

SCHOOL LAUNCH · EXPLORE TRACKS

EXPLORE ANIMALS · EXPERT

The ● Expert level of the Animals track for students ages 14 and up: mammals, birds, reptiles and amphibians, ocean life, insects and small creatures, and the amazing things animals do. Sixty self-paced stops with primary sources, real numbers, fine-art picture studies, field projects and a go-deeper list at every stop.

First edition

But ask now the beasts, and they shall teach thee; and the fowls of the air, and they shall tell thee:

Job 12:7 (KJV)

COURSE GUIDE

Explore Tracks are for students who want more of what they love. Each track is a set of trails made of short stops. At the ● Expert level every stop adds a primary source, hard numbers, a careful look at what is observed and what is inferred, and a go-deeper list of books, museum pages and a second video, alongside the story, picture study, hands-on project, Scripture and game.

The Animals track has six trails of ten stops each. Trail A meets the mammals, from the lion of Judah to the American bison's comeback. Trail B follows the birds, from the eagle of Isaiah 40:31 to John James Audubon and a real bird count. Trail C studies reptiles and amphibians, from crocodiles and Galápagos tortoises to poison dart frogs and the Gila monster. Trail D goes into the ocean, from sharks and the giant squid to the deep sea, salmon runs, and Jonah and Leviathan. Trail E looks closely at insects and small creatures, from the ant of Proverbs 6:6 and the locusts of Exodus 10 to Jean-Henri Fabre and a bug hotel. Trail F studies what animals do: echolocation, camouflage, hibernation, building, partnerships, tool use, long journeys, the sled dogs of the 1925 Nome serum run, designs copied by engineers, and Adam naming the animals in Genesis 2:19.

Each stop links to the matching full lesson in a School Launch course (Life Science, Earth Science, Geography, Gardening & Animals, History, Art, Literature, Arithmetic or Small Business & Economics) under "Goes deeper in," so the track feeds the courses. The trails may be done in any order.

WHO IT IS FOR

Written for students ages 14 and up who read on their own and can keep a notebook with sources. Younger students who have finished the ● Ranger stops can join in with help, and families can do a stop together at different depths. Nothing earlier is required.

HOW TO USE THIS COURSE

1. **One stop at a time.** A stop takes 25–40 minutes at this level: read the story and the primary source, work the numbers, study the picture, do the hands-on part and play the game. Two or three stops a week works well; the go-deeper list is for students who want more.
2. **Observation and inference.** Many stops ask the student to sort a claim into what was seen and measured, what is inferred from it, and how a Christian reads it in light of Scripture. The notebook keeps a running list.
3. **Any order.** The six trails are independent. Do one trail at a time, or rotate between them.
4. **Field Notebook.** Every stop ends with a notebook entry: a sketch, a data table or a short written answer, with the source named. At the end of each trail the entries become a booklet, and the parent signs the trail certificate.

5. **Badge quizzes.** Every five stops earns a printable badge, with a short optional quiz. They are for review, not grades.

SCOPE AND SEQUENCE

Trail 1: Animals 🐾 **Trail A: Mammals** (Self-paced)

Trail 2: Animals 🐾 **Trail B: Birds** (Self-paced)

Trail 3: Animals 🐾 **Trail C: Reptiles and Amphibians** (Self-paced)

Trail 4: Animals 🐾 **Trail D: Ocean Life** (Self-paced)

Trail 5: Animals 🐾 **Trail E: Insects and Small Creatures** (Self-paced)

Trail 6: Animals 🐾 **Trail F: Animals Doing Amazing Things** (Self-paced)

MATERIALS

- **Field Notebook (a sketchbook or composition book)** One for the track, or one per trail.
- **Pencils, colored pencils, a ruler, a calculator and a magnifying glass** For sketches, measurements and the number work.
- **Binoculars and a field guide (optional)** Helpful for the bird stops and the bird count; a library field guide is fine.
- **Household and craft things** Each hands-on project lists what it needs: plaster of Paris for track casts, a feeder kit or scrap wood, card stock for trading cards, a shoebox for a diorama, untreated wood and hollow stems for a bug hotel.
- **A Bible (KJV)** For the verse at each stop.

GRADING

Explore Tracks are not graded. A stop is done when the student has read the story and the source, done the hands-on part and made a notebook entry with its source named.

Badges and the trail certificates are earned by finishing the stops.

- Families who want to count the track toward a science or natural-history credit may use the Field Notebook, the projects and the badge quizzes as a record of work.

A NOTE TO PARENTS

You do not need to be an expert. Ask your student to explain the stop to you and show the notebook entry. Each stop has a short *For families* note with background, the sources used, and any facts or figures that scholars still discuss or that we could not confirm.

Creation and the sciences: the track teaches animals as the handiwork of God (Genesis 1–2; Job 38–41; Psalm 104) and treats Scripture as true history. Where a stop meets claims of

long ages or common descent (for example, Darwin and the Galápagos, or the age of a fossil), it states what the museum or textbook says, what is actually observed, and how Christians read it, fairly and without mockery.

Safety: hands-on stops include a safety line. Observe wild animals, snakes, spiders and stinging insects without handling them; wash hands after touching soil, insects, amphibians or birdseed; use plaster and tools with an adult nearby; and keep a safe distance from deep water and large animals on field trips. The animal-fact trading cards are for trading, not for sale; if a student wants to sell anything made in this track, a parent signs off first.

Pictures are public-domain fine art and historic illustrations, among them Albrecht Dürer, John James Audubon, Maria Sibylla Merian, George Stubbs, Rosa Bonheur, Edwin Landseer and Winslow Homer. Predator-and-prey scenes are described plainly, without gore.

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Trails may be done in any order.

ANIMALS TRAIL A: MAMMALS

The first trail of the Animals track visits ten mammals: the lion and the Lion of Judah, the elephant and the behemoth of Job, the “great whales” of Genesis 1:21, bats and the discovery of echolocation, the war horse of Job 39, wolves and dogs, bears and the first teddy bear, the cheetah, the kangaroo, and the near-loss and comeback of the American bison. Each stop studies how the animal is made for its life, what Scripture says about it, and how people have used, harmed and cared for it.

This is the  **Expert** level, written for ages 14 and up and planned for 35 to 50 minutes a stop. Each stop gives real numbers and honest questions, a primary source (a passage of Scripture, an old book, a government report, or a painting or photograph read as evidence), a project that works with that source, six practice problems including two challenge problems with full answers, a written narration for the portfolio, and a “Go deeper” list. Animals are treated as God’s handiwork, made “after his kind” (Genesis 1); where a museum gives a date in deep time, the stop calls it an interpretation. Conservation is taught as stewardship (Genesis 2:15). Every stop stands alone, so a student may take them in any order.

Five stops earn the **Mammal Expert badge, part 1**, and ten stops earn part 2 and the **Trail A certificate**. The two badge quizzes at the end of the trail are optional; badges and the certificate are earned by doing the stops and keeping the narrations.

BEFORE YOU BEGIN

- Read a page of nineteenth-century English (such as a chapter of the King James Version or a passage of Melville) and summarize it in your own words.
- Work with percentages, rates and unit conversions (miles per hour, meters per second, pounds and tons).

MASTERY CHECKLIST

- ☐ I can explain, with at least two numbers, how each of the ten mammals on this trail is designed for the way it lives.
- ☐ I can read a primary source (a Bible passage, an old book, a report, a painting or a photograph) and ask who made it, when, why, and how far to trust it.
- ☐ I can tell the difference between what scientists observe and how they interpret it, and give an example where scientists corrected an earlier idea (the “alpha wolf,” the overheating cheetah, the gallop).
- ☐ I can explain why old texts such as Leviticus 11, Jonah and Moby-Dick use words like “fowl” and “fish” differently from modern zoology, without calling them errors.
- ☐ I can tell the story of the bison, whales or Asiatic lions as a case of stewardship lost and regained, and connect it with Genesis 2:15.

OPTIONAL BOOKS AND RESOURCES

- **Project Gutenberg** (<https://www.gutenberg.org>): Free public-domain texts used on this trail, including Melville's *Moby-Dick* (eBook #2701) and Hornaday's *The Extermination of the American Bison* (eBook #17748).
- **Library of Congress: Prints and Photographs Online Catalog** (<https://www.loc.gov/pictures/>): Free high-resolution copies of the Berryman "Teddy bear" cartoon (Stop A7) and Muybridge's *The Horse in Motion* (Stop A5).
- **Smithsonian's National Zoo and Conservation Biology Institute** (<https://nationalzoo.si.edu>): Free fact pages on elephants, cheetahs, bears, bison and other mammals on this trail.

1.1 LIONS AND THE LION OF JUDAH

OBJECTIVES

- Explain how a lion pride is organized and how its hunting, roaring and resting fit the way the lion is made.
- Trace the lion through Scripture, from Jacob's blessing of Judah (Genesis 49) to "the Lion of the tribe of Juda" (Revelation 5:5), reading Genesis 49:8-10 as a primary source.
- Compare the African and Asiatic lions with real numbers and describe how careful stewardship has helped the Asiatic lion recover.

Warm-up. Write down three words people use when they call someone "a lion" (for example "brave," "proud," "fierce"). Then look up how many hours a day a wild lion usually spends resting (the answer is in this stop). Keep your list: by the end you will see why Scripture uses the lion both for strength and for something even greater.

Video slot. Video coming. African lion prides: hunting together, roaring and life on the Serengeti; Asiatic lions of the Gir Forest in India. Search approved channels (Smithsonian Channel, National Geographic, BBC Earth, Moody Science Classics); preview first.

KEY TERMS

pride

A lion family group: several related lionesses and their cubs, with one or a few adult males who defend the territory. Lions are the only truly social wild cats.

apex predator

A hunter at the top of its food chain, with no natural predators as an adult. Apex predators help keep herds of grazing animals in check.

Panthera leo

The scientific name of the lion. Lions today live in Africa south of the Sahara and, as the Asiatic lion, in and around the Gir Forest of western India.

the Lion of Judah

A title of Christ (Revelation 5:5) that looks back to Jacob's blessing of his son Judah as "a lion's whelp" (Genesis 49:9). David and his royal line came from the tribe of Judah.

tribe of Judah

One of the twelve tribes of Israel, descended from Jacob's fourth son. From it came King David and, according to the Gospels, Jesus Christ.

census

An official count. India counts its Asiatic lions every five years, which is how we know whether their numbers are rising or falling.

CORE IDEAS

Made for the hunt. A grown male lion weighs about 400 pounds (around 190 kg), a lioness about 280 pounds (around 125 kg). Lions are built for short, explosive power rather than long chases: they can sprint at perhaps 35 miles an hour for only a short distance, so they creep close using cover, then rush. Their eyes are set forward for judging distance, their night vision is far better than ours, and their claws stay sheathed until needed so they stay sharp. Lionesses, lighter and quicker, do most of the hunting, often working together to fan out and surround zebra, wildebeest or buffalo. Because a big meal can last days, lions rest or sleep up to about twenty hours a day. A lion that lies still most of the day is not lazy; it is saving the energy that its next hunt will need.

Life in the pride. The lion is the only wild cat that lives in true family groups. A **pride** is built around related lionesses: mothers, daughters, sisters and aunts, who often stay together for life and may nurse one another's cubs. One or a few males guard the territory. Their manes, which darken with age and health, make them look larger and may protect the neck in fights. A lion's roar can be heard about five miles away and tells rivals, "This land is held." Young males are driven out at two or three years old and must wander until they can win a pride of their own. Life in a pride is hard: many cubs do not survive their first year.

Lions in the Bible lands. In Bible times lions lived across the Middle East, and Scripture mentions them well over a hundred times, using several different Hebrew words for young lions, grown lions and lionesses. Samson tore a young lion apart with his hands (Judges 14). David the shepherd killed a lion and a bear to save his father's sheep (1 Samuel 17). Benaiah "slew a lion in the midst of a pit in time of snow" (2 Samuel 23:20). Daniel was thrown into a den of lions in Babylon and God "shut the lions' mouths" (Daniel 6:22). Babylon itself was decorated with striding lions: the glazed-brick lions of the Processional Way, from the time of Nebuchadnezzar, can still be seen in museums in Berlin, Istanbul, Chicago and New York. Lions disappeared from the Holy Land in the Middle Ages, probably around the time of the Crusades, though the exact date is not known.

The lion's whelp. When the aged Jacob blessed his twelve sons (Genesis 49), he called Judah "a lion's whelp" who "couched as a lion" and promised that "the sceptre shall not depart from Judah." The picture is of a young lion that has eaten its prey and lies down in such confidence that no one dares rouse it. Centuries later, David of the tribe of Judah became king, and the lion became the emblem of Judah. The promise of a lasting sceptre pointed further still, to a King who would come from David's line.

The Lion who is a Lamb. In Revelation 5 the apostle John weeps because no one is worthy to open the sealed book. An elder tells him, "behold, the Lion of the tribe of Juda... hath prevailed." But when John turns to look, he sees "a Lamb as it had been slain" (Revelation 5:6). This is one of the great surprises of Scripture. Christ is the Lion: royal, strong and victorious. Yet He won His victory as the Lamb, by laying down His life. A careful reader keeps both pictures together. C. S. Lewis built his lion Aslan on this same truth.

Lions today: honest numbers. Scientists estimate that roughly 20,000 to 25,000 wild lions live in Africa, though counting a shy, wide-ranging cat is difficult and estimates differ. Lions have disappeared from much of their old range as farms and towns spread, and lions that kill cattle are often killed in return. The Asiatic lion shows what patient stewardship can do. By the early 1900s only a small number survived in the Gir Forest of Gujarat, India, protected by the Nawab of Junagadh. India's official census counted 674 Asiatic lions in 2020 and 891 in May 2025, and more than half now live outside the protected forest, among villages and farms. Their growth is a success, and it also brings a new challenge: how lions and farming families can share the same land safely.

Why it matters. Genesis 1:24-25 says God made the beasts of the earth “after his kind” and saw that it was good. Genesis 2:15 gives people the work to “dress” and “keep” the earth. The lion is a test of that charge: it is beautiful and dangerous, and caring for it means caring for the herders who live beside it too.

PICTURE STUDY



Daniel's Answer to the King, Briton Rivière, 1890-1892 · Oil on canvas · Manchester Art Gallery, England
Wikimedia Commons · Public domain

Briton Rivière (1840-1920) was an English painter famous for animals, especially lions, which he studied at the London Zoo. He painted Daniel more than once. Here Daniel has spent the night in the den, and in the morning the king calls down to ask whether his God has delivered him (Daniel 6:20-22). We see only Daniel's back. All the expression in the painting is in the lions.

Look closely

- Count the lions. Where are their eyes pointed, and what does their posture tell you about what they are about to do, or not do?

- Find the light. Where does it come from, and what does it fall on?
- Look at Daniel's hands and his stance. How does Rivière show calm without showing Daniel's face?

Talk about it

1. Rivière was a careful painter of real lions. Which details look like they came from studying living animals (manes, paws, muscles, the way they stand)?
2. Why might the painter have chosen not to show Daniel's face? What does the viewer have to imagine, and how does that connect with Daniel 6:22?

HANDS-ON: READ LIKE A SCHOLAR: THE LION OF JUDAH FROM GENESIS TO REVELATION

A scholar reads an old text slowly, asking what each picture meant to its first hearers and how later writers used it. Read the primary source (Genesis 49:8-10) beside Revelation 5:1-7 and build a one-page study chart.

You will need

- A KJV Bible (or the primary source in this stop)
- Two colored pencils or highlighters
- A Field Notebook page turned sideways and ruled into three columns

Steps

1. Read Genesis 49:8-10 aloud. In one color, highlight every lion word (whelp, lion, old lion, couched). In the other color, highlight every royal word (praise, bow down, sceptre, lawgiver).
2. Column 1, "The real lion": from this stop, write four facts about real lions that explain Jacob's picture (for example: a lion rests after eating and few animals dare disturb it).
3. Column 2, "Judah's promise": write what verse 10 promises and find, using 2 Samuel 7:12-16, how God renewed that promise to David.
4. Column 3, "The Lion and the Lamb": read Revelation 5:5-6. Write what John hears, then what John sees, and one sentence on why both are true of Christ.
5. At the bottom, write a three-sentence summary connecting all three columns.

Check your work

- I marked lion words and royal words in the primary source in two colors.
- My first column uses real facts about lions, not guesses.
- I can explain why John hears "Lion" but sees "Lamb."

FIELD NOTEBOOK

1. **Field page: Lions.** Sketch a lion lying down "couched" as in Genesis 49:9, with its head up. Label the mane, the forward-facing eyes, the sheathed claws and the tail tuft.

Beside it, make a small table comparing the African lion and the Asiatic lion (where they live, rough numbers, one problem each faces).

2. **Narration (parent keeps).** Without looking back, write one well-built paragraph of eight to ten sentences on “The lion in creation and in Scripture.” Include at least two numbers from this stop, one story of a lion in the Old Testament, and the meaning of Revelation 5:5–6. Date it and give it to a parent for the portfolio.

Did you know? A lion’s roar is so loud partly because of the shape of its vocal folds, which are flat and square rather than thin, letting the lion make a deep, powerful sound with little effort. Lions usually roar most around dusk and through the night. Among the cats, only the lion, tiger, leopard and jaguar can truly roar.

Primary source. *Genesis 49:8–10, King James Version (1611)*

Judah, thou art he whom thy brethren shall praise: thy hand shall be in the neck of thine enemies; thy father’s children shall bow down before thee. Judah is a lion’s whelp: from the prey, my son, thou art gone up: he stooped down, he couched as a lion, and as an old lion; who shall rouse him up? The sceptre shall not depart from Judah, nor a lawgiver from between his feet, until Shiloh come; and unto him shall the gathering of the people be.

Go deeper. Joy Adamson, *Born Free* (1960), the true story of the lioness Elsa (read the book with a parent; it is summarized, not quoted, here). J. H. Patterson, *The Man-Eaters of Tsavo* (1907), public domain, a famous first-hand account of two lions in Kenya in 1898 (some passages are frightening; parents preview). The Oriental Institute at the University of Chicago and the Metropolitan Museum of Art both have online pages on the glazed-brick lions of Babylon’s Processional Way. Second video topic: the Asiatic lions of the Gir Forest.

Goes deeper in. Life Science, high school “Biology: Mammals and Ecosystems” (coming soon); and History, “The Ancient Near East” for Babylon and Daniel (coming soon).

For families. African lion numbers are estimates; the IUCN and other groups give figures in roughly the 20,000–25,000 range, and the stop says so. Asiatic lion figures are from India’s official censuses (674 in 2020; 891 in May 2025, with more than half outside Gir National Park and Sanctuary). The date lions vanished from the Holy Land is uncertain; the stop says “probably around the time of the Crusades.” Speeds and weights are typical averages. The stop counts “well over a hundred” mentions of lions in Scripture because totals depend on which Hebrew words are counted. Picture: Rivière, *Daniel’s Answer to the King*, Manchester Art Gallery.

PRACTICE

1. **EASY** Who does most of the hunting in a lion pride, and why are they suited to it?

2. **EASY** In the primary source, what does Jacob call Judah, and what does he say will not depart from Judah?
3. **MEDIUM** India counted 674 Asiatic lions in 2020 and 891 in 2025. By what percentage did the population grow? Round to the nearest whole percent.
4. **MEDIUM** A lion may rest up to 20 hours a day. Give one reason from the story why this is wise design rather than laziness.
5. **CHALLENGE** In Revelation 5:5-6, John hears about a Lion but sees a Lamb “as it had been slain.” Write three or four sentences explaining what this tells us about how Christ won His victory.
6. **CHALLENGE** More than half of the Asiatic lions now live outside the protected forest, near villages and farms. Using Genesis 2:15, explain why this is both good news and a new stewardship problem, and suggest one practical step that could help.

Make it a game · Rouse the Lion. One player is the “old lion” and lies couched with eyes closed in the middle of the room, guarding a “prey” (a beanbag) beside them. The others creep in from the walls to try to take the prey. If the lion hears a sound, it points and roars, and anyone pointed at must go back to the wall. Whoever gets the prey becomes the lion. Afterward, read Genesis 49:9: “who shall rouse him up?”

Scripture. “And one of the elders saith unto me, Weep not: behold, the Lion of the tribe of Juda, the Root of David, hath prevailed to open the book, and to loose the seven seals thereof.” (Revelation 5:5, KJV)

“Juda” is the Greek spelling of Judah. Jacob’s blessing in Genesis 49 and God’s promise to David both find their fulfillment here: the Lion from Judah has prevailed. Read the next verse to see how.

Practice: answers

1. The lionesses. They are lighter and quicker than the males and often hunt together, surrounding prey.
2. He calls Judah “a lion’s whelp,” and says “the sceptre shall not depart from Judah.”
3. $891 - 674 = 217$; $217 \div 674 \approx 0.322$, so about 32 percent growth in five years.
4. Lions hunt in short, explosive bursts and a big meal lasts days, so resting saves energy for the next hunt (and avoids the heat of the day).
5. Sample: The elder announces Christ as the royal, victorious Lion from Judah, fulfilling Genesis 49. But the Lion won His right to open the book by dying as the Lamb, the sacrifice for sin. His strength was shown through self-giving, not by crushing others. So the Lion and the Lamb are not two different persons but two truths about one Christ: He is King, and He reigns because He was slain and rose again.
6. Sample: It is good news because the population has grown so much that the forest cannot hold them all. It is a problem because lions may kill livestock and endanger people, and herders may kill lions in return. Keeping the earth means caring for both the creatures and the people who live with them. Practical steps include strong night corrals for livestock,

paying farmers fairly for animals lost to lions, and moving some lions to a second home so that one disease cannot wipe them all out.

1.2 ELEPHANTS

OBJECTIVES

- Describe the three living kinds of elephants and explain, with numbers, how the trunk, teeth and herd are designed for the life an elephant lives.
- Read Job 40:15-19 as a primary source and weigh fairly the main ideas about what “behemoth” was.
- Explain why elephants declined, what the 1989 ban on the ivory trade was meant to do, and why elephant protection is a question of stewardship for people as well as animals.

Warm-up. Measure how much food you eat in a day: guess the weight of your breakfast, lunch and dinner together. Write it down. An adult African elephant eats about 300 pounds of plants a day. How many of your days of food would that be? Keep the answer for the practice questions.

Video slot. Video coming. African and Asian elephants: how the trunk works, elephant families led by a matriarch, and elephant rumbles. Search approved channels (Smithsonian Channel, National Geographic, BBC Earth, the San Diego Zoo Wildlife Alliance); preview first.

KEY TERMS

proboscis

A long, flexible snout. An elephant’s trunk is its nose and upper lip joined together, moved by tens of thousands of small bundles of muscle with no bone at all.

matriarch

The oldest, most experienced female who leads an elephant family. Her memory of water holes and dangers can mean life or death for the herd in a drought.

tusk

A greatly enlarged incisor tooth that keeps growing through life. Tusks are made of ivory (dentine) and are used for digging, stripping bark, lifting and defense.

infrasound

Sound too low for human ears to hear. Elephants make low rumbles that can carry for miles and may also be felt through the ground.

behemoth

The great grass-eating beast God describes to Job in Job 40:15-24. Bible readers have identified it as the elephant, the hippopotamus, or a great creature no longer living.

poaching

Illegal hunting, usually for profit. Most elephant poaching is done to take ivory.

