How Christians read it*, fair to every view and mocking none.

Planning your display. Choose one animal from this trail: an ichthyosaur, plesiosaur, mosasaur, pterosaur, *Quetzalcoatlus*, mammoth, saber-toothed cat, ground sloth or a La Brea animal. Decide on the central object: a plaster cast, a clay model, a scale drawing or a life-size chalk outline photographed from above. Write a title and a main label of no more than 100 words. Add one "How do we know?" panel describing a single real fossil or study from

the stop. Add the observation box, a scale figure (a person or a child silhouette) and a Scripture panel with a verse and a sentence of explanation. Plan the layout on paper first, then build it on a table, a poster board or a tri-fold board.

Showing the work of God. Peale designed his museum to show the order of nature to ordinary citizens, and it was one of the first public museums in the United States. A Christian student builds a display for an even better reason: to show the works of God accurately to others. Psalm 111:2 says that God’s works are “sought out of all them that have pleasure therein,” and many scientists, from the Cavendish Laboratory in Cambridge to students at kitchen tables, have taken that verse as their charter. Your display will be small, but if it is true, clear and well made, it does the same work as the great halls of London, Chicago and Philadelphia.

PICTURE STUDY



The Artist in His Museum, Charles Willson Peale, 1822 · Oil on canvas · Pennsylvania Academy of the Fine Arts, Philadelphia

Wikimedia Commons · Public domain

When he was eighty-one, Peale painted himself welcoming the viewer into his museum, then in the State House (Independence Hall) in Philadelphia. He holds up the curtain like a host. In the long gallery behind him are rows of cases of birds with portraits of famous Americans above them, and at the far right, partly hidden, stands his mastodon skeleton.

Look closely

- Find the bones and the tools at Peale’s feet. Which animal do they belong to, and why did he include them?
- Find the visitors in the gallery. What is each doing? Look for the woman near the mastodon.

- Notice how the cases are arranged. What order or system did Peale use?

Talk about it

1. Peale invites us in by lifting a curtain. What does that gesture say about what he believed a museum was for?
2. If you painted yourself beside your own display, which object would you put at your feet, and why?

HANDS-ON: MY TRAIL E MUSEUM DISPLAY

Build a complete tabletop or poster-board display on one animal from this trail, and present it to an audience.

You will need

- A tri-fold board, poster board or table space
- Your central object: plaster cast, clay model, scale drawing or photograph of a life-size chalk outline
- Card stock, a printer or neat handwriting, glue, a ruler
- Your Field Notebook pages from this trail
- The primary source in the asides

Steps

1. Choose the animal and sketch the layout: title at top, object in the center, main label below it, side panels for “How do we know?”, the ⌚ box (if your animal has dates), a scale figure and Scripture.
2. Write the main label in no more than 100 words. Include the name and its meaning, size (marked “estimated” where it is an estimate), how it lived and one surprising fact. Read it aloud and cut every unnecessary word.
3. Write the “How do we know?” panel: one real fossil or study from the stop, with who found or did it, when and what it showed.
4. Write a short “Accuracy note” in the spirit of Rembrandt Peale: list which parts of your object are based on fossils and which are your best guess (color, skin, pose).
5. Build and assemble the display. Then give a three-minute guided tour to your family or co-op and answer at least two questions.

Check your work

- My display has a title, an object, a main label of 100 words or fewer, a “How do we know?” panel, an accuracy note and a Scripture panel.
- Every number is correct and estimates are marked as estimates.
- Observations and interpretations are clearly separated, and no view is mocked.
- I gave a tour and answered questions.

FIELD NOTEBOOK

1. Draw the layout plan of your display with every panel labeled and its word count written in.
2. Copy your final main label into your Field Notebook, with the date and the place you presented it.
3. **Narration (the parent keeps this).** Write one paragraph explaining what Rembrandt Peale got right and what he got wrong in 1802, and how you applied his rule “Nothing is imaginary” in your own display.