CORE IDEAS

Three living kinds. There are three living species of elephant. The **African savanna (bush) elephant** is the largest land animal on earth: a big bull can stand about 13 feet (4 m) at the shoulder and weigh around 6 tons. The smaller **African forest elephant** lives in the rainforests of central and western Africa and has straighter, downward-pointing tusks; in 2021 the IUCN, the main international body that assesses animals, began to list it separately from the savanna elephant. The **Asian elephant** of India and Southeast Asia has smaller ears, a rounded back and two domes on its forehead; usually only some males grow large tusks. African elephants have ears shaped a little like the map of Africa, and those great ears, full of blood vessels, work as radiators to cool the animal.

The trunk. An elephant's trunk is its nose and upper lip joined into one boneless limb. Anatomists have counted tens of thousands of separate muscle bundles in it. It can tear down a branch, lift a log of several hundred pounds, or pick up a single peanut. An African elephant can draw several gallons of water into its trunk and then squirt it into its mouth or over its back. The trunk smells, too: elephants have one of the keenest noses of any animal. With a trunk, an animal too tall to reach the ground with its mouth can still graze, drink and greet its young.

Teeth for a lifetime. An adult elephant spends about 16 hours a day feeding and may eat around 300 pounds (about 140 kg) of grass, leaves, bark and fruit. Food like that grinds teeth down fast. Elephants solve this with six sets of great molars in a lifetime. The teeth do not push up from below, as ours do, but move slowly forward along the jaw like a conveyor belt; as the front one wears away, the next one moves into place. When the last set is worn out, an old elephant can no longer chew well. This is one reason elephants in the wild rarely live much beyond about 60 or 70 years.

Families led by grandmothers. Elephant herds are families of related females and their young, led by a **matriarch**. Males leave at adolescence and live alone or in loose bachelor groups. A calf is carried for about 22 months, the longest pregnancy of any land animal, and weighs about 200 to 250 pounds at birth. The whole family helps guard it. Elephants keep in touch with low rumbles, much of it **infrasound** below the range of our hearing, that can carry across miles of savanna. Studies in Kenya have shown that families led by older matriarchs respond more wisely to danger, such as the roar of a lion, than families led by younger ones. Experience matters, even among elephants.

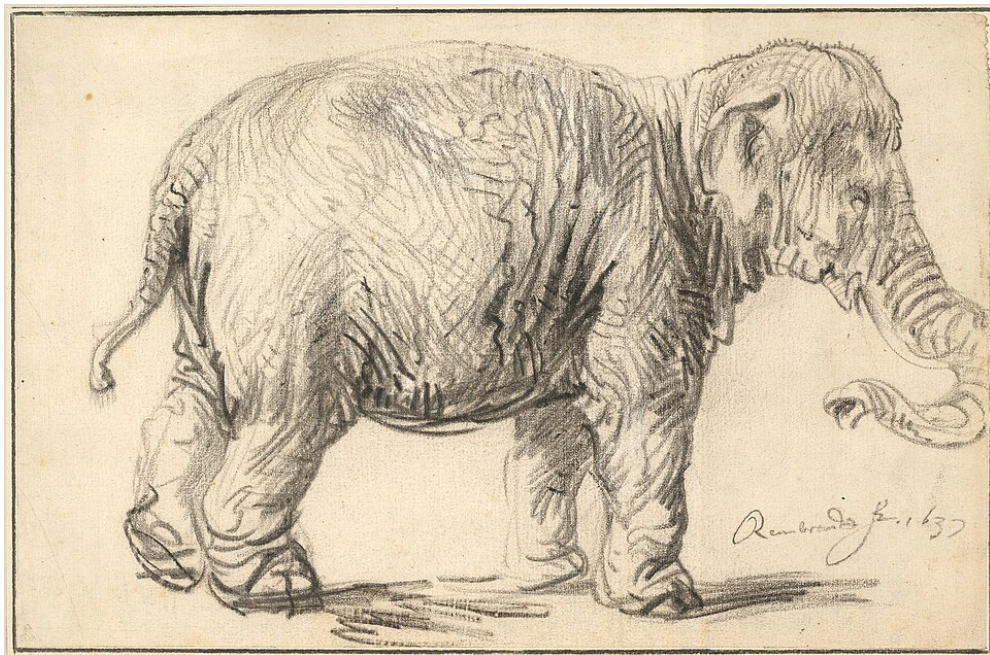
Behemoth. In Job 40 God says, "Behold now behemoth, which I made with thee," and describes a grass-eating giant whose bones are "like bars of iron" and who is "the chief of the ways of God." What was it? Many older commentators said the elephant, the largest beast they knew; others, including many modern scholars, say the hippopotamus, which lived along the Nile and the rivers of the region. Some Christians point out that "he moveth his tail like a cedar" fits neither animal well, since both have short tails, and suggest a great creature no longer living, such as a sauropod dinosaur. The Hebrew word itself is a plural of the ordinary word for "beast," perhaps meaning "the beast of beasts." A careful reader can

hold these views honestly. What is not in doubt is the point God makes to Job: He made this creature, He is greater than it, and Job is not.

Ivory and its cost. People have prized ivory for thousands of years. Solomon's throne was made of ivory overlaid with gold (1 Kings 10:18). In the 1800s and 1900s, ivory was used for piano keys, billiard balls and carvings, and hunting for it killed hundreds of thousands of elephants. Between 1979 and 1989, Africa's elephants are estimated to have fallen by about half. In 1989 the nations of the CITES treaty banned the international trade in new ivory. Poaching has continued, but many herds in southern and eastern Africa have recovered. A 2016 survey estimated about 415,000 African elephants of both kinds; Asian elephants number perhaps 40,000 to 50,000.

Stewardship with neighbors. Elephants also raid crops, flatten fences and sometimes kill people, so farmers who live beside them pay a real cost. Good stewardship looks for ways that elephants and families can both thrive: beehive fences (elephants avoid bees), chili-pepper barriers, corridors between parks, and rangers paid to protect herds. Psalm 50:10 says, "For every beast of the forest is mine." Elephants belong to God before they belong to any nation or trader.

PICTURE STUDY



An Elephant (Hansken), Rembrandt van Rijn, 1637 · Black chalk on paper · Albertina, Vienna
Wikimedia Commons · Public domain

In the 1630s an Asian elephant cow named Hansken was brought from Ceylon (Sri Lanka) to the Netherlands and shown all over Europe, doing tricks for paying crowds. Rembrandt, the great Dutch painter, drew her several times in black chalk in about 1637, and later put her into one of his prints of Adam and Eve. Very few Europeans of his day had ever seen a living elephant.

Look closely

- Follow the lines of the skin. How does Rembrandt show wrinkles, weight and the roundness of the body with only black chalk?
- Look at the trunk, the ear and the small eye. Which details tell you this is an Asian rather than an African elephant?
- Look at the legs and feet. How does Rembrandt make them look like pillars strong enough to carry several tons?

Talk about it

1. Compare this drawing with Albrecht Dürer's famous *Rhinoceros* (1515), which Dürer drew without ever seeing the animal. Why is Rembrandt's drawing more accurate?
2. What does it tell you about Rembrandt that he took time to draw a traveling show animal so carefully, and then signed and dated the sheet?

HANDS-ON: WEIGHING THE EVIDENCE: WHAT WAS BEHEMOTH?

Good readers test an interpretation against every line of the text. Use the primary source (Job 40:15-19) and real animal facts to judge three proposed answers: elephant, hippopotamus, or a creature no longer living.

You will need

- A KJV Bible open to Job 40:15-24 (the primary source in this stop gives verses 15 and 17-19)
- A Field Notebook page ruled into a grid: five rows for the clues, three columns for the candidates
- A library animal encyclopedia or a museum website for hippo and elephant facts

Steps

1. List five clues from Job 40:15-24 down the left side: eats grass "as an ox"; bones like brass and iron; tail like a cedar; lives among reeds and fens (verse 21); not troubled when the river floods (verse 23).
2. For each clue and each candidate, write ✓ (fits well), ~ (fits partly) or ✗ (does not fit), with a short reason. Use real facts: for example, an elephant's tail is about 4 feet long and thin.
3. Count the marks. Which candidate fits the most clues? Which clue is hardest for each?
4. Write a short paragraph: "What I think behemoth was, and why." Then add one sentence on the point of the passage that does not depend on the answer (Job 40:19).

Check your work

- I tested every candidate against the same five clues.
- My reasons use real facts about the animals.
- My paragraph states a view fairly and admits what is uncertain.

FIELD NOTEBOOK

1. **Field page: Elephants.** Draw an elephant's lower jaw from the side and show the conveyor-belt molars: one worn tooth at the front, one in use, one waiting behind. Beside it, make a three-column chart of savanna, forest and Asian elephants: size, ears, tusks, where they live.
2. **Narration (parent keeps).** Without looking back, write one well-built paragraph of eight to ten sentences: "How an elephant is made for its life." Include the trunk, the teeth, the matriarch and at least two numbers. End with one sentence about Job 40. Date it and give it to a parent.

Did you know? Elephants seem to recognize their own reflection: in a 2006 study at the Bronx Zoo, an Asian elephant named Happy repeatedly touched a painted mark on her head that she could see only in a mirror. Elephants also walk on tiptoe: a thick pad of fatty tissue behind the toe bones cushions every step, which is why a 6-ton animal can walk almost silently.

Primary source. *Job 40:15, 17-19, King James Version (1611)*

Behold now behemoth, which I made with thee; he eateth grass as an ox. ... He moveth his tail like a cedar: the sinews of his stones are wrapped together. His bones are as strong pieces of brass; his bones are like bars of iron. He is the chief of the ways of God: he that made him can make his sword to approach unto him.

Go deeper. Iain and Oria Douglas-Hamilton, *Among the Elephants* (1975), a classic first-hand study of elephant families at Lake Manyara. Katy Payne, *Silent Thunder* (1998), on the discovery of elephant infrasound. The Smithsonian's National Zoo and the San Diego Zoo Wildlife Alliance have good free pages on elephant biology. Second video topic: Hannibal's war elephants and the crossing of the Alps (218 B.C.).

Goes deeper in. Life Science, high school "Biology: Mammals and Ecosystems" (coming soon); and Literature, "Reading the Bible as Literature: Job" (coming soon).

For families. Sizes and food amounts are typical figures for adult savanna elephants. The muscle count of the trunk is given as "tens of thousands" because published counts vary (the older figure of about 40,000; newer studies count more bundles). The 2016 figure of about 415,000 African elephants is the IUCN African Elephant Status Report estimate; Asian elephant numbers are rough. The halving of African elephants in 1979-1989 is a commonly cited estimate. The identity of behemoth is presented as an open question: the elephant (many older commentators), the hippopotamus (many modern scholars), and an extinct creature such as a sauropod (many young-earth creationists). Picture: Rembrandt drew Hansken several times; the best-known sheet is in the Albertina, Vienna, and the British Museum holds another.

PRACTICE

1. **EASY** Name the three living kinds of elephants and one feature that tells an Asian elephant from an African one.
2. **EASY** Why can an elephant keep chewing tough plants for most of its life?
3. **MEDIUM** An elephant eats about 300 pounds of food a day. How many tons is that in one year (2,000 pounds = 1 ton)?
4. **MEDIUM** Why might a family led by an older matriarch survive a drought better than one led by a young female?
5. **CHALLENGE** Using the primary source, give one clue that supports the elephant view of behemoth, one that supports the hippopotamus view, and one that troubles both. Then state the point God makes in verse 19 that stands whatever the answer.
6. **CHALLENGE** A farmer in Kenya loses half a season's maize to elephants. Write a short argument (four sentences) for how good stewardship should treat both the farmer and the elephants, and name two practical tools.

Make it a game • Trunk Challenge. Pull a long sock over one hand and arm to make a "trunk." Without using your other hand or bending your fingers out of the sock, try to pick up, in order: a pillow, a pencil, a coin, and a single dry bean. Time each player. Talk about how an elephant does all four with one trunk and no bones.

Scripture. "For every beast of the forest is mine, and the cattle upon a thousand hills." (Psalm 50:10, KJV)

God, not the ivory trader or the farmer, is the first owner of the elephant. Stewards care for what belongs to their master.

Practice: answers

1. African savanna (bush) elephant, African forest elephant and Asian elephant. Any one: Asian elephants have smaller ears, a rounded back, two domes on the forehead, and often only males have large tusks.
2. It has six sets of molars that move forward along the jaw one after another as the front ones wear out.
3. $300 \times 365 = 109,500$ pounds; $109,500 \div 2,000 \approx 55$ tons a year.
4. The older matriarch remembers where water and food were found in past droughts and how to respond to dangers, and the family follows her experience.
5. Sample: "He eateth grass as an ox" and bones "like bars of iron" fit the huge, plant-eating elephant. The reeds and fens and the river in verses 21–23 fit the hippo. "He moveth his tail like a cedar" troubles both, since both have short tails. Whatever it was, verse 19 says it is "the chief of the ways of God" and that only its Maker can master it: God is greater than His mightiest creature, and Job should trust Him.
6. Sample: Genesis 2:15 gives people the duty to keep the earth, and that includes both the elephants God made and the neighbor whose family depends on the crop. Protecting elephants by ignoring the farmer's loss is not just, and killing elephants is not good keeping either. Practical tools include beehive fences and chili barriers that turn elephants away,

wildlife corridors between parks, and fair payment for crops lost. When local families gain from healthy herds (for example, through jobs as rangers or guides), they become the elephants' best protectors.

1.3 WHALES: THE “GREAT WHALES” OF GENESIS 1:21

OBJECTIVES

- Explain with numbers why the blue whale is the largest animal known, and how baleen whales and toothed whales are designed to feed in different ways.
- Read a passage from Melville’s *Moby-Dick* (1851) as a primary source and explain how the meaning of the word “fish” has changed, using Genesis 1:21, Jonah 1:17 and Matthew 12:40.
- Describe the rise and fall of whaling and how the great whales have begun to recover since commercial whaling was halted.

Warm-up. Go outside with a tape measure or count your steps. Mark out 100 feet in a straight line, about one-third of a football field. That is roughly the length of the largest blue whales ever measured. Lie down at one end. How many of you would fit along it?

Video slot. Video coming. Blue whales feeding on krill, humpback whale song, and sperm whales diving to the deep. Search approved channels (Smithsonian Channel, National Geographic, BBC Earth, NOAA Fisheries, Monterey Bay Aquarium); preview first.

KEY TERMS

cetacean

The group of sea mammals that includes whales, dolphins and porpoises (from the Greek *kētos*, “sea monster” or “great fish”).

baleen

Long plates of a fingernail-like material (keratin) that hang from the upper jaw of some whales and strain small animals out of seawater.

krill

Small, shrimp-like ocean animals, often only one or two inches long, that swarm in vast numbers and are the main food of blue whales.

fluke

One of the two flat lobes of a whale’s tail. Whale tails are horizontal and beat up and down; fish tails are vertical and sweep side to side.

blowhole

A whale’s nostril, set on top of the head so it can breathe at the surface without lifting its head. Baleen whales have two; toothed whales have one.

moratorium

An agreed pause. In 1982 the International Whaling Commission voted for a pause in commercial whaling that took effect in the 1985–86 season.

CORE IDEAS

“Great whales.” Genesis 1:21 says, “God created great whales, and every living creature that moveth, which the waters brought forth abundantly.” The Hebrew word the King James translators rendered “great whales” is *tanninim*, a broad word for great creatures of the sea and waters; many modern versions say “great sea creatures.” The point of the verse is that the largest living things in the sea did not make themselves and are not gods, as some ancient peoples thought: God created them “after their kind” and called them good. Whatever else the word includes, it certainly includes the whales, and no sea creature is greater than they are.

The largest animal. The blue whale is the largest animal known to have lived. The longest measured were close to 100 feet (30 m); the heaviest weighed perhaps 150 to 190 tons. A blue whale heart preserved by the Royal Ontario Museum in 2015 weighed about 400 pounds. A newborn calf is about 23 feet long and gains roughly 200 pounds a day on its mother’s rich milk. Yet this giant eats some of the smallest animals in the sea. Blue whales are **baleen** whales: a whale lunges into a swarm of **krill**, its pleated throat balloons to take in a mouthful of water larger than its own body, and then it pushes the water out through its baleen plates, trapping the krill. In a good feeding season a blue whale may eat about four tons of krill a day.

Teeth and sound. The other great group, the toothed whales, includes dolphins, orcas and the sperm whale, the giant of Moby-Dick. Sperm whales dive more than a mile deep and stay down for an hour or more, hunting squid in total darkness by bouncing clicks off them and listening to the echoes. Some of their clicks are among the loudest sounds made by any animal. Baleen whales make sound too: male humpbacks sing long, repeating songs that can last twenty minutes and are heard across many miles of ocean.

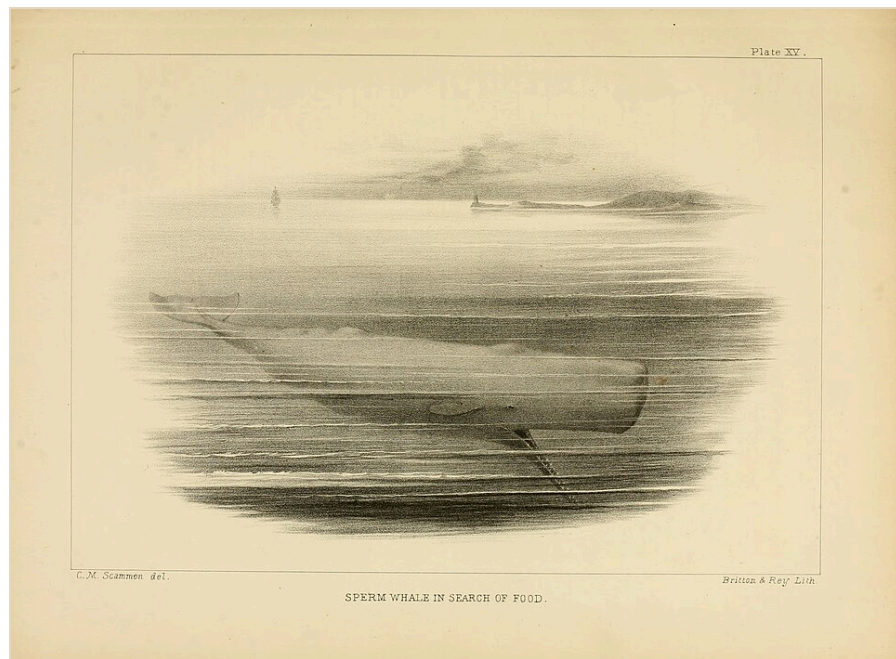
Mammals of the sea. Whales breathe air with lungs, are warm-blooded, give birth to live young and nurse them with milk. Their tails are horizontal. In 1758 the Swedish naturalist Carl Linnaeus placed whales among the mammals in his system of classification. But most sailors and ordinary people kept calling whales “fish” for another century, because to them a fish was simply any large creature that lives and swims in the sea. In 1818 a New York jury in the case of *Maurice v. Judd* even ruled that whale oil was “fish oil” for tax purposes. Melville’s narrator Ishmael playfully takes the old side in *Moby-Dick* (1851), as the primary source shows. This helps us read Scripture well: Jonah 1:17 says the LORD prepared “a great fish,” and in Matthew 12:40 the King James Version has Jesus speak of “the whale’s belly,” translating the Greek *kētos*, a great sea creature. Neither text is using the categories of modern zoology, and neither is in error by using the ordinary words of its day.

The age of whaling. For centuries people hunted whales for oil to light lamps and grease machines, for meat, and for baleen (“whalebone”), which was made into corset stays and buggy whips. In the 1840s the American whaling fleet, based in New England ports like Nantucket and New Bedford, numbered more than 700 ships. After petroleum was struck in Pennsylvania in 1859, cheaper kerosene began to replace whale oil, but in the 1900s explosive harpoons and huge factory ships made whaling more deadly than ever. In the

twentieth century alone, whalers killed more than two million whales, including about 360,000 blue whales, most of them in the Southern Ocean.

A recovery. The International Whaling Commission was formed in 1946, and in 1982 it voted for a pause, or **moratorium**, on commercial whaling that took effect in the 1985–86 season. A few nations still hunt whales, and native peoples in the Arctic are allowed a small traditional hunt. Since the pause, many populations have grown. Humpbacks in the western South Atlantic, once reduced to a few hundred, have climbed back to tens of thousands. Blue whales are recovering much more slowly. Stewardship of the sea, like stewardship on land, means using the creatures God made wisely rather than emptying the ocean of them.

PICTURE STUDY



Sperm Whale in Search of Food, Plate XV of The Marine Mammals of the North-western Coast of North America, Charles Melville Scammon (drawing); lithographed by Bricher & Russell, 1874 · Lithograph · From Scammon's book *The Marine Mammals of the North-western Coast of North America* (1874); scans in the Biodiversity Heritage Library
Wikimedia Commons · Public domain

Charles Melville Scammon was a whaling captain from Maine who hunted whales along the Pacific coast of North America for many years and then became one of the first careful students of the animals he had hunted. In 1874 he published a large book on the whales, dolphins, seals and sea otters of the Pacific coast, with drawings he made himself and an account of the American whale fishery. This plate shows the sperm whale, the toothed giant of *Moby-Dick*, as Scammon pictured it hunting beneath the surface.

Look closely

- Find the whale's lower jaw. How is it shaped, and does it tell you this is a baleen whale or a toothed whale?

- Look at the head. About what part of the whale's whole length is the great, square head?
- Find the ships and the land on the horizon. What do they add to the picture, and how do they make the sea feel?

Talk about it

1. Scammon had killed many whales before he began to study and draw them. How might a whaler's experience help a naturalist, and how might it get in the way?
2. Sperm whales hunt squid more than a mile down in total darkness. What has Scammon shown well here, and what could no one in 1874 have seen with his own eyes?

HANDS-ON: IS A WHALE A FISH? WORDS, CATEGORIES AND SCRIPTURE

Words do not always mean what they meant two hundred or two thousand years ago. Use the primary source from *Moby-Dick*, Genesis 1:21, Jonah 1:17 and Matthew 12:40 to write a short report on how the meaning of "fish" has changed and why that matters for reading old books well.

You will need

- The primary source in this stop
- A KJV Bible
- A dictionary, and if possible an old one (Noah Webster's 1828 *American Dictionary* is free online)
- A Field Notebook page

Steps

1. Read the primary source aloud. Underline Ishmael's definition of a whale. Circle the two things he says make whales different from other "fish."
2. Look up "fish" in a modern dictionary and, if you can, in Webster's 1828 dictionary. Copy both definitions. What changed?
3. Read Genesis 1:20-21, Jonah 1:17 and Matthew 12:40. Make a short table: reference, word used, what it meant to the first readers.
4. Make a second table: five traits that make a whale a mammal, with a one-line fact for each (lungs, warm blood, live birth, milk, horizontal tail).
5. Write a half-page report titled "Is a whale a fish?" Answer for a modern biologist, for a sailor in 1851 and for the writer of Jonah, and end with one sentence on how this helps you read Scripture carefully.