Did you know? To celebrate the mastodon, the Peales held a dinner party for a small group of guests seated around a table set inside the skeleton’s rib cage. Psalm 111:2 is carved, in Latin, over the doors of the old Cavendish Laboratory at the University of Cambridge, where the electron was discovered; it was put there at the suggestion of the physicist James Clerk Maxwell.

 **What the sign says / What we observe / How Christians read it.**  This is a model box for your display. **What the sign says:** “The American mastodon lived in North America until about 11,000 years ago.” **What we observe:** mastodon bones in bogs, marl pits and river gravels near the surface, like the Masten skeleton; radiocarbon measurements on bone and wood found with them. The date assumes a known history of carbon-14 in the atmosphere and clean samples. **How Christians read it:** many young-earth Christians place the mastodons in the centuries after the Flood, during and after the Ice Age, and adjust older radiocarbon ages; other Christians accept the standard dates. All agree on where and how the bones lie. Write a box like this, about your own animal, in the same fair way.

Primary source. *Rembrandt Peale, Account of the Skeleton of the Mammoth, a Non-Descript Carnivorous Animal of Immense Size, Found in America (London, 1802). Project Gutenberg eBook #48915.*

One of these skeletons is erected as a permanent establishment at the Museum, Philadelphia; the other I have brought with me, with an intention to travel through Europe, beginning with the metropolis of England.

For several weeks no exertions were spared, and those the most unremitting were required to insure success; bank after bank fell in; the increase of water was a constant impediment, the extreme coldness of which benumbed the workmen: Every day bones and pieces of bones were found between six and seven feet deep, but none of the most important ones.

In this manner the two skeletons were formed, and are in both instances composed of the appropriate bones of the animal, or exact imitations from the real bones in the same animal, or from those of the same proportion in the other: Nothing is imaginary, and what we do not unquestionably know, we leave

deficient; which happens in only two instances, the summit of the head and the end of the tail.

Three separate passages from the pamphlet, in the order they appear. Peale's "mammoth" was a mastodon.

Go deeper. Paul Semonin, *American Monster: How the Nation's First Prehistoric Creature Became a Symbol of National Identity* (2000). Keith Thomson, *The Legacy of the Mastodon* (Yale, 2008). Smithsonian Magazine, "The Story of Charles Willson Peale's Massive Mastodon" (2020). Pennsylvania Academy of the Fine Arts collection page for *The Artist in His Museum*. Rembrandt Peale's full *Account* (1802), free at Project Gutenberg. Second video topic: "How a fossil hall is designed and built."

Goes deeper in. Art, display design and lettering (coming soon); Literature, concise writing and editing; History, Philadelphia and the early republic; Earth Science, fossils.

For families. Masten farm purchase: \$200 for the bones and \$100 for the right to dig (Smithsonian Magazine and American Heritage accounts). The dig was in summer 1801; the Philadelphia skeleton was shown from late 1801, and Rembrandt sailed for London in 1802. Caspar Wistar's help and the London downward-tusk mount are widely reported; the exact number of dinner guests is given differently in different accounts, so it is left out. The three primary-source passages were checked word for word against Project Gutenberg #48915. The Cavendish inscription (*Magna opera Domini exquisita in omnes voluntates ejus*) dates from the 1870s. The ⏳ box is a model for the student and uses the mastodon from the picture and source; adapt it to the animal chosen. The display presentation can be done at home; no selling is involved.

PRACTICE

1. **EASY** Where did Charles Willson Peale find his "mammoth," and what animal was it really?
2. **EASY** Name four parts of a good museum display.
3. **MEDIUM** Rewrite this label so it separates observation from interpretation: "This terrifying 50-foot sea monster ruled the oceans 70 million years ago."
4. **MEDIUM** Why do museums often display casts instead of real bones? Give two reasons.
5. **CHALLENGE** Using the primary source, explain Rembrandt Peale's rule for building the skeletons in your own words. Then identify two claims in his pamphlet's title or display that broke the spirit of that rule, and explain what led him astray.
6. **CHALLENGE** Peale's measurements give the skeleton's height at the shoulders as 11 feet and its length from chin to rump as 15 feet. Convert both to meters (1 ft = 0.305 m). If you make a scale model at 1:20, how tall and long will it be in centimeters? Then write a 25-word label for the model that includes the scale.

Make it a game · Docent Challenge. Each player prepares a 60-second tour of one object in the house (a family photo, a clock, a rock). Listeners may ask one "How do we

know?" question each. The docent earns a point for every answer that names real evidence and loses one for any claim they cannot support. Rotate until everyone has given a tour.

Scripture. "The works of the LORD are great, sought out of all them that have pleasure therein." (Psalm 111:2, KJV)

To "seek out" God's works is to study them with delight. A museum display, large or small, is a way of sharing that delight truthfully with others.

Practice: answers

1. On John Masten's farm near Newburgh, New York (1801). It was a mastodon.
2. Any four: the object (specimen, cast or model), a title, a main label, smaller detail labels, a picture or diagram, a scale figure, a "How do we know?" panel, something to touch, sources.
3. Example: "This mosasaur skull is 1.6 m (5 ft) long. Comparing it with more complete skeletons, scientists estimate the animal was 12–16 m (40–52 ft) long. Museums date the chalk it was found in to the Late Cretaceous, about 70 million years ago; young-earth Christians read these layers as laid down in the Flood." (Removes exaggeration, marks estimates and gives both readings of the date.)
4. Any two: real bones are heavy and fragile, and drilling or hanging them on metal can damage them; casts are light and safe to mount; the real bones stay available for study in the collection; missing bones can be filled in with casts of matching bones; several museums can share one specimen through copies.
5. Rule: use only real bones or exact copies of real bones (from the same animal or matching ones from the other skeleton); where nothing is known for certain, leave a gap (the top of the head and the end of the tail) rather than invent. Broken in spirit: calling the animal "carnivorous" and mounting the tusks pointing down like fangs. He was led astray by an assumption about what a huge, tusked animal must have been, not by observation of the teeth, which were plainly for chewing plants; the urge to make the beast dramatic for paying audiences may also have played a part.
6. $11 \text{ ft} \approx 3.36 \text{ m}$; $15 \text{ ft} \approx 4.58 \text{ m}$. At 1:20: $336 \div 20 \approx 16.8 \text{ cm}$ tall; $458 \div 20 \approx 22.9 \text{ cm}$ long. Sample label: "American mastodon, model at 1:20 scale, based on Peale's 1801 skeleton from Newburgh, New York. Real animal: about 3.4 m tall, 4.6 m long." (Peale's mastodon height is now thought to be overstated; that can be noted.)

TRAIL 5 BADGE QUIZZES

The badge quizzes are optional and may be answered in writing or aloud. Answers should be in complete sentences and use evidence from the stops. Four good answers out of five earns the first badge; five out of six earns the second. Badges and the certificate are earned by doing the stops, not by scores.

Badge quiz 1 (Stops 1-5)

1. Give two pieces of fossil evidence that ichthyosaurs bore live young, and explain why the same fossils show the animals were buried quickly.
2. What did the 2017 robot flipper experiment show about plesiosaur swimming?
3. Why should a historian be cautious about the famous story of the Maastricht skull, and what did archival research find?
4. How did Cuvier distinguish the pterosaur wing from those of birds and bats?
5. Use the square-cube law to explain why very large flying animals face a special problem, and name one way *Quetzalcoatlus* may have solved it.

Badge quiz 2 (Stops 6-10)

6. How can you tell a mammoth from a mastodon by its teeth, and what does that tell you about Jefferson's "mammoth" bones from the Ohio?
7. Explain the canine shear-bite and the evidence for it.
8. What was Jefferson's argument that the "mammoth" and *Megalonyx* might still be alive, and what was wrong with it?
9. Why are about 90% of the mammal fossils at La Brea meat-eaters, and which two are most common?
10. State Rembrandt Peale's rule for assembling the mastodon skeletons, and give one way he failed to keep its spirit.
11. A sign says a La Brea bone is "28,000 years old." Name what was measured, two assumptions behind the number, and how a young-earth Christian would read it.