Check your work

- I quoted Ishmael's definition correctly from the primary source.
- My report gives three different answers and explains why each makes sense in its own setting.
- I can list five traits that make whales mammals.

FIELD NOTEBOOK

1. **Field page: Great whales.** Draw a blue whale and a sperm whale side by side at the same scale (1 inch = 10 feet works well). Label baleen or teeth, blowholes and flukes, and write each whale's length and main food.
2. **Narration (parent keeps).** Without looking back, write one well-built paragraph of eight to ten sentences: "The great whales, from Genesis to today." Include at least three numbers, the difference between baleen and toothed whales, and the story of whaling and the moratorium. Date it and give it to a parent.

Did you know? Scientists can tell a whale's age from its earwax. Baleen whales build up a waxy earplug in layers, light and dark, a little like tree rings, and counting the layers gives an estimate of age. Some bowhead whales of the Arctic have been found with old stone and iron harpoon points from the 1800s still lodged in their blubber, and studies of their eyes suggest some bowheads live past 150 years.

Primary source. *Herman Melville, Moby-Dick; or, The Whale (1851), Chapter 32, "Cetology" (first American edition)*

Be it known that, waiving all argument, I take the good old fashioned ground that the whale is a fish, and call upon holy Jonah to back me. This fundamental thing settled, the next point is, in what internal respect does the whale differ from other fish. Above, Linnæus has given you those items. But in brief they are these: lungs and warm blood; whereas, all other fish are lungless and cold blooded.

Next: how shall we define the whale, by his obvious externals, so as conspicuously to label him for all time to come? To be short, then, a whale is *a spouting fish with a horizontal tail*. There you have him.

Go deeper. D. Graham Burnett, *Trying Leviathan* (2007), the story of the 1818 New York trial over whether a whale is a fish. Nathaniel Philbrick, *In the Heart of the Sea* (2000), the true story of the whaleship *Essex*, which inspired Melville (some hard scenes of survival; parents preview). The New Bedford Whaling Museum website has free pages on the whaling era. Second video topic: humpback whale song and how scientists record it.

Goes deeper in. Life Science, high school "Biology: Mammals and Ecosystems" (coming soon); Literature, American literature unit on Melville (coming soon); and History, "America in the 1800s: Whaling and Industry" (coming soon).

For families. The primary source text is from Chapter 32 of *Moby-Dick* (1851). It follows the 1851 American edition (the full novel is free on Project Gutenberg, eBook #2701); the second paragraph is quoted only through "There you have him." Ishmael's view is a deliberate, playful stand for the old sailor's usage, not Melville's own science. Blue whale sizes are the largest reliable measurements; most adults are smaller. The figure of about 360,000 blue whales killed in the twentieth century is a commonly cited estimate. Many

museum signs present whales as descended from land mammals over millions of years; this stop does not tell that story and treats whales as created “after their kind” (Genesis 1:21), describing their design without deep-time dates. The beached-whale print: Saenredam’s engraving is dated 1602 for a stranding in December 1601 (sources give slightly different days).

PRACTICE

1. **EASY** Name two differences between a baleen whale and a toothed whale.
2. **EASY** In the primary source, how does Ishmael define a whale, and which two internal traits does he say set it apart from other fish?
3. **MEDIUM** A newborn blue whale gains about 200 pounds a day while nursing for about 7 months (about 210 days). How much weight could it gain in that time, in pounds and in tons?
4. **MEDIUM** Why did the whaling industry of New England decline after 1859, even though whaling worldwide later became more deadly?
5. **CHALLENGE** A friend says, “The Bible is wrong, because Matthew 12:40 calls the creature that swallowed Jonah a whale, and Jonah 1:17 calls it a fish.” Using this stop, write a reply of four or five sentences.
6. **CHALLENGE** Humpbacks in the western South Atlantic recovered from a few hundred to tens of thousands, but blue whales have recovered much more slowly. Suggest two reasons from what you know of their lives, and say why a moratorium alone may not be enough.

Make it a game · Krill and Baleen. Scatter a handful of uncooked rice (krill) in a shallow pan of water. Each player gets ten seconds to scoop with a slotted spoon (baleen) and ten seconds with a plain spoon (teeth). Which collects more rice and less water? Count the grains. Then explain why a blue whale needs baleen to live on krill.

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 verse uses the strong word “created,” used only a few times in Genesis 1. The greatest creatures of the sea are not rivals of God or gods themselves; they are His good work.

Practice: answers

1. Any two: baleen whales strain small animals with baleen plates, toothed whales catch larger prey with teeth; baleen whales have two blowholes, toothed whales one; toothed whales hunt by echolocation clicks.
2. “A spouting fish with a horizontal tail.” Lungs and warm blood.
3. $200 \times 210 = 42,000$ pounds, or 21 tons.
4. Petroleum was struck in Pennsylvania in 1859, and cheaper kerosene replaced whale oil for lamps. Later, explosive harpoons and factory ships let whalers kill far more whales, especially

in the Southern Ocean.

5. Sample: Neither word was meant as a modern scientific category. The Hebrew of Jonah says “a great fish,” and in ordinary speech for thousands of years “fish” meant any large swimming sea creature, as Melville’s Ishmael and an 1818 New York jury show. The Greek word in Matthew, *kētos*, means a great sea creature, and the King James translators rendered it “whale.” Both texts describe the same event in the everyday words of their time, so there is no contradiction. We also judge any old book unfairly if we demand that it use categories invented centuries later.
6. Sample: Blue whales were reduced to a far smaller fraction of their original numbers, so they began recovery from a very low base; they also have few calves (usually one every two to three years) and live spread across vast oceans, making it harder to find mates. They depend on krill swarms that vary from year to year. A pause in hunting removes one danger, but recovery also needs time, protection from ship strikes and entanglement, and healthy food supplies, which means ongoing careful stewardship.

1.4 BATS

OBJECTIVES

- Explain how a bat's wing is built and how echolocation works, using real frequencies and numbers.
- Retell how Lazzaro Spallanzani in the 1790s and Donald Griffin in the 1930s and 1940s discovered how bats "see" in the dark, and what their experiments show about good science.
- Read Leviticus 11:13-19 as a primary source and explain why listing the bat among the "fowls" is not an error, and describe the bat's value to farmers and the threat of white-nose syndrome.

Warm-up. In a quiet room, close your eyes and have someone clap once from different corners. Point to where you think the sound came from. Now stand about three feet from a wall, close your eyes and make a sharp "tsk" sound with your tongue, then step back and try again. Can you hear any difference? Bats do this many times a second, with sounds you cannot hear at all.

Video slot. Video coming. How bats echolocate; the evening emergence of the Mexican free-tailed bats at Bracken Cave or the Congress Avenue Bridge in Austin, Texas. Search approved channels (Smithsonian Channel, National Geographic, BBC Earth, Bat Conservation International, the National Park Service); preview first.

KEY TERMS

Chiroptera

The order of mammals made up of the bats. The name means "hand-wing," because a bat's wing is a hand with very long fingers.

patagium

The thin, stretchy skin membrane that forms a bat's wing, stretched between the long finger bones, the body and the legs.

echolocation

Finding objects by making sounds and listening for the echoes. The word was coined by the American scientist Donald Griffin in 1944.

ultrasound

Sound too high for human ears to hear, above about 20,000 vibrations a second (20 kilohertz). Most bat calls are ultrasound.

torpor

A state of lowered body temperature and slowed heartbeat that saves energy; long torpor through winter is hibernation.

white-nose syndrome

A disease caused by a fungus that grows on hibernating bats, wakes them too often and burns up their winter fat. First found in New York in 2006.

CORE IDEAS

The hand-wing. Bats are the only mammals that truly fly. Their order is called **Chiroptera**, “hand-wing,” and the name is exact: a bat’s wing is a hand with a thumb and four very long fingers, with a thin, living membrane of skin, the **patagium**, stretched between them and back to the legs. By bending its fingers, a bat can change the shape of each wing in mid-stroke, which makes bats more agile in the air than most birds. There are more than 1,400 kinds of bats, about one-fifth of all mammal species. The smallest, Kittie’s hog-nosed bat of Thailand, weighs about 2 grams, less than a penny; the largest flying foxes have wings spreading more than 5 feet.

Spallanzani’s puzzle. In the 1790s an Italian priest and scientist, Lazzaro Spallanzani, noticed that bats flew safely in a dark room while owls blundered into the walls. He covered the eyes of some bats and found they still flew safely around threads he had strung across a room. When a Swiss surgeon, Louis Jurine, plugged bats’ ears, they crashed. Spallanzani concluded that bats somehow found their way by hearing, but no one could hear any sound. Many scientists of his day laughed at the idea and suggested that bats used touch instead. The puzzle stayed unsolved for nearly 150 years.

Griffin hears the unheardable. In 1938 a Harvard student, Donald Griffin, brought bats to a physicist who had built a detector for high-pitched sound. The machine crackled with bat calls that no human ear could catch. With Robert Galambos, Griffin showed that bats cry out in **ultrasound** as they fly and steer by the echoes. In 1944 he named the ability **echolocation**. Most bat calls lie between about 20 and 120 kilohertz; human hearing stops near 20. A hunting bat calls perhaps 10 to 20 times a second while searching, then speeds up to as many as 200 calls a second in a final “feeding buzz” as it closes on an insect. To keep from deafening itself, a bat briefly tightens tiny muscles in its ears with each shout. Spallanzani had been right all along; he simply lacked the tools to prove it.

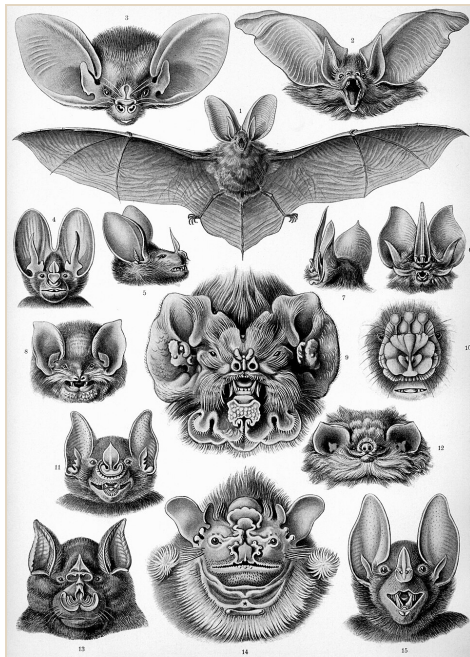
“And the bat.” Leviticus 11:13–19 lists the bat at the end of the “fowls” that Israel was not to eat. Some critics call this a mistake, since a bat is a mammal, not a bird. But the Hebrew word translated “fowls,” *’oph*, means flying creatures in general; it comes from a verb meaning “to fly.” The list sorts animals by how they live and move, not by modern classification, which did not exist until thousands of years later. By the standard of its own purpose, a list of flying creatures not to be eaten, it is perfectly accurate. The same lesson appears in Stop A3 with whales and fish: we must read each text by the categories its writer was using.

Night workers. About two-thirds of bat species eat insects. A small brown bat can catch hundreds of insects in an hour. The largest bat colony in the world, at Bracken Cave near San Antonio, Texas, holds perhaps 15 million Mexican free-tailed bats in summer; on a warm evening they pour out for more than an hour in a dark river across the sky and eat tons of moths, including pests of corn and cotton. A 2011 study in the journal *Science* estimated that

insect-eating bats save American farmers at least billions of dollars a year in crop damage and pesticide. Other bats pollinate flowers and spread seeds: the agave plants of Mexico and many tropical fruit trees depend on them. Only three species, all in Latin America, drink blood, and they mostly feed on livestock.

A new danger. In the winter of 2006, a caver photographed bats with a strange white fuzz on their noses in a cave near Albany, New York. The fungus, now called **white-nose syndrome**, grows on bats during hibernation and wakes them again and again, burning the fat they need to last the winter. It has spread across much of North America and killed millions of bats; some colonies of little brown bats lost more than 90 percent. Scientists are testing treatments, and people help by staying out of closed caves and following decontamination rules when they do go caving. Caring for unseen night creatures that quietly protect our crops is part of the work of keeping the garden (Genesis 2:15).

PICTURE STUDY



Chiroptera (Plate 67 of *Kunstformen der Natur*, "Art Forms in Nature"), Ernst Haeckel, 1904 · Lithograph (color print) from Haeckel's drawings · Published in Leipzig in *Kunstformen der Natur* (1899-1904); copies in many libraries

Wikimedia Commons · Public domain

Ernst Haeckel (1834-1919) was a German biologist and a gifted artist. His book *Art Forms in Nature* arranged animals and plants into dazzling, symmetrical designs. In this plate he gathered the faces of many kinds of bats. Haeckel was a strong opponent of Christianity, and some of his scientific drawings of embryos were later shown to be inaccurate; but his drawings of bat faces are careful records of real animals and show the astonishing variety of their design.

Look closely

- Find the bats with leaf-shaped flaps on their noses (nose leaves). Many of these bats send their calls out through the nose, and the nose leaf helps aim the sound.
- Compare the sizes and shapes of the ears. Why might a bat that listens for tiny echoes need ears like these?
- Look at the bat with spread wings. Can you find the thumb and the long fingers inside the wing?

Talk about it

1. Haeckel arranged real animals into a decorative pattern. Is this plate art, science, or both? Explain.
2. What does this variety of faces suggest about the Designer who made bats, compared with the uniform look people often imagine for “a bat”?

Safety first. Never touch a bat, living or dead, with bare hands. A small number of bats carry rabies. If a bat is found in a room where someone was sleeping, or if anyone may have been bitten or scratched, call your doctor or local health department right away.

HANDS-ON: ECHO RANGING: MEASURE DISTANCE BY SOUND

Bats judge distance by the time it takes an echo to return. Sound travels about 1,125 feet per second in air. Use a large wall and a stopwatch to measure distance the way a bat does, then compare with the categories of the primary source (Leviticus 11:13-19).

You will need

- A large, flat outside wall (a school or church building) with open space in front of it
- Two wooden blocks or a pair of pot lids to clap together
- A stopwatch and a long tape measure or measuring wheel
- A helper and a Field Notebook page

Steps

1. Stand about 200 feet from the wall (measure it). Clap the blocks sharply and listen for the echo. In a quiet place you will hear it.
2. Clap steadily so that each clap falls exactly on the echo of the one before. Have your helper time 20 claps. Divide the time by 20 to get the echo time.
3. Calculate the distance: $\text{distance} = 1,125 \times \text{echo time} \div 2$ (the sound goes there and back). Compare with your measured distance and work out your percentage error.
4. Now think like a bat: an insect 10 feet away. How long does the echo take? ($10 \times 2 \div 1,125 \approx 0.018$ seconds, about 18 thousandths of a second.)
5. Finally, read the primary source. Make two lists: the creatures there that are birds by modern classification, and the one that is not. Write one sentence on how the Hebrew word *'oph* (flying creatures) explains the list.

Check your work

- I measured the echo time over 20 claps and calculated the distance.
- I compared my answer with the measured distance and found my error.
- I can explain why the bat belongs on a list of flying creatures.

FIELD NOTEBOOK

1. **Field page: Bats.** Draw a bat's wing skeleton beside a human hand and arm. Use the same color for matching bones (upper arm, forearm, thumb, four fingers). Label the patagium. Add a small diagram of echolocation: bat, outgoing call, insect, returning echo.
2. **Narration (parent keeps).** Without looking back, write one well-built paragraph of eight to ten sentences: "How we learned that bats see with sound." Include Spallanzani, Jurine and Griffin in order, at least two numbers, and one lesson about patient science. Date it and give it to a parent.

Did you know? Some moths can hear bats coming. Tiger moths answer bat calls with ultrasonic clicks of their own that warn the bat they taste bad or, in at least one species, jam the bat's sonar. Bats, in turn, live remarkably long for their size: a little brown bat weighing less than half an ounce has been recorded living more than 30 years in the wild.

Primary source. *Leviticus 11:13-19, King James Version (1611)*

And these are they which ye shall have in abomination among the fowls; they shall not be eaten, they are an abomination: the eagle, and the ossifrage, and the ospray, And the vulture, and the kite after his kind; Every raven after his kind; And the owl, and the night hawk, and the cuckow, and the hawk after his kind, And the little owl, and the cormorant, and the great owl, And the swan, and the pelican, and the gier eagle, And the stork, the heron after her kind, and the lapwing, and the bat.

Go deeper. Donald R. Griffin, *Listening in the Dark* (1958), the classic account by the man who discovered echolocation (advanced). Merlin Tuttle, *The Secret Lives of Bats* (2015), by the founder of Bat Conservation International. Bat Conservation International (batcon.org) and the U.S. Fish and Wildlife Service's white-nose syndrome site have free pages and maps. Second video topic: the evening flight from the Congress Avenue Bridge in Austin, Texas.

Goes deeper in. Life Science, high school "Biology: Mammals and Ecosystems" (coming soon); and Gardening & Animals, "Helpful Creatures in the Garden: Bats and Bat Houses" (coming soon).

For families. Species counts (over 1,400) follow recent lists and keep rising as new species are described. The Bracken Cave figure is the usual estimate given by Bat Conservation International, which owns the cave. The economic estimate is from Boyles and others, *Science* (2011), which gave a range of about \$3.7 to \$53 billion a year; the

stop says “at least billions.” Spallanzani’s and Jurine’s experiments involved blinding and deafening bats, which was accepted practice in their day; the stop names the experiments without detail. The meaning of the Hebrew *’oph* as “flying creature” is standard in Hebrew lexicons. Haeckel’s embryo drawings were criticized for inaccuracy in his own lifetime; the stop uses only his bat plate, which shows real animals. Safety line: rabies guidance follows the CDC.

PRACTICE

1. **EASY** What does Chiroptera mean, and why is it a good name for bats?
2. **EASY** Who first showed that bats find their way by hearing, and who discovered the ultrasound and named echolocation?
3. **MEDIUM** A bat hears an echo from a moth 0.012 seconds after it calls. Sound travels about 1,125 feet per second. How far away is the moth?
4. **MEDIUM** Why did many scientists in Spallanzani’s day reject his conclusion, and what finally settled the question?
5. **CHALLENGE** A critic says Leviticus 11:19 is a scientific error because it lists the bat among the birds. Write a reply of four sentences using the primary source and the Hebrew word *’oph*.
6. **CHALLENGE** A colony of 10,000 little brown bats loses 90 percent of its members to white-nose syndrome. If each surviving bat raises at most one pup a year and about half the colony is female, roughly how many pups could be born the next year, and why does this make recovery slow?

Make it a game • Bat and Moth. In a clear, safe room or yard, one blindfolded player is the Bat. Two or three others are Moths and must stay inside a marked area. When the Bat calls “Bat!”, every Moth must answer “Moth!” right away. The Bat uses the answers to find and tag a Moth. Give one Moth a “tiger moth” power: once per round it may stay silent. Afterward, talk about how bats use echoes and how some moths fight back.

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. More than 1,400 kinds of bats, each with its own face, call and way of life, are a small part of the riches the psalmist praises.

Practice: answers

1. “Hand-wing.” A bat’s wing is a hand with very long finger bones and a skin membrane stretched between them.
2. Lazzaro Spallanzani (with Louis Jurine’s ear experiments) in the 1790s; Donald Griffin (with Robert Galambos) beginning in 1938, who coined “echolocation” in 1944.
3. Distance = $1,125 \times 0.012 \div 2 = 6.75$ feet, about $6\frac{3}{4}$ feet.
4. No one could hear any sound from flying bats, so hearing seemed impossible and some suggested touch instead. Griffin’s use of an ultrasound detector in 1938 revealed the calls,

proving that bats steer by echoes.

5. Sample: The Hebrew word translated “fowls” is ’oph, from a verb meaning “to fly,” so it means flying creatures, not birds in the modern sense. The list sorts animals by how they live and move, for the purpose of telling Israel which flying creatures not to eat. Modern classification, based on traits such as fur and milk, was not invented until the 1700s, so the text is not trying to use it. Judged by its own purpose, the list is accurate: the bat is a flying creature, and Israel was not to eat it.
6. $10,000 \times 0.10 = 1,000$ bats survive; about 500 are female, so at most about 500 pups a year (fewer, since not all survive). Because bats have only one pup a year, a colony can grow only slowly, so it may take many decades to return to its former size even if the disease stopped.

1.5 HORSES

OBJECTIVES

- Explain how a horse's legs, eyes and digestion are designed for a fast-running grazing animal, using real measurements.
- Read Job 39:19-25 as a primary source and connect its picture of the war horse with what we know of horses in Bible times.
- Tell how Eadweard Muybridge's 1878 photographs settled the question of the gallop and why artists such as George Stubbs and later painters drew horses as they did.

Warm-up. Stand up and walk across the room, then jog, then skip. Notice which feet touch the ground together. Now picture a horse: when it trots, which legs move together? Write your guess. In 1878 a photographer settled an argument about this that had puzzled people for centuries.

Video slot. Video coming. Horse gaits in slow motion (walk, trot, canter, gallop); Eadweard Muybridge's "The Horse in Motion" (1878) animated. Search approved channels (Smithsonian Channel, the Library of Congress, the Kentucky Horse Park, Moody Science Classics); preview first.

KEY TERMS

hoof

The hard, horn-covered tip of a horse's single toe. A horse stands and runs on the equivalent of one fingertip on each leg.

gait

A pattern of leg movement. The four natural gaits of most horses are the walk, trot, canter and gallop.

hand

The unit for measuring a horse's height at the withers (the top of the shoulders). One hand equals 4 inches.

stay apparatus

A system of tendons and ligaments that lets a horse lock its legs and doze standing up without falling.

Thoroughbred

A breed of racehorse developed in England in the 1700s; nearly all Thoroughbreds trace back to three imported stallions, the Byerley Turk, the Darley Arabian and the Godolphin Arabian.

chariot

A light, two-wheeled vehicle pulled by horses, used in war and travel in Bible times by Egypt, Assyria and Israel.

CORE IDEAS

Made to run. A horse is a grazing animal whose first defense is flight. A typical riding horse stands about 15 to 16 **hands** (60 to 64 inches) at the withers and weighs about 1,000 pounds. Its long legs carry almost no muscle below the knee and hock: the lower leg is mostly bone, tendon and ligament, which keeps it light and quick to swing, like the end of a whip. The horse runs on a single toe on each foot, capped by the hoof. Racing Thoroughbreds have been timed at more than 40 miles an hour over a short distance. A horse's heart weighs about 8 to 10 pounds, and its spleen can release a store of extra red blood cells when it gallops.

Eyes and sleep. A horse's eyes are among the largest of any land mammal and are set on the sides of its head, giving it a field of view of roughly 350 degrees. It has blind spots only directly in front of its nose and directly behind it, which is why you should never approach a horse from behind. Horses can doze standing up, using the **stay apparatus** to lock their legs, and they need only a few short spells of deep sleep lying down. A herd usually keeps one horse standing watch while others lie down. Everything about the horse is built for spotting danger early and getting away fast.

The war horse of Job. In Job 39 God asks Job, "Hast thou given the horse strength?" and paints the war horse that "mocketh at fear" and "smelleth the battle afar off." A creature made to flee becomes, under training, one that charges toward the trumpet. The ancient world prized such horses. Egypt's chariots pursued Israel to the Red Sea (Exodus 14). The law warned Israel's kings not to "multiply horses" (Deuteronomy 17:16), because horses meant military power and the temptation to trust it; yet Solomon gathered great stables of chariot horses (1 Kings 10:26-29). Proverbs 21:31 sums up the balance: the horse is prepared for battle, "but safety is of the LORD."

Horses and history. Horses changed how people farmed, traveled, traded and fought on every inhabited continent. Museum signs often date the first domestic horses to the grasslands of Central Asia some five or six thousand years ago; those dates are interpretations based on bones, bridle wear and genetics, and scholars still argue about them. The Spanish brought horses to the Americas in the 1500s, and within two centuries the peoples of the Great Plains had become some of the finest riders in the world. In England in the 1700s, breeders crossed native mares with three imported Eastern stallions to produce the **Thoroughbred**, the racehorse that Stubbs painted.

The question of the gallop. For centuries painters showed galloping horses with all four legs stretched out at once, front legs forward and back legs behind, like a rocking horse. Does a horse ever have all four feet off the ground, and when? In 1878, at Palo Alto, California, the photographer Eadweard Muybridge set up a row of twelve cameras with tripwires along a track. As the mare Sallie Gardner galloped past, the cameras snapped one after another. The pictures showed that a galloping horse does have all four feet off the ground, but with its legs gathered *under* its body, not stretched out. Artists had been painting a pose no horse ever makes. Muybridge's series, *The Horse in Motion*, is also one of the ancestors of the motion picture.

Partners, not machines. Horses are herd animals that read body language closely. A good horseman earns a horse's trust through calm, consistent handling, not fear. Before tractors, horses and mules pulled the plows of nearly every American farm; in 1915 there were about 21 million horses on U.S. farms. Many Amish and Mennonite farmers still work their fields with horses today. The horse in Job is God's own handiwork, and the strength that men harness in it is a gift on loan from Him.

PICTURE STUDY



Whistlejacket, George Stubbs, about 1762 · Oil on canvas · The National Gallery, London
Wikimedia Commons · Public domain

Whistlejacket was a famous racehorse owned by the Marquess of Rockingham, and in 1759 he won a long, hard race at York. George Stubbs (1724–1806) had spent about eighteen months dissecting and drawing horses to learn their anatomy, and he published *The Anatomy of the Horse* in 1766. In this huge picture, almost 10 feet tall, he painted Whistlejacket life-size, rearing, with nothing behind him at all: no rider, no landscape, no stable.

Look closely

- Find the muscles and veins on the shoulder, neck and legs. How does Stubbs's study of anatomy show?
- Look at the eye and nostrils. Compare them with Job 39:20: "the glory of his nostrils is terrible."
- Look at the background. What is missing, and what does that do to the way you see the horse?

Talk about it

1. Why might an artist leave out every background detail in a portrait of an animal?

2. Stubbs painted Whistlejacket rearing, a pose a horse really makes. Elsewhere he and other painters showed galloping horses with legs stretched out, a pose Muybridge later showed to be wrong. Why could even a careful anatomist make that mistake before 1878?

Safety first. Around horses, always have an experienced adult with you. Approach from the side where the horse can see you, speak calmly, and never walk directly behind a horse or stand where it could step on your feet. Wear a properly fitted riding helmet and boots with a heel whenever you ride.

HANDS-ON: THE WAR HORSE AND THE CAMERA: JOB 39 MEETS MUYBRIDGE

Study the horse two ways: through the poetry of the primary source (Job 39:19-25) and through careful observation of motion. You will annotate the text and then make your own gait study.

You will need

- The primary source in this stop
- Muybridge's *The Horse in Motion* (1878): the Library of Congress has the cards online and free
- Plain paper cut into 12 small cards, a pencil and a binder clip (for a flip book)
- Optional: a visit to a farm or stable with a parent, or a slow-motion horse video

Steps

1. Read Job 39:19-25 aloud. In the margin of your notebook, list every action of the horse (paweth, rejoiceth, goeth on, mocketh, swalloweth the ground, saith Ha, ha, smelleth). Beside each, write what real horse behavior it describes.
2. Underline the two questions God asks Job in verses 19-20. Write one sentence on what those questions are meant to teach Job.
3. Study the Muybridge sequence. On a chart, record for each frame which hooves touch the ground. Find the frame where none do. Where are the legs?
4. Draw a simple 12-card flip book of a galloping horse, copying the leg positions from Muybridge. Flip it and watch the gallop.
5. If you can watch a real horse safely with an adult, count the beats of its walk (4) and trot (2) out loud.

Check your work

- I matched each action in Job 39:19-25 to real horse behavior.
- I found the airborne frame and can describe where the legs are.
- My flip book shows a full gallop stride.

FIELD NOTEBOOK

1. **Field page: Horses.** Draw a horse's foreleg from the shoulder down beside your own arm and hand. Label the knee (really the wrist), the cannon bone (your middle-finger bone), the fetlock and the hoof (your fingertip). Write the horse's height in hands and in inches.
2. **Narration (parent keeps).** Without looking back, write one well-built paragraph of eight to ten sentences: "The horse: made to flee, trained to charge." Include at least two design features, one Bible passage about horses, and Muybridge's discovery. Date it and give it to a parent.

Did you know? A horse's "knee" on the front leg is really its wrist, and the joint halfway up its hind leg, the hock, is its ankle. Horses cannot vomit and cannot breathe through their mouths, so a horse's nostrils are its only airway when galloping, which is part of why they flare so wide. A horse's teeth keep growing through much of its life and wear down with grazing; the old saying "long in the tooth" for an old person comes from judging a horse's age by its teeth.

Primary source. *Job 39:19-25, King James Version (1611)*

Hast thou given the horse strength? hast thou clothed his neck with thunder?
Canst thou make him afraid as a grasshopper? the glory of his nostrils is terrible.
He paweth in the valley, and rejoiceth in his strength: he goeth on to meet the
armed men. He mocketh at fear, and is not affrighted; neither turneth he back
from the sword. The quiver rattleth against him, the glittering spear and the
shield. He swalloweth the ground with fierceness and rage: neither believeth he
that it is the sound of the trumpet. He saith among the trumpets, Ha, ha; and he
smelleth the battle afar off, the thunder of the captains, and the shouting.

Go deeper. Marguerite Henry, *King of the Wind* (1948), a novel about the Godolphin Arabian (summarized, not quoted). George Stubbs, *The Anatomy of the Horse* (1766): scans of the plates are free at the Royal Academy and other libraries. The Library of Congress's online collection of Muybridge's *The Horse in Motion*. The National Gallery's web page on *Whistlejacket*. Second video topic: draft horses and how a team pulls a plow.

Goes deeper in. Gardening & Animals, "Horses and Their Care" (coming soon); Art, "George Stubbs and the Animal Portrait" (coming soon); and the Horses track at this site.

For families. Heights, weights and heart weights are typical figures. The top recorded Thoroughbred speed is about 44 miles an hour over a quarter mile. The farm-horse figure (about 21 million in 1915) is from U.S. Department of Agriculture historical counts and refers to horses on farms. Domestication dates are given as museum interpretations; recent genetic studies have argued for later dates than the older Botai figure, and the stop does not choose between them. 1 Kings 4:26 gives forty thousand stalls and 2 Chronicles 9:25 four thousand; many scholars see a copyist's variation, and the stop cites

1 Kings 10 instead. *Whistlejacket* is about 292×246 cm and was bought by the National Gallery in 1997. Safety line included because this is a horse stop.

PRACTICE

1. **EASY** A horse measures 15.2 hands. How tall is it at the withers in inches? (In horse measure, “15.2” means 15 hands and 2 inches.)
2. **EASY** Why should you never walk up directly behind a horse?
3. **MEDIUM** In the primary source, find two phrases that show the war horse’s courage and one that shows its eagerness for battle.
4. **MEDIUM** What did Muybridge’s 1878 photographs prove about the gallop, and why was this important to artists?
5. **CHALLENGE** Deuteronomy 17:16 told Israel’s kings not to “multiply horses,” yet Job 39 praises the horse as God’s glorious work. Explain in four sentences how both can be true, using Proverbs 21:31.
6. **CHALLENGE** In 1915 there were about 21 million horses on U.S. farms. If a horse eats about 20 pounds of hay and grain a day, how many tons of feed did those horses eat in a year? What does this suggest about how much farmland was used to feed horses before tractors?

Make it a game • Name That Gait. One player claps out a horse gait with hands on a table: the walk (four even beats, 1-2-3-4), the trot (two beats, 1-2), the canter (three beats and a pause, 1-2-3, rest) or the gallop (four quick beats and a pause). The others call out the gait. Then switch roles and try it faster.

Scripture. “The horse is prepared against the day of battle: but safety is of the LORD.” (Proverbs 21:31, KJV)

Solomon, who owned thousands of horses, wrote this. Preparing well is wise and right; trusting in our preparations instead of God is not.

Practice: answers

1. $15 \times 4 + 2 = 62$ inches.
2. A horse has a blind spot directly behind it; startled by something it cannot see, it may kick.
3. Courage: “He mocketh at fear, and is not affrighted”; “neither turneth he back from the sword.” Eagerness: “He saith among the trumpets, Ha, ha”; “he smelleth the battle afar off”; or “He swalloweth the ground with fierceness and rage.”
4. That a galloping horse has all four feet off the ground at one moment, but with its legs gathered under its body, not stretched out. Painters had for centuries shown a stretched-out pose that never happens, so his photographs corrected art by observation.
5. Sample: Job 39 shows that the horse’s strength and courage are God’s gifts and display His power. Deuteronomy 17 warns kings not to pile up horses because horses meant military might, and a king could be tempted to trust in chariots instead of God and to lead his people back toward Egypt. The horse itself is good; the danger is in the heart that trusts it. Proverbs

21:31 holds both together: it is right to prepare the horse for battle, "but safety is of the LORD."

6. $21,000,000 \times 20 \times 365 = 153,300,000,000$ pounds, or about 76.65 million tons a year. A very large share of American farmland had to grow feed for the horses themselves; when tractors replaced horses, that land could grow food for people instead.

1.6 WOLVES AND DOGS

OBJECTIVES

- Describe how a wolf pack really works and explain how scientists corrected the popular “alpha wolf” idea.
- Explain why wolves and dogs are one created kind, and how hundreds of breeds can come from it.
- Read John 10:11-13 as a primary source and weigh, with real numbers, the stewardship questions raised by the return of wolves to Yellowstone.

Warm-up. List every dog breed you can name in two minutes. Then sort them into three groups by size: under 20 pounds, 20 to 60 pounds, over 60 pounds. A Chihuahua and a Great Dane look almost nothing alike. Keep your list: by the end of this stop you will know why they still belong to the same kind as the gray wolf.

Video slot. Video coming. Gray wolf packs in Yellowstone National Park; livestock guardian dogs protecting sheep. Search approved channels (Smithsonian Channel, National Geographic, BBC Earth, the National Park Service, Yellowstone Forever); preview first.

KEY TERMS

Canis lupus

The scientific name of the gray wolf. Many scientists name the dog *Canis lupus familiaris*, a form of the same species; others call it *Canis familiaris*.

pack

A wolf family: usually a breeding pair (the parents) and their offspring of the last one to three years.

kind

The Bible’s word for the groups God created to reproduce “after his kind” (Genesis 1). Creation biologists often treat animals that can interbreed as belonging to one created kind.

breed

A group of dogs (or other domestic animals) selected by people over many generations for a particular look or skill.

selective breeding

Choosing which animals become parents in order to strengthen certain traits, such as herding, guarding or small size.

livestock guardian dog

A large dog raised from a pup among sheep or goats that lives with the flock and drives off wolves, coyotes and other predators.

CORE IDEAS

The gray wolf. The gray wolf is the largest wild member of the dog family. Males in North America usually weigh about 80 to 110 pounds, females somewhat less. A wolf can travel 30 miles in a day at a steady trot and can run in bursts at more than 35 miles an hour. Its huge feet act like snowshoes, and its sense of smell is perhaps a hundred times keener than ours. Wolves hunt deer, elk, moose and bison, often testing a herd by chasing it and watching for the animal that is slow, old, young or sick. Most hunts fail. A pack's territory may cover anywhere from about 50 to more than 1,000 square miles, depending on how much prey there is, and its howling helps the pack find one another and warns rival packs away.

Correcting the "alpha." Many people have heard that wolf packs are ruled by an "alpha" that fights its way to the top. That idea came largely from studies in the 1940s of unrelated wolves crowded together in a zoo, and it was spread by a popular 1970 book by the wolf biologist L. David Mech. But after years of watching wild wolves on Ellesmere Island in the Canadian Arctic, Mech himself published a paper in 1999 explaining that the idea was misleading. A wild pack is simply a family: a mother and father and their young, who stay a few years and then leave to start packs of their own. The "leaders" are the parents. Mech has spent years asking people to stop using the old word. It is a fine example of a scientist correcting his own earlier teaching when better evidence came.

One kind, many breeds. Wolves and dogs can interbreed and have fertile young, and their DNA is very similar. For that reason many scientists treat the dog as a domestic form of the wolf, and creation biologists count wolves, dogs, coyotes and jackals, which can also interbreed, within one created dog kind. The amazing variety of dogs, from the 4-pound Chihuahua to the 150-pound mastiff, came from people choosing which dogs would become parents, generation after generation: **selective breeding**. Most of the breeds we know were developed in only the last few hundred years. The American Kennel Club recognizes about 200 breeds. This variety within a kind is real change, and it shows how much God built into the original kind; but it never turned a dog into anything other than a dog.

Dogs and people. Dogs have lived with people since very early times; ancient burials sometimes show a person laid to rest beside a dog, and museum signs give early dates for this that rest on interpretation. In the Bible, dogs are mostly half-wild scavengers in the streets (1 Kings 21:19; Psalm 59:6), but Job speaks of "the dogs of my flock" (Job 30:1), and later Christian art often shows the faithful dog as a picture of loyalty. Dogs herd, guard, hunt, pull sleds, lead the blind, find lost hikers and sniff out danger. Their skill at reading human faces and pointing gestures is unusual among animals.

The wolf and the shepherd. To a shepherd in Bible lands, the wolf was a real enemy. Jesus used this when He called Himself the good shepherd who "giveth his life for the sheep," unlike the hired man who "seeth the wolf coming, and leaveth the sheep" (John 10:11-12). He warned of false prophets who are "ravening wolves" in sheep's clothing (Matthew 7:15). Isaiah looks ahead to a day when "the wolf also shall dwell with the lamb" (Isaiah 11:6). Even today, shepherds in Turkey, the Pyrenees, Italy and the American West protect flocks with **livestock guardian dogs**: a dog guarding sheep against its own wild relative.

Wolves return to Yellowstone. By the 1930s, wolves had been hunted and trapped out of nearly all of the lower 48 states except northern Minnesota, often with government bounties, because they killed cattle and sheep. In 1995 and 1996, 31 wolves from Canada were released in Yellowstone National Park, and 10 more from Montana followed in 1997. The park's elk herd, which had grown very large, fell and changed its grazing habits, and some studies report that willows and aspens recovered along some streams, though scientists still debate how much of that was due to wolves. Outside the park, ranchers have lost cattle and sheep to wolves, and states now manage wolf numbers with hunting seasons. Honest stewardship weighs both the good of the wolf in God's creation and the good of the families who live by their flocks.

PICTURE STUDY



Dignity and Impudence, Sir Edwin Landseer, 1839 · Oil on canvas · Tate Britain, London
Wikimedia Commons · Public domain

Sir Edwin Landseer (1802-1873) was the most famous animal painter of Victorian Britain and a favorite of Queen Victoria. He was so admired for painting dogs that people said he could make them almost speak. This painting shows a bloodhound named Grafton and a little West Highland-type terrier named Scratch, belonging to Landseer's friend Jacob Bell, peering out of the same kennel. The title tells you which is which.

Look closely

- Compare the two heads: the size, the ears, the eyes, the mouths. Which is "Dignity" and which is "Impudence"?
- Look at the bloodhound's loose skin and long ears. A bloodhound's ears and wrinkles may help gather scent toward the nose. What was this breed developed to do?
- Look at the wood, the straw and the fur. How does Landseer show different textures?

Talk about it

1. These two dogs belong to the same species as the gray wolf. Which features of each still look like a wolf, and which were changed by breeding?
2. Landseer gives his dogs human-sounding personalities. Is that good observation, good storytelling, or both?

HANDS-ON: THE SHEPHERD'S PROBLEM: A STEWARDSHIP CASE STUDY

Read the primary source (John 10:11-13) and then work through a real stewardship problem: wolves near a sheep ranch. You will gather facts, weigh choices and write a recommendation the way a county planner or a ranch family would.

You will need

- The primary source in this stop and a KJV Bible
- The National Park Service's Yellowstone wolf pages or a state wildlife agency's wolf management page (free online)
- A Field Notebook page divided into four boxes

Steps

1. Read John 10:11-13. In box 1, list what the good shepherd does and what the hireling does when the wolf comes. What makes the difference between them?
2. In box 2, write five facts about wolves from this stop that a sheep rancher would need to know (pack size, travel distance, prey, hunting habits).
3. In box 3, list four ways to protect sheep: livestock guardian dogs, night corrals, range riders who stay with the herd, and removing a wolf that keeps killing livestock. For each, write one strength and one cost.
4. In box 4, write a one-paragraph recommendation for a ranch family near Yellowstone. Explain how your plan cares for the flock, the family's living and the wolf as part of creation.
5. Underline the sentence in your recommendation that most reflects the good shepherd of John 10.

Check your work

- I compared the shepherd and the hireling using the words of the primary source.
- I listed at least four ways to protect sheep, each with a strength and a cost.
- My recommendation is fair to both the rancher and the wolf.

FIELD NOTEBOOK

1. **Field page: Wolves and dogs.** Draw a gray wolf's head and a dog's head (your own dog or a breed you like) side by side. Label five features: ears, muzzle, eyes, teeth, coat. Circle the ones that changed with breeding. Add a simple family-tree diagram of a wolf pack: two parents and their pups of three years.

2. **Narration (parent keeps).** Without looking back, write one well-built paragraph of eight to ten sentences: “Wolf and dog: one kind, two lives.” Include how a pack really works, Mech’s correction, how breeds are made, and at least two numbers. Date it and give it to a parent.

Did you know? The wolves of Isle Royale, an island in Lake Superior, have been studied every winter since 1958, the longest-running study of predators and prey in the world. Wolves first reached the island, scientists believe, by walking across an ice bridge from Canada in the late 1940s. A dog’s nose has up to about 300 million scent receptors, compared with about 6 million in a person.

Primary source. *John 10:11-13, King James Version (1611)*

I am the good shepherd: the good shepherd giveth his life for the sheep. But he that is an hireling, and not the shepherd, whose own the sheep are not, seeth the wolf coming, and leaveth the sheep, and fleeth: and the wolf catcheth them, and scattereth the sheep. The hireling fleeth, because he is an hireling, and careth not for the sheep.

Go deeper. L. David Mech, “Alpha Status, Dominance, and Division of Labor in Wolf Packs,” *Canadian Journal of Zoology* (1999), short and readable for a strong student. Jack London, *White Fang* (1906), a classic novel of a wolf-dog (some violent scenes; parents preview). The National Park Service’s Yellowstone wolf pages and the Isle Royale wolf-moose project website. Second video topic: how sheepdogs are trained to herd.

Goes deeper in. Life Science, high school “Biology: Heredity and Created Kinds” (coming soon); and Gardening & Animals, “Dogs: Breeds, Training and Care” (coming soon).

For families. Wolf weights, ranges and speeds are typical figures. The Yellowstone numbers (14 wolves in 1995, 17 in 1996, 10 from Montana in 1997) are from the National Park Service. The “trophic cascade” claim (wolves → fewer elk → more willows) is disputed among scientists, and the stop says so. Mech’s 1999 paper and his later public statements are the source for the “alpha” correction. The “dog kind” is a creation-biology category; the stop explains it as such alongside the common scientific view that the dog is a domestic form of the wolf. Museum dates for the first domestic dogs are interpretations and are not given here. Picture: Landseer, *Dignity and Impudence*, Tate (given by Jacob Bell, 1859).

PRACTICE

1. **EASY** What is a wild wolf pack made of?
2. **EASY** In the primary source, what does the hireling do when he sees the wolf coming, and why?

3. **MEDIUM** How many wolves were released in Yellowstone in 1995, 1996 and 1997 together? If the population later reached about 100 in the park, by what factor did it grow?
4. **MEDIUM** Why did the early “alpha wolf” studies give a misleading picture of wild packs?
5. **CHALLENGE** A friend says, “The hundreds of dog breeds prove that animals can change into anything over time.” Write a careful reply of four or five sentences.
6. **CHALLENGE** Some scientists say Yellowstone’s wolves caused willows to recover by reducing elk; others say drought, bears, hunting outside the park and other factors explain much of it. Explain why this is hard to prove and what kind of evidence would help.

Make it a game · Shepherd, Guardian and Wolf. Play outside. One player is the Shepherd, one the Guardian Dog, and one or two are Wolves; everyone else is a sheep in a marked pasture. Wolves try to tag sheep and lead them out to their “den.” The Guardian Dog may tag a Wolf to send it back to the edge for a count of ten. The Shepherd may free one captured sheep at a time by walking it back. Switch roles each round and talk about John 10:11.

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)

Today shepherds must guard sheep from wolves. Isaiah looks forward to the reign of the Messiah, when that enmity will end. Christians pray and work as stewards while they wait for that day.

Practice: answers

1. A family: a breeding pair (the parents) and their young from the last one to three years.
2. He leaves the sheep and flees, “because he is an hireling, and careth not for the sheep.”
3. $14 + 17 + 10 = 41$ wolves. $100 \div 41 \approx 2.4$, so about two and a half times.
4. They watched unrelated adult wolves crowded together in captivity, which caused fighting for rank. Wild packs are families in which the parents lead naturally.
5. Sample: Dog breeds do show real and impressive change, and they show how much variety God built into the dog kind. But that change came from people choosing parents over many generations, sorting and concentrating traits already present. After all of it, every breed is still a dog, able to interbreed with wolves; none has become a different kind of animal. Many breeds also carry health problems from narrow breeding, which shows that selection often removes variety rather than adding new abilities. So dog breeding is evidence of variation within a kind, not of one kind changing into another.
6. Sample: Many things changed at the same time: wolves returned, but grizzly bears and cougars also increased, droughts came and went, and elk were hunted when they left the park. In a single national park there is no second, identical Yellowstone without wolves to compare. Evidence that would help includes long-term measurements of willow height and elk browsing at many sites, fenced plots that keep elk out, comparisons with nearby areas

without wolves, and careful counts of each predator. Honest scientists say how sure they are and do not claim more than the evidence shows.