TRAIL CERTIFICATE: MY SEA, SKY AND ICE AGE FIELD NOTEBOOK, MUSEUM DISPLAY AND TRAIL E CERTIFICATE

Gather the Field Notebook pages from all ten stops into one booklet titled "Sea, Sky and Ice Age," with your name and the dates you started and finished. Put the ten narration paragraphs together in a section of their own; these are the pages the parent keeps.

Include a photograph of your Stop E10 museum display, its main label, its "How do we know?" panel, its accuracy note and its 🕒 box, with the date and place you presented it.

Add one page of source work: the primary source from Stop E3, E6, E8 or E10 with your marked-up analysis of its facts, judgments and assumptions.

When the booklet and display are complete, a parent signs the Trail E certificate.

- **Completeness:** All ten stops have notebook pages and a narration paragraph, each with a title and date.
- **Accuracy:** Names, numbers and dates are correct; estimates are marked as estimates; sources are named.
- **Reasoning:** The student separates observation from interpretation, analyzes at least one primary source critically and presents the dating views fairly without mocking either.
- **Display and presentation:** The museum display is clear, neat and well organized, its main label is 100 words or fewer, and the student gave a tour and answered questions.

Answer key

1. Mothers found with unborn young inside, and some in the act of giving birth (mostly tail-first; one *Chaohusaurus* head-first). A mother and her young preserved together, often with soft outlines, must have been covered before scavengers or decay could scatter them.
2. Hind flippers beating in step with the front ones, using their wake, produced up to about 60% more thrust and 40% better efficiency than beating alone, so four flippers were an effective design.
3. It reaches us through three writers (Faujas, Mantell, Lucas), and Faujas was among the French officials who removed the fossil and had reason to justify it. Archival research found that canon Godding was the rightful owner and that the lawsuit story against Hoffmann is largely unsupported.
4. Birds' wings have fingers not separately distinguishable (feathers on a fused hand); bats stretch a membrane between several long fingers; the pterosaur wing was held mainly by one greatly lengthened finger, the fourth, with the others short and clawed.
5. When an animal doubles in length, its wing area grows four times but its weight eight times, so each square meter of wing must carry more load. Solutions (any one): very light, hollow, air-filled bones; launching by vaulting on strong forelimbs; soaring on rising air with little flapping.
6. Mammoth molars have many thin enamel ridges for grinding grass; mastodon molars have rounded cone-shaped cusps for browsing. Most of Jefferson's Ohio "mammoth" bones had mastodon teeth, so they were mastodons.
7. *Smilodon* pinned prey with its powerful forelimbs and drove its sabers in with a downward push of its strong neck muscles. A 2007 computer study found its jaw-muscle bite was only about a third of a lion's, but its skull and neck were built to handle large forces when the prey was held still; its gape of about 110° let the sabers clear the prey.
8. He reasoned that nature never allows any kind of animal to become extinct or any link in her work to break, and added Indian traditions that the animal still lived in the West. The premise was a philosophical assumption (the Great Chain of Being), not an observation; fossils like *Megatherium* and the mammoth showed that extinction had happened, and Scripture does not teach that every kind must survive.
9. A plant-eater stuck in the asphalt drew many predators and scavengers, which were trapped in turn (a predator trap). Dire wolves are the most common, saber-toothed cats second.
10. "Nothing is imaginary, and what we do not unquestionably know, we leave deficient": only real bones or exact copies, and gaps where nothing was known. He nonetheless called the animal carnivorous and mounted the tusks pointing downward like fangs, though it was a plant-eater with upward-curving tusks.

11. Measured: carbon-14 in cleaned bone collagen. Assumptions (any two): a known history of atmospheric carbon-14 (calibration), steady decay, no carbon gained or lost, complete removal of asphalt. Young-earth reading: the animal lived after the Flood during the Ice Age, and a different carbon balance then makes the radiocarbon age too high; the true age is within a few thousand years.