1.7 BEARS

OBJECTIVES

- Name the eight living kinds of bears and explain, with real numbers, how a bear survives months of winter denning without eating or drinking.
- Read 1 Samuel 17:34-37 as a primary source and explain how David used his past experience with a lion and a bear as an argument from God's faithfulness.
- Tell the true story behind the teddy bear (1902) using a primary-source cartoon, and describe how grizzlies and black bears have been managed and protected.

Warm-up. Imagine you had to go five months without eating, drinking or getting up to use the bathroom, and then come out in spring strong enough to walk miles. Write down what you think would happen to your muscles and bones. Keep your answer: a black bear does exactly this every winter, and scientists are still studying how.

Video slot. Video coming. Black bears in winter dens; grizzly bears catching salmon; polar bears on sea ice. Search approved channels (Smithsonian Channel, National Geographic, BBC Earth, the National Park Service, Katmai National Park's bear cams at explore.org); preview first.

KEY TERMS

Ursidae

The bear family. Its eight living species are the American black bear, brown bear (including the grizzly), polar bear, Asiatic black bear, sun bear, sloth bear, spectacled bear and giant panda.

denning

Spending the winter in a den in a deep, energy-saving sleep. Many scientists call it hibernation; others reserve that word for animals whose body temperature drops much further.

delayed implantation

A pause in which a fertilized egg waits for months before it attaches in the womb and begins to grow. In bears it lets cubs be born in the den in midwinter.

hyperphagia

A season of heavy eating in late summer and fall, when a bear may eat 20,000 calories a day or more to store fat for winter.

omnivore

An animal that eats both plants and animals. Most bears are omnivores and eat far more berries, nuts, roots and grass than meat.

threatened species

Under the U.S. Endangered Species Act, a species likely to become endangered in the near future. Grizzlies in the lower 48 states were listed as threatened in 1975.

CORE IDEAS

Eight bears. There are eight living species of bears, found in North and South America, Europe and Asia. They range from the sun bear of Southeast Asia, which may weigh under 100 pounds and has a long tongue for licking honey and insects from logs, to the polar bear, the largest land carnivore, whose males often weigh 800 to 1,300 pounds. The American black bear is by far the most common bear in North America, with perhaps 800,000 or more across the continent. Despite their reputation, most bears eat mostly plants: berries, acorns, roots, grass and insects. Only the polar bear lives almost entirely on meat, chiefly seals.

The bear of the Bible. The bear David fought was the Syrian brown bear, a lighter-colored relative of the grizzly that once lived in the hills of Lebanon and Israel and survived there into the early twentieth century. Scripture uses the bear above all as a picture of fury: Hushai warns Absalom that David's men are "as a bear robbed of her whelps in the field" (2 Samuel 17:8), and Proverbs says it would be better to meet such a bear than "a fool in his folly" (Proverbs 17:12). A mother bear defending her cubs is one of the most dangerous animals in the world, and every ranger in bear country still warns hikers never to come between a sow and her cubs.

Five months in the dark. In the fall, bears enter **hyperphagia**, eating almost constantly to build a thick layer of fat. Then, in a hollow log, rock cave or hole under a tree, a northern black bear may den for five to seven months. Its heart rate drops from about 40 to 50 beats a minute to as few as 8 to 19, and its breathing slows to a few breaths a minute; its body temperature falls only several degrees, so it can wake quickly if disturbed. It does not eat, drink, urinate or defecate. Instead of making waste, its body recycles urea, a waste product, back into protein, so it loses little muscle; and its bones stay strong even though it barely moves. A bear may lose a quarter to a third of its body weight over the winter. Doctors study bears for clues to treating kidney disease and the bone loss of bedridden patients.

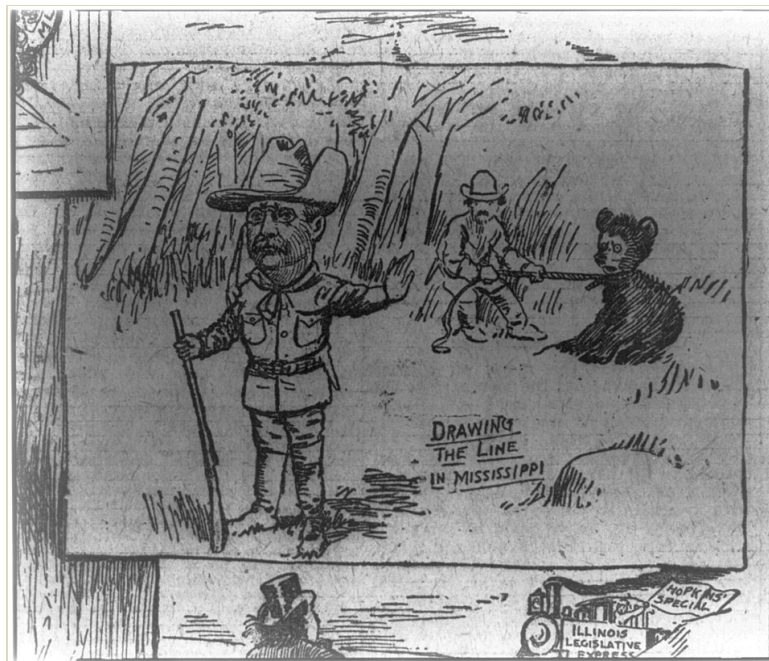
Born in the den. Bears mate in early summer, but the tiny embryo does not attach and begin to grow until the fall, through **delayed implantation**; if the mother is too thin, it may not grow at all. Cubs are born in January or February while the mother is denning. A newborn black bear cub weighs only about half a pound to a pound, has closed eyes and almost no fur, and nurses on the mother's rich milk while she sleeps. By the time they leave the den in spring, cubs weigh 5 to 10 pounds. They stay with their mother for about a year and a half, learning where to find food in every season.

The teddy bear. In November 1902, President Theodore Roosevelt went bear hunting in Mississippi. His guide, Holt Collier, a famous bear hunter, cornered an old black bear and tied it to a tree so the president could shoot it. Roosevelt refused, saying it would be unsportsmanlike to shoot a tied animal, and ordered it put out of its misery instead. Two days later the cartoonist Clifford Berryman drew the scene for the *Washington Post*: "Drawing the Line in Mississippi." In Brooklyn, a shopkeeper named Morris Michtom and his

wife Rose made a stuffed toy bear and called it “Teddy’s bear”; at about the same time the Steiff company in Germany began making jointed toy bears. The teddy bear has been a favorite toy ever since.

Bears and stewardship. Grizzly bears once ranged across the West from Mexico to Canada; by the 1970s about a thousand or fewer remained in the lower 48 states, and in 1975 they were listed as threatened. Today there are around 2,000, mostly around Yellowstone and Glacier National Parks. Black bears, once rare in much of the eastern United States, have returned to many states with good forest management and hunting seasons. Most bear trouble today begins with human food: a bear that learns to raid garbage cans and campsites often has to be moved or killed. As rangers say, “A fed bear is a dead bear.” Keeping a clean camp is a small, real way to care for God’s creatures.

PICTURE STUDY



Drawing the Line in Mississippi, Clifford K. Berryman, 1902 · Pen and ink cartoon, published in the Washington Post · Library of Congress, Prints and Photographs Division
Wikimedia Commons · Public domain

Clifford Berryman (1869–1949) drew cartoons for Washington newspapers for more than fifty years. This one appeared on November 16, 1902, two days after Roosevelt refused to shoot the tied bear. Its title has a double meaning: Roosevelt was also in Mississippi to help settle a border dispute between Mississippi and Louisiana. In later cartoons Berryman made the bear smaller and cuter, and it became his trademark, the “Teddy bear.” The cartoon is a primary source: it shows how the story was told to the public in its own week.

Look closely

- Find Roosevelt’s raised hand. What is he saying with it?

- Look at the bear. How does Berryman make you feel about it, and how does that compare with a real adult black bear?
- Find the title and any words in the cartoon. What are the two “lines” being drawn?

Talk about it

1. A cartoon is not a photograph. What did Berryman change or simplify to make his point quickly?
2. Why do you think a small act of fair play by a president became so popular that it gave its name to a toy?

Safety first. Never approach, feed or follow a bear. In bear country, hike in groups, make noise, keep food sealed and away from tents, and carry bear spray where rangers recommend it. Follow the posted rules of the park.

HANDS-ON: PAST FAITHFULNESS, PRESENT COURAGE: READING DAVID’S ARGUMENT

In the primary source (1 Samuel 17:34–37), David gives Saul an argument for why he can face Goliath. Analyze its structure, connect it with real bear behavior, and then write your own “record of faithfulness” page.

You will need

- The primary source in this stop and a KJV Bible open to 1 Samuel 17
- Three colored pencils
- A Field Notebook page

Steps

1. Read 1 Samuel 17:34–37 aloud. In color 1, underline what David did (his past actions). In color 2, underline what David says the LORD did. In color 3, underline what David expects to happen next.
2. Write David’s argument as three numbered steps: (1) what happened before, (2) who really did it, (3) therefore what will happen now.
3. From this stop, list three facts about bears that show how dangerous it was for a shepherd boy to take a lamb back from one (size, a mother’s defense of cubs, strength). Why did David tell Saul about a lion and a bear and not about something easier?
4. Write a short paragraph: “Why David’s argument is not boasting.” Use the words “The LORD that delivered me.”
5. Optional: on the back, make your own family “record of faithfulness,” listing three times God has helped your family, the way David remembered the lion and the bear.

Check your work

- I marked David’s actions, God’s actions and David’s expectation in three colors.
- I wrote David’s argument in three clear steps.

- I explained why David’s words are trust in God, not boasting.

FIELD NOTEBOOK

1. **Field page: Bears.** Draw a cross-section of a black bear den under a fallen tree with the mother curled inside and two tiny cubs. Around it, write five numbers from this stop: winter heart rate, months in the den, weight loss, cub birth weight, cub weight in spring.
2. **Narration (parent keeps).** Without looking back, write one well-built paragraph of eight to ten sentences: “How a bear survives the winter.” Include hyperphagia, the slowed heart, urea recycling, delayed implantation and the birth of cubs, with at least three numbers. Date it and give it to a parent.

Did you know? A polar bear’s fur is not white. Each hair is transparent and hollow, and it looks white because it scatters light, the way snow does. Underneath, the bear’s skin is black. A grizzly’s sense of smell is thought to be several times keener than a bloodhound’s, and the big hump on its shoulders is solid muscle used for digging.

Primary source. *1 Samuel 17:34–37, King James Version (1611)*

And David said unto Saul, Thy servant kept his father’s sheep, and there came a lion, and a bear, and took a lamb out of the flock: And I went out after him, and smote him, and delivered it out of his mouth: and when he arose against me, I caught him by his beard, and smote him, and slew him. Thy servant slew both the lion and the bear: and this uncircumcised Philistine shall be as one of them, seeing he hath defied the armies of the living God. David said moreover, The LORD that delivered me out of the paw of the lion, and out of the paw of the bear, he will deliver me out of the hand of this Philistine. And Saul said unto David, Go, and the LORD be with thee.

Go deeper. Enos Mills, *The Grizzly, Our Greatest Wild Animal* (1919), by the naturalist who helped found Rocky Mountain National Park (public domain; look for free library or online copies). The Library of Congress’s online collection of Clifford Berryman cartoons. The National Park Service’s bear safety pages and Katmai National Park’s live bear cams (seasonal). Second video topic: polar bears hunting seals on the sea ice.

Goes deeper in. Life Science, high school “Biology: Mammals and Ecosystems” (coming soon); and History, “The Progressive Era and Theodore Roosevelt” (coming soon).

For families. Heart rates, weight loss and denning times are typical ranges from studies of black bears; they vary with region and season. Black bear and grizzly numbers are rounded estimates from the U.S. Fish and Wildlife Service and state agencies. Whether bears truly “hibernate” is a question of definition; the stop explains both uses. The 1902 hunt took place near Onward, Mississippi, on November 14; the bear had been injured by dogs and was put down at Roosevelt’s order. Holt Collier had been born into slavery and

later became one of the best-known hunters and guides of the Delta; the stop names him with respect. The Syrian brown bear disappeared from the land of Israel in the early 1900s; exact dates vary by source. The cartoon is in the public domain (Library of Congress, LCCN 2008678324).

PRACTICE

1. **EASY** Name four of the eight living species of bears.
2. **EASY** In the primary source, what two animals did David fight, and whom does he say delivered him?
3. **MEDIUM** A 300-pound black bear loses 30 percent of its body weight while denning for 150 days. How many pounds does it lose in all, and how much on average per day?
4. **MEDIUM** How does delayed implantation help a mother bear and her cubs?
5. **CHALLENGE** Is the Berryman cartoon a reliable primary source for what happened on the 1902 hunt? Explain what it can and cannot tell a historian.
6. **CHALLENGE** Grizzlies in the lower 48 states grew from about 1,000 or fewer in 1975 to about 2,000 today. What average yearly growth rate (to the nearest tenth of a percent) would double a population in about 50 years? Then name one reason growth can be slow for bears.

Make it a game • Clean Camp Inspection. A parent sets up a pretend campsite indoors or in the yard with ten “bear attractants” hidden around it: a candy wrapper, toothpaste, a granola bar, a cooler, a frying pan, sunscreen and so on. Players have three minutes to find them and put each in the “bear box” (a closed bin). Score one point for each item found and lose two for each still out when time is up. Talk about why a fed bear is in danger.

Scripture. “Let a bear robbed of her whelps meet a man, rather than a fool in his folly.” (Proverbs 17:12, KJV)

Solomon used the most dangerous animal a traveler in Israel could meet, a mother bear who has lost her cubs, to show how harmful foolishness is. Wisdom guards us from worse dangers than bears.

Practice: answers

1. Any four: American black bear, brown bear (grizzly), polar bear, Asiatic black bear, sun bear, sloth bear, spectacled bear, giant panda.
2. A lion and a bear. “The LORD that delivered me out of the paw of the lion, and out of the paw of the bear.”
3. $300 \times 0.30 = 90$ pounds; $90 \div 150 = 0.6$ pounds a day.
4. The embryo waits until fall to begin growing, so cubs are born in the safety of the den in midwinter, and if the mother has not stored enough fat, the pregnancy may not continue, sparing her strength.

5. Sample: It is a reliable source for how the event was presented to the public within two days, and it confirms the main point that Roosevelt refused to shoot a captured bear. But a cartoon simplifies and exaggerates to make a point: the bear is drawn small and pitiful, and other people and details are left out. It does not show that the bear was injured or that it was put down afterward. A historian would compare it with newspaper reports, letters and the accounts of people who were there.
6. Using the rule of 70, doubling time $\approx 70 \div \text{rate}$, so rate $\approx 70 \div 50 = 1.4$ percent a year. Bear growth is slow because females do not breed until about five years old, have small litters, and keep cubs for two years or more before breeding again; many bears also die from conflicts with people.

1.8 CHEETAHS, THE FASTEST RUNNER

OBJECTIVES

- Explain, with real measurements, how the cheetah's spine, claws, tail, heart and lungs are designed for speed, and why its hunts are so short.
- Use the record run of the cheetah Sarah (2012) and field studies with GPS collars to calculate speeds and compare them with the fastest human sprinters.
- Read Habakkuk 1:8 as a primary source, describe the cheetah's long history with people from the Mughal emperors to modern conservation, and apply Ecclesiastes 9:11.

Warm-up. With a parent, measure 100 meters (about 109 yards) on a field or quiet path. Time yourself running it, and write down your time. Usain Bolt's world record is 9.58 seconds. A cheetah named Sarah ran it in 5.95. Keep your time for the practice questions.

Video slot. Video coming. Cheetah running in slow motion (the Cincinnati Zoo and National Geographic filmed Sarah in 2012); cheetah hunting on the African savanna. Search approved channels (Smithsonian Channel, National Geographic, BBC Earth, the Cincinnati Zoo, the Cheetah Conservation Fund); preview first.

KEY TERMS

Acinonyx jubatus

The scientific name of the cheetah. It is the only living member of its genus and differs from the other big cats in many ways.

semi-retractable claws

Claws that can be pulled back only partly. A cheetah's blunt, always-exposed claws grip the ground like the spikes of a running shoe.

acceleration

How quickly speed increases. A cheetah's ability to speed up, slow down and turn quickly matters more in a hunt than its top speed.

stride

The distance covered in one full cycle of the legs. A cheetah at full speed covers about 20 to 25 feet in a stride.

genetic bottleneck

A time when a population becomes very small, leaving the survivors with little genetic variety. Cheetahs are unusually alike in their genes.

tear marks

The black lines running from the inner corners of a cheetah's eyes to its mouth. They may cut glare from the sun, like the black under a ballplayer's eyes.

CORE IDEAS

A body built for speed. Every part of the cheetah seems shaped for one purpose. It is light for a big cat, usually about 75 to 140 pounds, with long, thin legs, a small head and a deep chest. Its spine is unusually flexible: at full gallop it bends and stretches like a spring, letting the back legs reach far ahead of the front legs and pushing the stride to about 20 to 25 feet. At top speed a cheetah takes about three strides a second and for much of each stride has no feet on the ground at all. Its blunt claws stay partly out, gripping the earth like cleats, and hard pads on its feet act like tire treads. Large nostrils, lungs and heart pump extra oxygen. A long, flattened tail works as a rudder and counterweight, swinging to balance the cat in sharp turns.

How fast? Wild cheetahs are hard to time. In 2012, at the Cincinnati Zoo's breeding center in Ohio, an eleven-year-old cheetah named Sarah chased a lure along a measured 100-meter track and ran it in 5.95 seconds, reaching about 61 miles an hour (98 km/h); that is her world record for a land mammal over 100 meters. In 2013 a team led by Alan Wilson fitted wild cheetahs in Botswana with GPS collars and recorded hundreds of hunts. The fastest speed they measured was about 58 miles an hour, but most hunts were run much slower. What stood out was not top speed but **acceleration** and agility: cheetahs could gain or lose several miles an hour in a single stride and turn sharply at high speed, far more than a racehorse or greyhound.

A short sprint. A cheetah stalks to within about 50 to 100 yards of a gazelle or impala, then explodes into the chase. Most chases last under a minute and cover only a few hundred yards. For years books said cheetahs stopped because they overheated. A 2013 study that measured the body temperature of wild cheetahs found that it barely rose during the chase and climbed afterward, probably from stress, so the overheating explanation is now doubted. More likely, the sprint simply burns energy so fast that it cannot last. After a kill, the cheetah must pant to recover for many minutes, and lions, hyenas or leopards often steal its meal. A cheetah is fast, but it is not strong, and it rarely fights for its food.

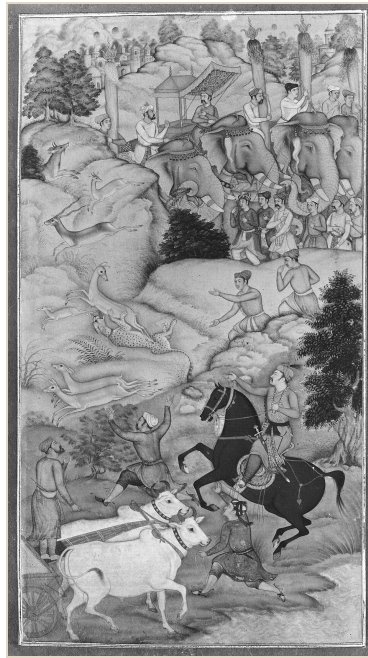
Cheetahs and kings. Cheetahs are easily tamed, and for thousands of years kings kept them for hunting. Egyptian art shows tame cheetahs on leashes. In Mughal India, the emperor Akbar, who ruled from 1556 to 1605, kept great numbers of hunting cheetahs; court accounts speak of hundreds at a time, some say a thousand. Hooded cheetahs rode to the hunt on carts or horseback and were released when the antelope were near. Because cheetahs rarely breed in captivity without special care, the emperors kept capturing wild ones, and that hunger for cheetahs helped drive them out of India. The last wild Asiatic cheetahs of India were reported shot in the late 1940s, and today only a few dozen survive in Iran. In 2022 India brought cheetahs from Namibia to Kuno National Park in an effort to restore them.

Few and much alike. About 7,000 cheetahs are estimated to live in the wild, most of them in southern and eastern Africa, and almost all outside protected parks, on farms and ranches. Cheetahs have remarkably little genetic variety; skin grafts from one unrelated cheetah to another were accepted in a famous experiment, as if they were twins. Scientists

explain this as a past **genetic bottleneck**. Low variety can make cheetahs vulnerable to disease. Farmers who lose goats to cheetahs once shot them freely. In Namibia, the Cheetah Conservation Fund, founded in 1990, has given hundreds of Anatolian shepherd guardian dogs to farmers; the dogs scare cheetahs away from the herds, and farmers who use them kill far fewer cheetahs.

Swift, but not sovereign. Ecclesiastes 9:11 says that “the race is not to the swift.” The cheetah, the fastest runner God made, loses most of its races and many of its meals. Speed is a real gift, but it does not guarantee success, and no creature controls “time and chance.” The verse is not a call to give up running but a reminder that the outcome is in God’s hands.

PICTURE STUDY



Akbar Hunting with Cheetahs, folio from an Akbarnama, Attributed to Manohar, about 1604 · Ink, opaque watercolor and gold on paper · The Metropolitan Museum of Art, New York
Wikimedia Commons · CC0

The *Akbarnama*, “the Book of Akbar,” is the official history of the Mughal emperor Akbar, written by his courtier Abu’l Fazl in the 1590s. Akbar had his court painters illustrate it richly. This page, attributed to the painter Manohar, shows the emperor hunting with trained cheetahs. Mughal painters worked in tiny, careful brushstrokes, often with gold, and filled every part of the page with life.

Look closely

- Find the cheetahs. How can you tell them from leopards? (Look for single spots rather than rosettes, the slim body and the tear marks.)
- Find the emperor. How does the painter show who is most important?
- Look at the antelope. How does the painter show speed and fear?

Talk about it

1. This picture was made for an emperor, to show his power. What does it tell a historian about how cheetahs were used, and what might it exaggerate?
2. The demand for hunting cheetahs at courts like Akbar's helped empty India of wild cheetahs. What does that teach about using a creature well and using it up?

HANDS-ON: CLOCK THE CHEETAH: SPEED, STRIDE AND SCRIPTURE

Use real data to compare your own sprint with Sarah's record and with Usain Bolt's, convert between units, and then read the primary source (Habakkuk 1:8) to see how the prophet used the speed of the spotted cats.

You will need

- A tape measure, a stopwatch and a helper
- A safe, flat 100-meter (or 50-meter) course
- Graph paper and a calculator
- The primary source in this stop

Steps

1. Run 100 meters (or 50) twice and record your best time. Count your strides on one run.
2. Calculate your average speed in meters per second (distance $\div$ time) and in miles an hour (multiply meters per second by 2.237). Do the same for Bolt (100 m in 9.58 s) and for Sarah (100 m in 5.95 s).
3. Find your average stride length (distance $\div$ strides). Compare it with a cheetah's stride of about 7 meters (23 feet).
4. Make a bar graph of the three average speeds. Under it, write two sentences explaining what in the cheetah's design makes the difference.
5. Read Habakkuk 1:8. The prophet compares the Chaldean army's horses to leopards, wolves and eagles. Write one sentence on what each comparison was meant to make Judah feel.

Check your work

- I calculated three speeds in two units correctly.
- My bar graph has a title, labeled axes and units.
- I explained what Habakkuk's animal comparisons meant.

FIELD NOTEBOOK

1. **Field page: Cheetahs.** Draw a cheetah at full stretch and again with its legs gathered under it, as in two frames of a running film. Label the flexible spine, the tail, the claws, the deep chest and the tear marks. Write Sarah's record under it.
2. **Narration (parent keeps).** Without looking back, write one well-built paragraph of eight to ten sentences: "Why the fastest runner often loses the race." Include three

design features, the Botswana collar study, the theft of kills by lions and hyenas, and Ecclesiastes 9:11. Date it and give it to a parent.

Did you know? Cheetahs cannot roar. They chirp like birds, purr loudly, and make a stuttering “churr” sound. Cheetah cubs have a thick, smoky-gray mantle of fur down their backs for their first few months, which may make them look like the fierce honey badger and help protect them from predators. Unlike lions, cheetahs hunt mostly by day, when bigger predators are resting.

Primary source. *Habakkuk 1:8, King James Version (1611)*

Their horses also are swifter than the leopards, and are more fierce than the evening wolves: and their horsemen shall spread themselves, and their horsemen shall come from far; they shall fly as the eagle that hasteth to eat.

Go deeper. Joy Adamson, *The Spotted Sphinx* (1969), the true story of the cheetah Pippa (summarized, not quoted). The Cheetah Conservation Fund (cheetah.org) and the Smithsonian’s National Zoo pages on cheetahs. The Metropolitan Museum of Art’s online pages on the *Akbarnama*. Second video topic: livestock guardian dogs protecting goats from cheetahs in Namibia.

Goes deeper in. Life Science, high school “Biology: Mammals and Ecosystems” (coming soon); Arithmetic, “Rates, Speed and Unit Conversion” (coming soon); and History, “The Mughal Empire” (coming soon).

For families. Sarah’s record (5.95 seconds for 100 m, June 20, 2012) is from the Cincinnati Zoo and Guinness World Records. The wild-speed and acceleration figures are from Wilson and others, *Nature* (2013); the body-temperature finding is from Hetem and others, *Biology Letters* (2013). The wild population estimate (about 7,100) is from Durant and others (2017); the IUCN has given about 6,600 adults. Akbar’s numbers come from court sources and are probably exaggerated, so the stop gives them as reports. The Hebrew word in Habakkuk 1:8, *namer*, means “leopard”; the KJV says “leopards,” and the stop does not claim the verse refers to cheetahs. The cheetah’s genetic sameness is described in Stephen O’Brien’s studies of the 1980s; the stop does not give museum dates for the bottleneck.

PRACTICE

1. **EASY** Name three features of the cheetah’s body designed for speed.
2. **EASY** In the primary source, what three animals does Habakkuk compare the Chaldean army to?
3. **MEDIUM** Sarah ran 100 meters in 5.95 seconds; Usain Bolt ran it in 9.58 seconds. Find each average speed in meters per second, and how far behind Sarah Bolt would be when she crossed the line.
4. **MEDIUM** Why do scientists now doubt that cheetahs stop chasing because they overheat?

5. **CHALLENGE** A cheetah at top speed takes about 3 strides a second with a stride of about 7 meters. What speed is that in meters per second and miles an hour ($1 \text{ m/s} \approx 2.237 \text{ mph}$)? If only about half of a cheetah's hunts succeed and lions or hyenas steal some of the rest, what does this say about Ecclesiastes 9:11?
6. **CHALLENGE** Most wild cheetahs live on private farmland, not in parks. Write a four-sentence plan for protecting them that a Namibian goat farmer would accept, using what you learned in this stop.

Make it a game • Sprint and Steal. Play outside. The Cheetah stands 10 steps from a beanbag “gazelle” and races a second player, the Gazelle, who starts 5 steps away and runs to a safe line. If the Cheetah grabs the beanbag first, it must then count to five out loud to “catch its breath” while a third player, the Hyena, walks (no running) from 15 steps away to try to snatch it. Rotate roles and count how many meals each Cheetah keeps.

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)

The cheetah is the fastest runner God made, yet it loses most races and many meals. Gifts are real, but the outcome of every race belongs to God.

Practice: answers

1. Any three: a flexible, spring-like spine; long thin legs; semi-retractable claws that grip like cleats; hard foot pads; large nostrils, heart and lungs; a long tail for balance and steering; a light body.
2. Leopards (their horses are swifter), evening wolves (more fierce) and the eagle (they fly as the eagle that hasteth to eat).
3. Sarah: $100 \div 5.95 \approx 16.8 \text{ m/s}$. Bolt: $100 \div 9.58 \approx 10.4 \text{ m/s}$. In 5.95 s Bolt covers about $10.44 \times 5.95 \approx 62 \text{ m}$, so he would be about 38 meters behind.
4. A 2013 study measured wild cheetahs' body temperature and found it barely rose during chases and climbed afterward, probably from stress. The sprint more likely ends because it uses energy too fast to last.
5. $3 \times 7 = 21 \text{ m/s}$; $21 \times 2.237 \approx 47 \text{ miles an hour}$. (Longer strides and faster rates give the higher top speeds.) Even the fastest runner often fails or loses its meal, which illustrates that “the race is not to the swift”: speed is a gift, but outcomes depend on more than ability, and ultimately on God's providence.
6. Sample: Protection must work for the farmer's family as well as for the cheetah, or it will not last. Guardian dogs such as Anatolian shepherds, raised with the goats, can keep cheetahs away so that fewer animals are lost and fewer cheetahs are shot. Farmers can also keep young goats in corrals at night and during calving and be helped with the cost of dogs and fencing. Showing that cheetahs bring visitors and jobs, and that a farm can be a good home for both livestock and wildlife, makes the farmer a steward rather than an enemy of the cheetah.

1.9 KANGAROOS

OBJECTIVES

- Explain how the kangaroo's legs, tendons and tail make hopping an efficient way to travel, and describe the remarkable growth of a joey, with real numbers.
- Tell how Europeans first met and named the kangaroo at the Endeavour River in 1770, and correct a popular myth about the word "kangaroo."
- Read George Stubbs's 1772 painting as a primary source: judge what it shows accurately and what it gets wrong, and explain why.

Warm-up. Stand with your feet together and jump forward as far as you can. Measure it. Now try ten jumps in a row and notice how tired your legs get. A big red kangaroo can cover about 25 feet in a single bound and keep hopping for miles. As you read, look for the hidden "springs" that make the difference.

Video slot. Video coming. Red kangaroos hopping in slow motion; a newborn joey climbing to the pouch; kangaroo mothers and joeys. Search approved channels (Smithsonian Channel, National Geographic, BBC Earth, the Australian Museum, Zoos Victoria); preview first.

KEY TERMS

marsupial

A mammal whose young are born very small and finish growing while nursing, usually in a pouch. Kangaroos, koalas, wombats and opossums are marsupials.

macropod

"Big foot": the family of kangaroos, wallabies, wallaroos and tree-kangaroos, about sixty kinds in all.

joey

A baby kangaroo or other marsupial.

tendon

A tough, stretchy cord joining muscle to bone. A kangaroo's long leg tendons stretch on landing and spring back, storing and returning energy.

embryonic diapause

A pause in the growth of a very early embryo. A kangaroo mother can keep a tiny embryo "on hold" until the joey in her pouch is ready to leave.

Guugu Yimithirr

The language of the Aboriginal people of the Endeavour River area in northern Queensland, from which the word "kangaroo" comes.

CORE IDEAS

Big feet and long springs. Kangaroos belong to the **macropods**, “big feet,” a family of about sixty kinds that includes wallabies and even tree-climbing kangaroos. The largest, the red kangaroo of the dry interior of Australia, is the largest living marsupial: a big male can stand about 6 feet tall and weigh around 190 pounds. Its hind feet are long and narrow, and its leg **tendons** are long and elastic. When a kangaroo lands from a hop, those tendons stretch like rubber bands and store energy; as it leaves the ground, they spring back and return much of it. A red kangaroo can travel comfortably at about 15 to 25 miles an hour, sprint faster than 35 for a short way, and cover about 25 feet in a single bound.

Hopping for free. In 1973 two scientists, Terence Dawson and Richard Taylor, trained kangaroos to hop on a treadmill while they measured how much oxygen the animals used. For most running animals, going faster costs more energy. But above a certain speed, the kangaroos used about the same energy whether they hopped slowly or fast: they simply took longer bounds instead of quicker ones, and the springy tendons did much of the work. Their breathing is even timed to their hops, as the gut swings back and forth like a piston and helps push air in and out of the lungs. When moving slowly while grazing, kangaroos use their thick, muscular tail like a fifth leg, planting it with the front paws while swinging the hind legs forward.

A jellybean in the pouch. A red kangaroo is pregnant for only about 33 days. The newborn joey is about the size of a jellybean, roughly an inch long and less than a gram in weight, blind and hairless, with strong little front arms. Unaided, it climbs up through its mother’s fur into her pouch, a journey of a few minutes, and fastens onto a teat. There it stays for months, growing. It first pokes its head out at about five months and leaves the pouch for good at about eight months, though it keeps nursing for some time after. Meanwhile, the mother may already carry a tiny embryo in **embryonic diapause**, waiting to grow until the pouch is empty. A mother can nurse a newborn in the pouch and a larger joey at foot at the same time, making two different kinds of milk from two different teats.

“Kangooroo or Kanguru.” In June 1770, Lieutenant James Cook’s ship *Endeavour* struck the Great Barrier Reef. Cook brought the damaged ship into a river mouth in northern Queensland, which he named the Endeavour River, and the crew spent about seven weeks repairing her. There they saw strange animals that leaped on their hind legs. On July 14 Lieutenant John Gore shot one, and the botanist Joseph Banks described it carefully. Cook wrote down the local people’s name for it as “Kangooroo or Kanguru.” A popular story says the word means “I don’t understand” in the local language. That is a myth. In the 1970s the linguist John Haviland, working with speakers of **Guugu Yimithirr**, confirmed that *gangurru* is their name for a large grey kangaroo. Cook had written down the word correctly.

Kangaroos today. Australia has tens of millions of kangaroos; government estimates for the main species have ranged from about 25 to 50 million in different years, rising after rains and falling in droughts. That is more kangaroos than there are people in Australia. They graze the same grass as sheep and cattle and can be a hazard on country roads, so Australian states set yearly harvest quotas for the most common species, and kangaroo meat

and leather are sold. Some smaller macropods, such as certain rock-wallabies, are rare and protected. The kangaroo and the emu hold up the shield on Australia's coat of arms, first granted in 1908.

An honest question. Why do so many marsupials live in Australia and almost nowhere else? Scientists who hold to long ages and Christians who believe in a worldwide Flood answer this differently. Many creation scientists suggest that after the Flood, animals spread out from the mountains of Ararat (Genesis 8:4) and that lower sea levels during an ice age may have opened land bridges through Southeast Asia, with marsupials perhaps reaching and thriving in a land where few large placental mammals competed with them. No one was there to watch, so both sides are interpreting evidence. What is certain is the wisdom displayed in the design: "Who knoweth not in all these that the hand of the LORD hath wrought this?" (Job 12:9).

PICTURE STUDY



The Kongouro from New Holland, George Stubbs, 1772 · Oil on panel · National Maritime Museum, Greenwich, London
Wikimedia Commons · Public domain

Joseph Banks brought kangaroo skins and skulls home to England from the voyage of the *Endeavour*, and he asked George Stubbs, the great animal painter of Whistlejacket (Stop A5), to paint the animal. Stubbs had never seen a live kangaroo. He worked from a skin, which may have been inflated or stuffed, and from sketches made on the voyage by the artist Sydney Parkinson. The painting was shown in London in 1773 and was the first picture of a kangaroo most English people ever saw. It is a primary source: it shows what Europeans knew, and did not know, about the kangaroo in 1772.

Look closely

- Look at the kangaroo's head, ears and face. Compare them with a modern photograph of an eastern grey kangaroo.
- Look at the front legs, hind legs and tail. Are the proportions right? What seems too large or too small?
- Look at the landscape. Does it look like the Australian bush, or like somewhere else? Why might that be?

Talk about it

1. Stubbs was one of the most careful anatomists who ever painted animals. Why might even he get some things wrong here?
2. What would a scientist in 1773 learn from this painting, and what would they need to check before trusting it?

HANDS-ON: READING A PAINTING AS EVIDENCE

In this stop the primary source is a picture, not a text. Historians and scientists read old images the way they read documents: asking who made it, how, for whom, and how far to trust it. Compare Stubbs's 1772 kangaroo with modern photographs and data, then make a scale chart of a joey's growth.

You will need

- A copy of Stubbs's *The Kongouro from New Holland* (the National Maritime Museum website has a large free image)
- Two modern photographs of eastern grey kangaroos sitting up (from a library book or a museum website)
- A ruler, graph paper and colored pencils
- A Field Notebook page

Steps

1. Source questions: write who made the painting, when, from what evidence (skins, sketches, descriptions), and for whom (Joseph Banks).
2. Make a two-column chart, "Accurate" and "Inaccurate or doubtful." Compare the painting with your photographs, feature by feature: head, ears, eyes, front legs, hind legs, tail, fur, posture, background. Put at least eight features in the chart.
3. Write one paragraph: "What Stubbs got right, what he got wrong, and why." Use the words "evidence" and "interpretation."
4. Scale chart: on graph paper, draw a newborn joey (about 1 inch), a joey leaving the pouch for good (about 2 feet sitting), and an adult male red kangaroo (about 6 feet) at the same scale (1 square = 1 inch, or choose your own). Label each with its weight.
5. Below the chart, calculate: a newborn red kangaroo weighs about 0.8 gram and an adult male about 85 kilograms. How many times heavier is the adult?

Check your work

- I answered the source questions (who, when, how, for whom).
- My chart compares at least eight features with modern evidence.
- My scale drawing and calculation are correct and labeled.

FIELD NOTEBOOK

1. **Field page: Kangaroos.** Draw a kangaroo's hind leg from the side as a simple diagram. Color the long tendon at the back of the leg and show with arrows how it stretches on landing and springs back on take-off. Add a small map of Australia with the Endeavour River (Cooktown) marked.
2. **Narration (parent keeps).** Without looking back, write one well-built paragraph of eight to ten sentences: "The kangaroo, from the jellybean joey to the 25-foot bound." Include the tendons, Dawson and Taylor's treadmill study, the joey's journey to the pouch, Cook's "Kangooroo," and at least three numbers. Date it and give it to a parent.

Did you know? Kangaroos cannot easily walk backward, which is often given as one reason the kangaroo and the emu, who both mostly move forward, were chosen for Australia's coat of arms; the coat of arms itself does not say so. A kangaroo's pouch opens upward, at the top, but the pouch of a wombat, which digs burrows, opens toward its back legs so it does not fill with dirt. Male kangaroos "box" by leaning back on their tails and kicking with both hind feet.

Go deeper. J. C. Beaglehole, ed., *The Endeavour Journal of Joseph Banks* (1962), for the full account of the Endeavour River (a large scholarly book; library). Royal Museums Greenwich (rmg.co.uk) has free pages on Stubbs's kangaroo and dingo paintings. The Australian Museum (australian.museum) has free fact pages on kangaroos and other macropods. Second video topic: tree-kangaroos of New Guinea and Queensland.

Goes deeper in. Life Science, high school "Biology: Mammals and Ecosystems" (coming soon); Geography, "Australia and Oceania" (coming soon); and Art, "George Stubbs and the Animal Portrait" (coming soon).

For families. This stop has no text excerpt for its primary source; Stubbs's 1772 painting serves as the primary source. Cook's spelling "Kangooroo or Kanguru" is from his journal entry of August 4, 1770, as transcribed by the State Library of New South Wales; the stop quotes only that phrase. Gore's shooting of the first specimen on July 14, 1770 follows Banks's and Cook's journals. Haviland's work on Guugu Yimithirr dates from the 1970s. Population figures are government estimates for the commercially harvested species and vary widely with rainfall. The treadmill study is Dawson and Taylor, *Nature* (1973). The post-Flood dispersal idea is presented as one creation view, with the long-age view mentioned; the stop does not claim certainty for either. Stubbs's painting and its companion, a dingo, were bought by the National Maritime Museum in 2013.

PRACTICE

1. **EASY** What is a marsupial, and what is a macropod?
2. **EASY** Is it true that “kangaroo” means “I don’t understand”? Explain.
3. **MEDIUM** A newborn red kangaroo weighs about 0.8 gram and an adult male about 85 kilograms. How many times heavier is the adult? (1 kilogram = 1,000 grams.)
4. **MEDIUM** What did Dawson and Taylor discover in 1973, and what design explains it?
5. **CHALLENGE** Using the painting as a primary source, explain what kind of evidence Stubbs had, why that evidence could lead to mistakes, and how a scientist of 1773 should have used the painting.
6. **CHALLENGE** A red kangaroo mother can have an embryo in diapause, a joey in the pouch and a young joey at foot all at once. Explain how this helps kangaroos survive in a land of droughts and rains, and why it is an example of wise design.

Make it a game · Kangaroo Spring Relay. Mark a course 20 yards long. Each player hops it with feet together, counting bounds. Then each tries again, focusing on long, springy bounds with soft knees instead of quick little hops. Did the number of bounds go down? Record the best score in each family. Finish with the tallest player and the shortest player comparing bound lengths: how does leg length change it?

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? In whose hand is the soul of every living thing, and the breath of all mankind.” (Job 12:7–10, KJV)

Job says the animals themselves are teachers. A newborn joey climbing unaided to the pouch and a red kangaroo bounding 25 feet on springs of tendon both point to the hand that made them.

Practice: answers

1. A marsupial is a mammal whose young are born tiny and finish growing while nursing, usually in a pouch. A macropod (“big foot”) is a member of the kangaroo family: kangaroos, wallabies, wallaroos and tree-kangaroos.
2. No. It is a myth. The word comes from gangurru, the Guugu Yimithirr name for a large grey kangaroo, which Cook recorded as “Kangooroo or Kanguru” in 1770; the linguist John Haviland confirmed it in the 1970s.
3. $85 \text{ kg} = 85,000 \text{ g}$; $85,000 \div 0.8 = 106,250$. The adult is more than 100,000 times heavier.
4. Above a certain speed, kangaroos used about the same energy whether they hopped slowly or fast. Their long, elastic leg tendons store energy on landing and return it on take-off, and they lengthen their bounds rather than hopping more often.
5. Sample: Stubbs had a skin (possibly inflated or stuffed), a skull, Parkinson’s field sketches and descriptions from Banks, but he never saw a live kangaroo. A dried or stuffed skin can distort the shape of the body and legs, and a sketch may be quick or incomplete, so proportions and posture could be wrong, and he gave it an English-looking landscape. A scientist in 1773

should have treated the painting as a useful first picture but checked it against the skins, the skeleton and written field notes, and waited for more specimens before drawing firm conclusions.

6. Sample: In good seasons a mother can produce young one after another with no wasted time, because the paused embryo begins to grow as soon as the pouch is empty. In a drought, the embryo can stay paused, and if the pouch young dies, the next one is ready to grow when conditions improve, so the mother does not waste scarce food on pregnancy. Making two kinds of milk for two ages of young lets her raise them at the same time. These features fit together so well for the unpredictable climate of Australia that they display the wisdom of the Creator, as Job 12:9 says.

1.10 THE AMERICAN BISON'S COMEBACK

OBJECTIVES

- Explain the causes of the near-destruction of the American bison between about 1870 and 1890, naming economic, technological and political causes and using real numbers.
- Read the Prefatory Note of William T. Hornaday's 1889 report as a primary source and evaluate his argument.
- Tell how ranchers, scientists, a president, tribal nations and the public brought the bison back from about a thousand animals, and connect the story with Genesis 2:15.

Warm-up. Look at the photograph in the picture study for one full minute without reading anything about it. Write three things you observe and one question you have. Then read on. By the end of this stop you will be able to answer your question.

Video slot. Video coming. American bison in Yellowstone's Lamar and Hayden Valleys; the history of the bison's near-extinction and recovery. Search approved channels (the National Park Service, Smithsonian Channel, the U.S. Fish and Wildlife Service, Ken Burns's The American Buffalo (PBS; preview for content)); preview first.

KEY TERMS

Bison bison

The scientific name of the American bison, the largest land mammal in North America. Americans have long called it the buffalo.

hide hunter

A commercial hunter of the 1870s and 1880s who killed bison for their skins, often leaving the meat to rot.

pocket veto

A president's way of killing a bill by not signing it when Congress has adjourned. In 1874 President Ulysses S. Grant let a bill to protect bison die this way.

American Bison Society

A group founded in 1905 at the Bronx Zoo, with William Hornaday as president and Theodore Roosevelt as honorary president, to save the bison.

Lacey Act of 1894

The law that made poaching in Yellowstone National Park a federal crime with real penalties, passed after a poacher was caught killing the park's bison.

conservation herd

A herd kept mainly to preserve the bison as a wild animal (in parks, refuges or tribal lands), as opposed to a commercial herd raised for meat.

CORE IDEAS

The great herds. The American bison is the largest land animal in North America: a bull can stand 6 feet at the hump and weigh about 2,000 pounds, yet it can run about 35 miles an hour and turn on a dime. Before 1800, bison ranged across the Great Plains and well beyond, in herds so large that travelers described them blackening the land for miles. No one counted them; modern estimates of the total commonly run from about 30 to 60 million. For the peoples of the Plains, such as the Lakota, Cheyenne, Comanche and Blackfeet, the bison supplied food, robes, lodge covers, tools and much else, and after Spanish horses spread north in the 1600s and 1700s, mounted hunters followed the herds across the plains.

The slaughter. The herds fell in a single generation. Several causes worked together. After the first transcontinental railroad was completed in 1869, rail lines cut the range in two and could carry hides east cheaply. In 1871 tanners found a way to make strong, useful leather from bison hides, and factories wanted it for machine belts and shoes; a hide could bring a few dollars, so thousands of **hide hunters** went west with heavy rifles. A skilled hunter could kill dozens of bison in a day. The southern herd was largely destroyed between about 1872 and 1878; the northern herd was gone by 1883. Then bone pickers gathered the skeletons that whitened the prairie and sold them by the ton to be ground for fertilizer and for refining sugar.

Who was responsible? The honest answer is: many people, for many reasons. Hunters and hide buyers wanted profit. Railroads and settlers wanted the land for cattle and farms. Some army officers and officials welcomed the end of the bison because it would force the Plains tribes onto reservations, and in 1874 Congress passed a bill to limit the killing that President Grant let die by **pocket veto**. Not everyone agreed: some congressmen, army officers and writers protested at the time. The Plains peoples lost the animal at the center of their way of life, a real wrong that should be named plainly. Greed, short-sightedness and policy all played their part.

Hornaday's count. William Temple Hornaday, chief taxidermist of the Smithsonian's National Museum, went west in 1886 to collect specimens for the museum before the bison vanished. He was shocked by what he found. In 1889 he published *The Extinction of the American Bison* and estimated that only 1,091 bison were left in the United States and Canada, wild and captive together, with fewer than about 300 of them wild in the United States. In Yellowstone National Park, poachers kept killing the last wild herd until 1894, when the capture of a poacher there led Congress to pass the **Lacey Act**, making such poaching a federal crime. By 1902 Yellowstone's wild herd was down to about two dozen animals.

The rescue. The bison were saved largely by private individuals. Charles and Mary Ann Goodnight kept a herd on their Texas ranch, partly at Mary Ann's urging. James "Scotty" Philip in South Dakota, and Michel Pablo and Charles Allard on the Flathead Reservation in Montana, built herds from a few captured calves; the Pablo herd was later sold to Canada and began herds there. In 1905 Hornaday and others founded the **American Bison Society**, with Theodore Roosevelt as honorary president. In 1907, fifteen bison from the Bronx Zoo

traveled by train to the new Wichita Mountains reserve in Oklahoma; in 1908 Congress created the National Bison Range in Montana. Yellowstone added bison from private herds in 1902 and slowly rebuilt its own.

The comeback today. Today there are roughly 30,000 bison in conservation herds in North America and several hundred thousand more on private ranches. Yellowstone's herd, the only one in the United States that has lived continuously in the wild since prehistoric times, numbers several thousand. Many tribal nations, working together since 1992 through the InterTribal Buffalo Council, have returned bison to their lands. In 2016 Congress named the bison the national mammal of the United States. The bison is not back on all its old range, and the problems of disease, fences and grazing land are real. But a creature that was nearly wiped out by human greed was brought back by human care. That is what Genesis 2:15 asks of people: to "dress" and "keep" what God has given.

PICTURE STUDY



Pile of bison skulls waiting to be ground for fertilizer, Unknown photographer, about 1892 · Photograph · Burton Historical Collection, Detroit Public Library
Wikimedia Commons · Public domain

This photograph was taken outside the Michigan Carbon Works near Detroit, a factory that bought bison bones by the ton and burned and ground them into bone charcoal for refining sugar and into fertilizer. The skulls had been gathered from the prairies after the hide hunters were gone and shipped east by rail. It is a primary source: one of the most powerful images ever taken of what happened to the bison.

Look closely

- Find the two men. Use them to estimate how tall and wide the pile is.

- Look closely at a few skulls. Can you see the horn cores? Estimate how many skulls are in one small section, then for the whole pile.
- Look at the factory setting. What does it tell you about how the bones were used?

Talk about it

1. Hornaday wrote of “the whitened bones of the last bleaching skeleton” being “shipped East for commercial uses.” How does this photograph confirm his words?
2. Why do you think this photograph is so often shown in museums and books? What feeling does it create, and is that feeling fair to the facts?

HANDS-ON: READ LIKE A HISTORIAN: HORNADAY’S WARNING

Read the primary source, the Prefatory Note to Hornaday’s 1889 report, and analyze it as a historian: its author, purpose, audience, claims and evidence. Then test it against the photograph and the history in this stop and write a short argument.

You will need

- The primary source in this stop (the full report is free on Project Gutenberg, eBook #17748)
- The photograph in the picture study
- Two colored pencils and a Field Notebook page

Steps

1. Source questions: Who wrote this? When? For whom (it was a report for the Smithsonian, printed by the U.S. government)? What did he want readers to do?
2. In one color, underline Hornaday’s claims about the past (what happened). In another, underline his warnings about the future (what he fears or hopes).
3. Find the phrase Hornaday put in italics. Why did he stress it? Which other animals might he have had in mind in 1889?
4. Compare the primary source with the photograph and with the numbers in this stop. Write two places where the evidence supports him.
5. Hornaday wrote that the wild buffalo was “practically gone forever.” Was he right? Write a one-paragraph argument answering: “Was Hornaday wrong, and was he glad to be?” Use at least three facts from the rescue.

Check your work

- I answered the four source questions.
- I marked past claims and future warnings in two colors and found the italic phrase.
- My argument uses evidence from the primary source, the photograph and the rescue story.

FIELD NOTEBOOK

1. **Field page: Bison.** Draw a bison bull from the side and label the hump (muscle for swinging the great head through snow), the horns, the beard and the short tail. Beside it, draw a simple line graph of bison numbers: tens of millions (before 1800), 1,091 (1889), about two dozen wild in Yellowstone (1902), roughly 30,000 in conservation herds today.
2. **Narration (parent keeps).** Without looking back, write one well-built paragraph of eight to ten sentences: “How the bison was lost and saved.” Include at least three causes of the slaughter, Hornaday’s count, two people or groups who saved the bison, and Genesis 2:15. Date it and give it to a parent for the portfolio.

Did you know? A bison’s hump is not fat but muscle, attached to long spines on its backbone. In winter, a bison swings its huge head from side to side like a snowplow to clear snow from the grass beneath, while cattle tend to push snow with their noses. Bison have been timed jumping fences about 6 feet high. Every year, visitors to Yellowstone are hurt by approaching bison too closely: park rules require staying at least 25 yards away.

Primary source. William T. Hornaday, *The Extermination of the American Bison (Report of the U.S. National Museum, 1889), Prefatory Note (Project Gutenberg eBook #17748)*

It is hoped that the following historical account of the discovery, partial utilization, and almost complete extermination of the great American bison may serve to cause the public to fully realize the folly of allowing all our most valuable and interesting American mammals to be wantonly destroyed in the same manner. The wild buffalo is practically gone forever, and in a few more years, when the whitened bones of the last bleaching skeleton shall have been picked up and shipped East for commercial uses, nothing will remain of him save his old, well-worn trails along the water-courses, a few museum specimens, and regret for his fate. If his untimely end fails even to point a moral that shall benefit the surviving species of mammals *which are now being slaughtered in like manner*, it will be sad indeed.

Go deeper. William T. Hornaday, *The Extermination of the American Bison* (1889), free on Project Gutenberg (read the chapters on the slaughter and the census). Stefan Bechtel, *Mr. Hornaday’s War* (2012), a biography of Hornaday. The National Park Service’s Yellowstone bison pages and the U.S. Fish and Wildlife Service’s Wichita Mountains Wildlife Refuge page. Second video topic: the Wichita Mountains herd and the 1907 train from the Bronx Zoo.

Goes deeper in. History, “The American West, 1865–1900” (coming soon); Life Science, high school “Biology: Ecosystems and Stewardship” (coming soon); and Small Business & Economics, “Markets, Prices and the Commons” (coming soon).

For families. The original bison population is unknown; 30–60 million is the range most often cited. Hornaday’s 1,091 is his 1889 estimate (including captive animals and those in Canada). The 1874 bison-protection bill passed Congress and was not signed by President Grant (pocket veto); some officials’ support for the slaughter as a way to pressure the Plains tribes is well documented, though historians debate how much official policy, as opposed to the market, drove it. The stop names the loss suffered by the Plains peoples plainly and without modern slogans. Modern numbers are rounded estimates (U.S. Department of the Interior and others). The photograph is in the Burton Historical Collection, Detroit Public Library, dated about 1892; contains no gore. Ken Burns’s documentary (2023) is listed only as a search topic; parents should preview. The primary source keeps Hornaday’s italics.

PRACTICE

1. **EASY** Name three causes of the destruction of the bison herds between 1870 and 1890.
2. **EASY** In the primary source, what three things does Hornaday say will remain of the bison?
3. **MEDIUM** If there were 30 million bison in 1800 and 1,091 in 1889, what percentage survived? Round to four decimal places.
4. **MEDIUM** Why were private ranchers so important to saving the bison?
5. **CHALLENGE** In the primary source, Hornaday says the bison’s “untimely end” should “point a moral.” State that moral in your own words and give two examples from later history (from this trail or elsewhere) where people seem to have learned it.
6. **CHALLENGE** Some say the bison were destroyed mainly by government policy; others say mainly by the market for hides. Write a balanced paragraph of four or five sentences weighing both, and say what you conclude.

Make it a game • From 1,091 to Thousands. Start with 10 beans in a cup (the herds of 1889). Each round is “five years.” Roll a die: on 1, a harsh winter or poachers (remove 2 beans); on 2–3, a quiet time (add 2); on 4–5, a good season (add 3); on 6, a new refuge is founded (add 5). Play ten rounds and graph your herd. Then play again, but now every 1 counts double. Talk about why protection in the early years mattered most.

Scripture. “And the LORD God took the man, and put him into the garden of Eden to dress it and to keep it.” (Genesis 2:15, KJV)

To “dress” is to work and cultivate; to “keep” is to guard. The bison story shows both the failure to keep and the work of keeping done well. Stewardship is not leaving creation untouched, but caring for it as a trust from God.

Practice: answers

1. Any three: railroads that split the range and carried hides east; the 1871 tanning method that made hides valuable; thousands of hide hunters; demand for land for cattle and farms; some

officials' support for the slaughter to pressure the Plains tribes; the 1874 pocket veto of a protection bill.

2. "His old, well-worn trails along the water-courses, a few museum specimens, and regret for his fate."
3. $1,091 \div 30,000,000 \approx 0.0000364$, or about 0.0036 percent; more than 99.99 percent were gone.
4. By the late 1880s almost no wild bison were left, and there was little government protection. Ranchers such as the Goodnights, Scotty Philip, and Pablo and Allard kept small herds alive and growing, and their animals later stocked parks, refuges and the herds of the American Bison Society.
5. Sample: The moral is that people must not allow valuable animals to be wantonly destroyed for quick profit, because once gone they cannot be brought back. Examples: the bison itself was rescued by the American Bison Society and refuges; the Lacey Act (1894) protected Yellowstone's wildlife; whales gained the 1986 whaling moratorium (Stop A3); elephants gained the 1989 ivory trade ban (Stop A2); Asiatic lions were protected in Gir (Stop A1).
6. Sample: The market was the engine: once hides could be tanned into useful leather in 1871 and railroads could carry them east cheaply, thousands of hunters went west to make money, and they would have done so with or without official approval. But government choices mattered too: some army officers and officials welcomed the slaughter as a way to force the Plains tribes onto reservations, and President Grant let the 1874 protection bill die. Strong laws enforced in time might have slowed or stopped the killing, as the Lacey Act later did in Yellowstone. I conclude that the market caused the slaughter and government failed to stop it, and some officials were glad of it, so both share the blame.

TRAIL 1 BADGE QUIZZES

The badge quizzes are optional. Students may answer in writing or aloud. Each quiz has five questions, one per stop; four correct out of five, answered in full sentences, earns the 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. In Revelation 5:5–6, John hears of “the Lion of the tribe of Juda” and then sees something else. What does he see, and what does the pairing mean?
2. Name two features of the elephant (other than size) designed for its life, and give the three main views of what behemoth (Job 40) was.
3. Why did Melville’s Ishmael call the whale a fish, and why is it not an error that Jonah 1:17 says “a great fish”?
4. Who first showed that bats find their way by hearing, and who discovered the ultrasound that explained it?
5. What did Muybridge’s 1878 photographs show about the gallop, and why did that matter to painters?

Badge quiz 2 (Stops 6–10)

6. What is a wild wolf pack, and who corrected the old “alpha wolf” idea?
7. Name two ways a black bear survives five months in its den without eating or drinking.
8. The GPS-collar study in Botswana (2013) found that what mattered most in a cheetah’s hunt was not top speed. What was it?
9. Where does the word “kangaroo” come from?
10. About how many bison did Hornaday count in 1889, and name two people or groups who helped bring them back.

TRAIL CERTIFICATE: MY MAMMALS FIELD NOTEBOOK AND TRAIL A CERTIFICATE

Gather the Field Notebook pages and the ten narrations from this trail into one booklet with a cover: “Mammals: An Expert Field Notebook,” your name and the dates you started and finished.

Add a one-page index listing the ten primary sources you studied (Genesis 49, Job 40, Moby-Dick, Leviticus 11, Job 39, John 10, 1 Samuel 17, Habakkuk 1, Stubbs’s Kongouro, Hornaday’s Prefatory Note) with one sentence on what each taught you.

Choose your best project (for example, the behemoth evidence grid, the echo-ranging experiment or the Hornaday argument) and revise it into a clean final copy of one to two pages.

When the booklet is done, a parent reads the narrations, signs the Trail A certificate and keeps the narrations in the student’s records.

- **Ten narrations:** One paragraph of eight to ten sentences for each stop, written from memory, dated, with the required numbers and Scripture.
- **Use of sources:** The primary-source index is complete, and projects quote sources accurately and ask who made them, when, why and how far to trust them.
- **Reasoning:** Challenge answers and the final project separate observation from interpretation, weigh more than one view fairly, and show calculations clearly.
- **Care:** Drawings are labeled, pages are neat and titled, and the final project has been revised for spelling and clarity.

Answer key

1. "A Lamb as it had been slain." Christ is the royal, victorious Lion from Judah (Genesis 49:9–10), and He won His victory as the Lamb, by giving His life.
2. Any two: the boneless, muscular trunk; six sets of molars moving forward; ears that cool the body; infrasound rumbles; long-lived matriarchs. Behemoth: the elephant, the hippopotamus, or a great creature no longer living such as a sauropod.
3. For centuries "fish" meant any large creature living in the sea; Ishmael playfully takes that old sailor's view. Jonah uses the everyday Hebrew words of its time, not the categories of modern zoology, so it is not wrong.
4. Lazzaro Spallanzani (with Louis Jurine) in the 1790s; Donald Griffin, beginning in 1938, who named it echolocation in 1944.
5. A galloping horse has all four feet off the ground at one moment, but with its legs gathered under its body; painters had long shown a stretched-out pose that never happens.
6. A family of parents and their offspring; L. David Mech, in his 1999 paper based on watching wild wolves.
7. Any two: it stores fat in the fall (hyperphagia); its heart rate and breathing slow greatly; it recycles urea into protein instead of making waste; it keeps its muscles and bones strong while barely moving.
8. Acceleration and agility: the ability to speed up, slow down and turn sharply at high speed.
9. From gangurru in the Guugu Yimithirr language of the Endeavour River area, recorded by Cook in 1770 as "Kangooroo or Kanguru." It does not mean "I don't understand."
10. About 1,091. Any two: Charles and Mary Ann Goodnight; Scotty Philip; Michel Pablo and Charles Allard; the American Bison Society (Hornaday and Theodore Roosevelt); the Wichita Mountains refuge; the National Bison Range; Yellowstone; the InterTribal Buffalo Council.

ANIMALS TRAIL B: BIRDS

The second trail of the Animals track studies the birds: the soaring eagle of Isaiah 40:31, the silent owl, the hummingbird living on the edge of its energy, the penguins of the frozen deep, the ostrich of Job 39, the parrots, the great journeys of migration, the engineering of nests, John James Audubon and *The Birds of America*, and a real backyard bird count. Each stop joins careful science (numbers, experiments and honest debates) with history, art and Scripture.

This is the  **Expert** level, written for ages 14 and up. Each stop takes about 35 to 50 minutes and stands by itself. The student reads the core ideas, studies a picture, works through a primary source where one exists (Gilbert White, Xenophon, Cherry-Garrard, Audubon, Florence Merriam and the King James Bible), completes a hands-on project with real data, writes a narration paragraph for the parent to keep, and answers six practice questions, two of them challenge problems. The trail is creation-friendly: birds are God's handiwork, made "after their kind," and conservation is taught as stewardship (Genesis 2:15).

Stops 1–5 earn the **Bird Expert badge, part 1**, and Stops 6–10 earn part 2 and the **Trail B certificate**. The two badge quizzes at the end of the trail are optional; badges and the certificate are earned by doing the stops and keeping the Field Notebook, not by scores.

BEFORE YOU BEGIN

- Comfortable with percentages, unit conversions, averages and simple graphs (a calculator is fine; a few challenge problems use exponents or logarithms).
- Able to read a 300-word older text (such as a letter from the 1700s) and summarize it in one's own words.

MASTERY CHECKLIST

- ☐ I can explain, with numbers, how eagles soar, owls hear in the dark, hummingbirds hover and penguins stay warm.
- ☐ I can read a primary source about birds closely, quote it accurately, and separate what the writer observed from what he or she believed.
- ☐ I can explain how birds migrate and navigate, and how scientists found out, from the arrow stork of 1822 to modern radar.
- ☐ I can tell the story of Audubon's *Birds of America* and judge his life fairly, naming both achievements and faults.
- ☐ I can carry out a timed, documented bird count, explain its sources of error, and connect bird study to Scripture and stewardship.

OPTIONAL BOOKS AND RESOURCES

- **Cornell Lab of Ornithology: All About Birds, eBird and Merlin** (<https://www.allaboutbirds.org>): Free species accounts, songs and calls; eBird (ebird.org) and the free Merlin app are used in Stop B10, and the Lab's Macaulay Library of recorded sounds in Stop B6.
- **Project Gutenberg** (<https://www.gutenberg.org>): Free texts used as primary sources: Gilbert White's *Natural History of Selborne*, Xenophon's *Anabasis*, Cherry-Garrard's *The Worst Journey in the World*, Audubon's *Ornithological Biography* and Florence Merriam's *A-Birding on a Bronco*.
- **National Audubon Society: The Birds of America online** (<https://www.audubon.org/birds-of-america>): Every Audubon plate, free to view and print, for the picture studies and the grid-copy project in Stop B9.
- **BirdCast** (<https://birdcast.info>): Free radar-based migration maps and forecasts for the night-migration project in Stop B7.
- **NestWatch** (<https://nestwatch.org>): Free nest-box plans and the nest-monitoring code for Stop B8.
- **Great Backyard Bird Count** (<https://www.birdcount.org>): The free February count used in Stop B10; results maps from past years for practice in reading data.

2.1 EAGLES: “MOUNT UP WITH WINGS” (ISAIAH 40:31)

OBJECTIVES

- Explain how eagles soar on thermals and ridge lift, using numbers for climb rate, sink rate and flapping effort.
- Trace the decline and recovery of the bald eagle in the lower 48 states and explain biomagnification.
- Read Deuteronomy 32:11, Exodus 19:4 and Isaiah 40:31 closely and compare the Bible’s eagle pictures with observed eagle behavior.

Warm-up. In 1784 Benjamin Franklin called the bald eagle “a Bird of bad moral Character.” Before you read, write one sentence: can a bird have a moral character at all? Keep the sentence; you will come back to it in the practice.

Video slot. Video coming. Eagles soaring in thermals, bald eagles fishing and stealing fish from ospreys, golden eagles hunting; fall raptor migration at Hawk Mountain. Search approved channels (Cornell Lab of Ornithology Bird Cams, U.S. Fish and Wildlife Service, National Park Service, Hawk Mountain Sanctuary); preview first.

KEY TERMS

thermal

A column of warm air rising from ground heated by the sun; soaring birds circle inside it to gain height without flapping.

orographic (ridge) lift

Air pushed upward when wind strikes a ridge or cliff; migrating raptors ride it along mountain chains.

slotted primaries

The separated “finger” feathers at the tip of a soaring bird’s wing, which reduce drag at the wingtip, much like the winglets on an airliner.

fovea

A small pit in the retina packed with light-sensing cones, where vision is sharpest; an eagle has two in each eye.

kleptoparasitism

Stealing food that another animal has caught, as when a bald eagle chases an osprey until it drops its fish.

biomagnification

The increase in concentration of a long-lasting chemical at each higher step of a food chain.

CORE IDEAS

The prophet's eagle. When Isaiah wrote that those who wait upon the LORD “shall mount up with wings as eagles” (Isaiah 40:31), his hearers knew exactly what he meant: a great bird rising over the hills of Judah without a single wingbeat. The Hebrew word *nesher* probably covered more than one large bird of prey. The golden eagle lives in Israel, but so does the griffon vulture, and Micah 1:16 (“enlarge thy baldness as the eagle”) fits the griffon's bare head better than any eagle. Either way, the picture is the same: a heavy bird carried upward by a power outside itself.

How soaring works. A soaring bird is always gliding downhill through the air. A large raptor in a glide sinks perhaps 1 to 2 meters per second. On a sunny day, a thermal may rise at 2 to 5 meters per second. If the air rises faster than the bird sinks, the bird climbs, and it circles tightly to stay inside the column. Broad wings give a low **wing loading** (weight per area of wing), so the bird sinks slowly; the **slotted primaries** at the tips spread like fingers and cut the swirling drag that forms at a wingtip. Eagles also ride ridge lift: each autumn, thousands of hawks and eagles stream down the Appalachian ridges past Hawk Mountain, Pennsylvania, where counts have been kept since 1934. How efficient is all this? A 2020 study fitted Andean condors with recorders and found they flapped during about 1 percent of their flying time; one bird flew more than five hours and over 100 miles without flapping.

Eyes built for distance. An eagle's eye is roughly as large as a human eye, although its head is far smaller, and the eyes leave little room in the skull. Each eye has two **foveae**: one looking sideways and one looking forward, so the bird can watch the landscape and judge distance to a target at once. The cones are packed far more densely than ours, and studies of eagles' visual sharpness put it at roughly two to three times the best human vision. When a golden eagle folds its wings and stoops on a hare, it can pass well over 100 miles per hour. At the last moment it swings its feet forward, and the long curved talons do the killing; the hooked beak is for tearing, not catching.

Franklin's complaint. In a January 1784 letter to his daughter Sarah Bache, Franklin wrote that he wished the bald eagle “had not been chosen” as the emblem of the nation: “He is a Bird of bad moral Character. He does not get his Living honestly.” He described an eagle waiting for the fishing hawk (the osprey) to catch a fish, then chasing it until “the Bald Eagle pursues him and takes it from him.” Franklin was describing real behavior: bald eagles do practice **kleptoparasitism**, and they also eat carrion. But they are also strong hunters of fish and waterfowl. Franklin was partly joking; the letter mainly mocked a new military society's eagle badge, which he thought looked more like a turkey. The bald eagle had been on the Great Seal since 1782, and a law signed in December 2024 made it the national bird.

Decline. Bald eagles were shot as pests for generations, and Congress protected them in the Bald Eagle Protection Act of 1940. A quieter danger came after World War II: the insecticide DDT. DDT broke down into a compound called DDE that lasted for years in soil and water. Tiny amounts in water became larger amounts in small fish, more in big fish, and most in the eagles that ate them. This **biomagnification** interfered with the female's ability to lay down

calcium, so eggshells came out thin and cracked under the incubating parent. By 1963 the U.S. Fish and Wildlife Service could find only 417 nesting pairs in the lower 48 states.

Recovery. The Environmental Protection Agency banned most uses of DDT in 1972. Eagles were listed as endangered, nest sites were protected, and young eagles were released in states that had lost theirs. Eggshells thickened again. Bald eagles were removed from the endangered species list in 2007, and a 2021 federal report estimated about 71,400 nesting pairs and roughly 316,700 bald eagles in the lower 48. Honest complexity: other threats remain, such as collisions, poisoning from eating contaminated carcasses and loss of shoreline trees, so the work of stewardship (Genesis 2:15) is never quite finished.

Renewal. Psalm 103:5 says “thy youth is renewed like the eagle’s.” Ancient writers told legends of eagles growing young again; the real bird renews itself more quietly, by molting and replacing its flight feathers a few at a time over a year or more, so it never loses the power to fly. Isaiah’s promise does not depend on the legend. It rests on the LORD who “giveth power to the faint” (Isaiah 40:29). The eagle does not climb by effort; it climbs by spreading its wings in air that is already rising.

PICTURE STUDY



Golden Eagle, Plate 181 of The Birds of America, John James Audubon (engraved by Robert Havell Jr.), 1833 (watercolor); engraved for The Birds of America · Hand-colored engraving and aquatint after Audubon’s watercolor · From The Birds of America; the original watercolor is at the New-York Historical Society
Wikimedia Commons · CC BY-SA 4.0

Audubon painted the golden eagle in Boston in 1833 from a living bird he had bought. He posed it rising with a hare above a mountain gorge. The golden eagle is a good bird to study for Isaiah: it lives across the Northern Hemisphere, in Israel as well as in western North America. Stop B9 tells more about Audubon and how his plates were made.

Look closely

- Trace the line of the wings. Where are the slotted “finger” feathers at the tips?
- Study the feet. How many talons grip the hare, and where?
- Look at the background far below the bird. What does the height tell you about how the eagle hunts?

Talk about it

1. Audubon chose a moment of struggle and lift rather than a bird perched calmly. What does that choice say about how he saw eagles?
2. Compare this plate with Deuteronomy 32:11 (in the Primary source box). Which part of the verse could Audubon have painted, and which part would be hard to paint?

HANDS-ON: FLAP COUNT: MEASURING SOARING IN THE FIELD

Gather real data on how soaring birds save energy, then test the Bible’s eagle pictures against what you observe. Any large soaring bird will do: eagle, hawk, osprey or turkey vulture. Clear, sunny late mornings and early afternoons are best, when thermals are rising.

You will need

- A notebook and pencil, and a watch or phone timer
- Binoculars (helpful but not required)
- An open place with a wide view of sky, such as a field, hilltop or lakeshore
- The Primary source box from this stop

Steps

1. Find a soaring bird. Start the timer and count every wingbeat for 60 seconds, or until the bird is lost from view. Record the time, weather, species (or “unknown hawk”) and whether the bird was circling or gliding straight.
2. Repeat for at least three soaring birds. Then do the same for three flapping birds such as crows, pigeons or gulls.
3. Compute wingbeats per minute for each bird and the average for each group. Make a simple bar graph.
4. Write a paragraph: what do your numbers show about the cost of soaring? Did birds circle in one place (a thermal) or glide along a ridge or shoreline?
5. Read Deuteronomy 32:11–12 and Exodus 19:4. List each action the verse gives the eagle. Mark which ones you could check by observation and which are a picture of God’s care that does not depend on a single observation.

Check your work

- I timed at least three soaring and three flapping birds.
- I calculated wingbeats per minute and drew a bar graph.
- I wrote a paragraph explaining my results with the words thermal or ridge lift.

- I listed the eagle's actions in Deuteronomy 32:11 and sorted them.

FIELD NOTEBOOK

1. **Narration.** Write one paragraph, in your own words and without looking at the text, explaining why bald eagles nearly disappeared from the lower 48 states and how they came back. Use the words DDT, biomagnification and eggshell. Give it to your parent to keep.
2. Draw a cross-section of a thermal: the sun, warm ground, a rising column of air, and an eagle circling inside it. Label the climb rate of the air, the sink rate of the bird and the net climb.
3. Sketch an eagle seen from below and label the slotted primaries, secondaries, tail and talons.

Did you know? Raptor-watchers at Hawk Mountain Sanctuary in Pennsylvania have counted migrating hawks and eagles every autumn since 1934. Its founder, Rosalie Edge, bought the mountain to stop the shooting of hawks that passed along the ridge. Bald eagles are found only in North America, but golden eagles nest from Mexico and the American West across Europe and Asia to the hills of the Middle East.

Primary source. *The Bible, King James Version: Deuteronomy 32:11-12 (from the Song of Moses) and Exodus 19:4*

As an eagle stirreth up her nest, fluttereth over her young, spreadeth abroad her wings, taketh them, beareth them on her wings: So the LORD alone did lead him, and there was no strange god with him.

Ye have seen what I did unto the Egyptians, and how I bare you on eagles' wings, and brought you unto myself.

Read the five verbs in Deuteronomy 32:11. Use them in Step 5 of the project and in Practice 3.

Go deeper. Ruth E. Tingay and Todd E. Katzner, eds., *The Eagle Watchers: Observing and Conserving Raptors Around the World* (Cornell University Press, 2010). U.S. Fish and Wildlife Service pages on the bald eagle's recovery (fws.gov). Cornell Lab of Ornithology, All About Birds: "Bald Eagle" and "Golden Eagle." Hawk Mountain Sanctuary (hawkmountain.org) for count data you can graph. Second video topic: the Decorah or other eagle nest cameras, watching parents feed young and the young bird's first flights.

Goes deeper in. Life Science, high-school Biology, "Birds" and "Ecology" units (coming soon); Earth Science, "Weather and the Atmosphere," for thermals and lift; History, the founding era, for the Great Seal.

For families. Franklin's words are quoted from his letter to Sarah Bache of January 26, 1784, as printed by the National Archives (Papers of Benjamin Franklin); the letter mainly

satirized the Society of the Cincinnati. Bald eagle numbers are from the U.S. Fish and Wildlife Service (417 pairs in 1963; about 71,400 pairs and 316,700 birds in its March 2021 report). DDT was banned for most uses in 1972; the eagle was delisted in 2007; the national-bird law was signed in December 2024. The condor flapping figure is Williams and others, *PNAS* (2020). Stoop speeds and visual-acuity ratios are estimates and vary by study, so the stop gives ranges. The Hebrew *nesher* may include the griffon vulture; the KJV says “eagle.” Reports of eagles carrying their young on their backs are few and unconfirmed, so the stop does not claim it; Deuteronomy 32:11 is read as a true picture of God’s care.

PRACTICE

1. **EASY** What is a thermal, and how does an eagle use one to gain height without flapping?
2. **MEDIUM** Explain in three or four sentences how DDT harmed bald eagles even though eagles were never sprayed.
3. **MEDIUM** **Primary source.** List the five actions of the eagle in Deuteronomy 32:11. Then read verse 12. What is the eagle a picture of?
4. **MEDIUM** A thermal rises at 3 meters per second. An eagle gliding inside it sinks through the air at 1 meter per second. How long will it take the eagle to climb 1,000 meters?
5. **CHALLENGE** In 1963 there were 417 nesting pairs of bald eagles in the lower 48 states; about 56 years later there were about 71,400. (a) By what factor did the number grow? (b) What average yearly growth rate would produce that change? (Hint: $\text{rate} = \text{factor}^{(1/56)} - 1$.)
6. **CHALLENGE** Return to your warm-up sentence. Was Franklin fair to call the bald eagle “a Bird of bad moral Character” who “does not get his Living honestly”? Give one point of evidence for him, one against him, and a judgment about whether moral words fit animals at all.

Make it a game · Silhouette Spotter. One player draws or shows silhouettes of soaring birds seen from below: bald eagle (long, flat, plank-like wings and a big head), turkey vulture (wings held in a shallow V, tipping side to side), red-tailed hawk (shorter, rounder wings and a fanned tail) and osprey (long wings bent like a flattened M). The others have three seconds to name each one. Then play it outdoors with real birds.

Scripture. “But they that wait upon the LORD shall renew their strength; they shall mount up with wings as eagles; they shall run, and not be weary; and they shall walk, and not faint.” (Isaiah 40:31, KJV)

The soaring eagle rises by resting its full weight on air that is already rising. Isaiah’s promise is not to the strong but to those who wait upon the LORD: their strength is renewed because it comes from Him.

Practice: answers

1. A thermal is a rising column of warm air over sun-heated ground. The eagle spreads its wings and circles inside it; because the air rises faster than the bird sinks in its glide, the bird climbs.
2. DDT broke down into DDE, which lasted a long time in water and soil. It built up in small fish, more in larger fish, and most in eagles at the top of the food chain (biomagnification). DDE interfered with the female's calcium use, so she laid thin eggshells that cracked during incubation. Few chicks hatched, and the population fell.
3. She stirreth up her nest, fluttereth over her young, spreadeth abroad her wings, taketh them, and beareth them on her wings. Verse 12 says "So the LORD alone did lead him": the eagle is a picture of God leading and carrying Israel out of Egypt and through the wilderness, as Exodus 19:4 also says.
4. Net climb = $3 - 1 = 2$ m/s. Time = $1,000 \div 2 = 500$ seconds, about 8 minutes 20 seconds.
5. (a) $71,400 \div 417 \approx 171$ times as many. (b) $171^{(1/56)}$: $\ln 171 \approx 5.14$; $5.14 \div 56 \approx 0.092$; $e^{0.092} \approx 1.096$. So about 9.6 percent growth per year on average. (Real growth was slow at first and faster later, so the average hides the shape of the curve.)
6. For: bald eagles really do steal fish from ospreys (kleptoparasitism) and eat carrion. Against: they are also skilled hunters of fish and waterfowl, and Franklin was partly joking and aiming at a human society's badge. Judgment: animals act by the natures God gave them and are not moral agents; they do not sin or deserve praise. Moral words are fair only as figures of speech, which is how Franklin (and Scripture's animal pictures) use them. Accept any well-reasoned answer that uses evidence.

2.2 OWLS: HUNTERS OF THE SILENT NIGHT

OBJECTIVES

- Explain how an owl's facial disc and uneven ears let it locate prey by sound, and calculate the time differences involved.
- Describe three feather features that make owl flight nearly silent and one way engineers have copied them.
- Analyze an owl pellet (or pellet data) and Gilbert White's 1773 observations to estimate how much an owl eats.

Warm-up. Close your eyes. Have someone snap their fingers quietly somewhere in the room, and point to the sound. Now cover one ear tightly and try again. Which was harder: telling left from right, or telling high from low? Write down what you notice.

Video slot. Video coming. Barn owl hunting by sound, slow-motion owl flight compared with a pigeon, owl pellet dissection, barn owl nest boxes on farms. Search approved channels (Cornell Lab of Ornithology, BBC Earth, Smithsonian, National Park Service); preview first.

KEY TERMS

facial disc

The round or heart-shaped dish of stiff feathers around an owl's face, which gathers sound and funnels it toward the ears.

asymmetrical ears

Ear openings set at different heights on the two sides of the head, so a sound reaches each ear a little differently depending on whether it comes from above or below.

sound localization

Finding where a sound comes from by comparing when and how loudly it reaches each ear.

leading-edge serrations

The comb-like fringe on the front edge of an owl's outer wing feather, which breaks up the air into small, quiet swirls.

pellet

A compact lump of fur, bones and other indigestible parts that an owl coughs up several hours after a meal.

nocturnal

Active at night. Many owls are nocturnal, but some, such as the snowy owl and burrowing owl, often hunt by day.

CORE IDEAS

A hunt in the dark. At dusk a barn owl floats low over a hayfield, slow and buoyant, its pale face tilted down. It stops, hovers, and swings its head a few degrees left. It has not seen anything. It has heard a vole rustling under the grass. The owl drops with its wings raised and its feet thrown forward, and the talons close on a spot it could not see. The vole never heard it coming.

The owls. There are about 250 kinds of owls, in two families: the barn owls, with heart-shaped faces, and the much larger family of typical owls, such as the great horned owl and the screech owls. They range from the elf owl of the Southwest, which weighs about 1.4 ounces (40 grams) and nests in old woodpecker holes in saguaro cactus, to the Eurasian eagle-owl and Blakiston's fish owl, which can weigh 8 or 9 pounds with wings spreading about 6 feet. All share the same plan: forward-facing eyes, a hooked beak, strong feet with sharp talons, and an outer toe that can swing forward or back.

Hearing in three dimensions. An owl's face works like a satellite dish. The stiff feathers of the **facial disc** collect sound and guide it to the ear openings hidden at the sides. In barn owls and several other owls, one ear opening sits higher than the other. A sound to the owl's left reaches the left ear first, by a few millionths of a second; a sound from below is louder in the lower ear. The owl's brain compares timing for left and right and loudness for up and down, and builds a map of sound space. In experiments beginning in the 1970s, scientists including Roger Payne, Masakazu Konishi and Eric Knudsen showed that barn owls in total darkness could strike a mouse by sound alone, aiming within one or two degrees. Owls can also hear prey under snow; great gray owls plunge through snow to catch voles they cannot see.

Silent wings. Most birds make a whooshing noise in flight. An owl's wings are hushed by three features. The front edge of the outer flight feather carries a fringe of tiny hooks, the **leading-edge serrations**, which break the airflow into small, quiet eddies. The upper surface of the feathers is soft and velvety, so feathers do not rasp as they slide. The trailing edges are fringed, softening the turbulence behind the wing. Large wings for its weight let the owl fly slowly, and slow flight is quiet flight. Engineers have copied these ideas: the designers of Japan's 500 Series bullet train (1997) shaped the pantograph, the arm that touches the power line, with owl-like serrations to cut noise, and owl-inspired edges are tested on fans and turbine blades.

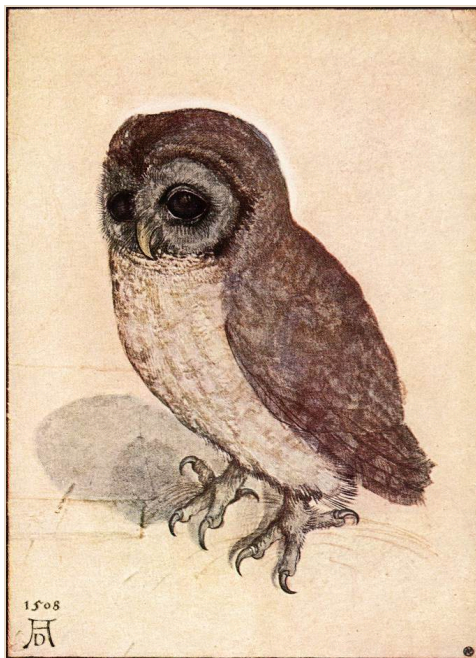
Eyes that cannot turn. Owl eyes are long tubes held in rings of bone, and they barely move in their sockets. Instead the owl turns its whole head, as far as about 270 degrees. A human neck has 7 vertebrae; an owl's has 14. A 2013 study at Johns Hopkins found special features in owl arteries, including small reservoirs and roomy bony channels, that keep blood flowing to the brain during such twists. Owl eyes are rich in rod cells, which work in dim light, so an owl sees well in the dark, but on a truly black night the ears do the work.

Pellets and pest control. Owls usually swallow small prey whole. The gizzard keeps back fur, bones, teeth and beetle shells and packs them into a **pellet**, which the owl coughs up

several hours later. Because the skeletons stay nearly intact, pellets are a record of exactly what the owl ate. A family of barn owls can eat thousands of rodents in one nesting season. Farmers have noticed: in Israel, a program led by ornithologist Yossi Leshem beginning in the 1980s set up thousands of barn owl nest boxes in fields as natural pest control, and growers in California and elsewhere do the same.

Owls in Scripture and in fear. The owl is listed among the unclean birds in Leviticus 11, and the psalmist in distress says, “I am like an owl of the desert” (Psalm 102:6), a picture of loneliness among ruins. The Hebrew bird names in these lists are not always certain, and the KJV’s “owl” may cover more than one kind. In many cultures owls were feared as omens of death. Christians need not fear them. The owl is not a messenger of doom but a creature fitted with remarkable ears and wings, hunting by the same Creator’s design every night.

PICTURE STUDY



Little Owl, Albrecht Dürer, 1506 · Watercolor and gouache on paper · Albertina, Vienna
Wikimedia Commons · Public domain

Albrecht Dürer of Nuremberg, the master who painted the *Young Hare* in 1502, made this small, careful study of a little owl. The little owl was a familiar bird of fields and walls in Europe, and in ancient Greece it was the bird of Athens, stamped on its silver coins.

Look closely

- Find the facial disc. How did Dürer show the ring of feathers that gathers sound?
- Study the eyes. Are they on the sides of the head, like a pigeon’s, or facing forward? What does that do for judging distance?
- Look at the feathers on the breast and wings. How did Dürer show that they are soft rather than stiff?

Talk about it

1. Dürer painted animals as carefully as he painted people. What can an artist learn from studying a creature this closely, and what can a scientist learn from the artist?
2. Why might people in the past have feared owls, and how does knowing how an owl hunts change the way you see it?

Safety first. Use only heat-sterilized owl pellets bought from a science supplier, never pellets picked up outdoors. Wear disposable gloves, work on newspaper, keep food away from the work area and wash hands well afterward.

HANDS-ON: OWL PELLET INVESTIGATION

Take apart an owl pellet, identify the prey, and use your results with Gilbert White's 1773 observations to estimate an owl's food needs. If you cannot get a pellet, use the online virtual pellet dissections and bone charts offered by several science suppliers and museums, and record the bones you find there.

You will need

- One or two sterilized barn owl pellets (from a science supplier)
- Disposable gloves, toothpicks or wooden skewers, tweezers, a paper plate and a magnifying glass
- A bone identification chart for small mammals and birds (usually included with pellets, or free online)
- A sheet of dark paper and glue for laying out bones
- The Primary source box from this stop

Steps

1. Weigh or measure the pellet and sketch it before you begin.
2. Gently tease apart the fur with toothpicks. Separate every bone and lay the bones on the paper plate.
3. Sort the bones into groups: skulls, jaws, leg bones, ribs, vertebrae and others. Count the skulls (or pairs of lower jaws) to find how many animals the owl ate.
4. Use the chart to identify the prey by the skull and teeth: vole, mouse, shrew or small bird. Glue one nearly complete skeleton onto dark paper in its natural shape and label it.
5. Read Gilbert White's observation. Using his "once in five minutes," calculate how many visits the pair made to the nest in one hour and in three hours. Then write a paragraph: what can you conclude about how much a barn owl family eats, and what do you not know from White's words alone?

Check your work

- I identified the prey animals in my pellet and counted them by skulls or jaws.

- I mounted and labeled one skeleton.
- I calculated feeding visits from White’s observation.
- My paragraph separates what White observed from what I am estimating.

FIELD NOTEBOOK

1. **Narration.** Write one paragraph, without looking back, explaining how a barn owl can catch a mouse in total darkness. Use the words facial disc, asymmetrical ears and silent flight. Give it to your parent to keep.
2. Draw an owl’s outer flight feather enlarged. Label the leading-edge serrations, the velvety surface and the fringed trailing edge.
3. Draw a diagram of an owl’s head from the front, with one ear opening higher than the other, and arrows showing a sound reaching each ear.

Did you know? Owls cannot move their eyes much, but they bob and sway their heads to judge distance by looking from slightly different positions. The burrowing owl of the western prairies nests underground in old prairie-dog and ground-squirrel burrows, and when disturbed its young can make a hiss that sounds like a rattlesnake.

Primary source. *Gilbert White, The Natural History of Selborne, Letter XV to the Hon. Daines Barrington, July 8, 1773 (Project Gutenberg eBook #20934). White was the curate of a country parish in Hampshire, England, and his “white owls” are barn owls.*

We have had, ever since I can remember, a pair of white owls that constantly breed under the eaves of this church. ... About an hour before sunset (for then the mice begin to run) they sally forth in quest of prey, and hunt all round the hedges of meadows and small enclosures for them, which seem to be their only food. ... I have minuted these birds with my watch for an hour together, and have found that they return to their nest, the one or the other of them, about once in five minutes; reflecting at the same time on the adroitness that every animal is possessed of as far as regards the well-being of itself and offspring.

Use this in Step 5 of the project and in Practice 4.

Go deeper. Gilbert White, *The Natural History of Selborne* (free at Project Gutenberg; read the rest of Letter XV). Cornell Lab of Ornithology, All About Birds: “Barn Owl” and “Great Horned Owl,” with recordings of their calls. The Owl Pages (owlpages.com) for species accounts. Second video topic: slow-motion comparisons of owl, pigeon and falcon flight recorded with sensitive microphones.

Goes deeper in. Life Science, high-school Biology, “Birds” and “The Senses” units (coming soon); Gardening & Animals, for barn owl boxes and natural pest control.

For families. Species counts vary with the authority (about 250 owl species). The sound-localization work is from Roger Payne (1971) and Masakazu Konishi and Eric Knudsen

(1970s); precision figures vary by study. The 270-degree head turn and the artery findings are from a 2013 Johns Hopkins study (de Kok-Mercado and colleagues). The 500 Series Shinkansen pantograph story is told by its engineer, Eiji Nakatsu. The Israeli barn owl program is associated with Yossi Leshem of Tel Aviv University. White's text is copied from Project Gutenberg; the ellipses mark omitted sentences. Pellets can carry bacteria unless heat-sterilized, hence the safety line.

PRACTICE

1. **EASY** Name the two families of owls and one feature of each.
2. **MEDIUM** How do uneven ear openings help a barn owl tell whether a sound is above or below it?
3. **MEDIUM** Why must an owl turn its head so far, and what keeps its brain supplied with blood while it does?
4. **MEDIUM** **Primary source.** White timed his owls returning "about once in five minutes." (a) How many returns is that per hour? (b) In a three-hour evening hunt? (c) Can you conclude that each return meant one mouse? Why or why not?
5. **CHALLENGE** Sound travels about 343 meters per second. A barn owl's ears are about 5 centimeters apart. (a) What is the largest possible difference in arrival time between the two ears, in microseconds? (b) If an owl can detect a difference of about 10 microseconds, what fraction of the maximum is that?
6. **CHALLENGE** A barn owl produces about one or two pellets a day. A class's pellets averaged 2.5 rodent skulls each. Estimate how many rodents one barn owl eats in a year, giving a low and a high estimate, and name two reasons your estimate could be wrong.

Make it a game • Owl Ears. One player sits blindfolded in the middle of a quiet room: the owl. The others stand around the room and, one at a time when the leader points, make a single soft click or tap. The owl points to the sound. Score how many times the owl is within an arm's width. Play again with the owl covering one ear. Then try the clicks from high (standing on a step) and low (on the floor). Which is hardest for a human, and why is it easier for a barn owl?

Scripture. "I am like a pelican of the wilderness: I am like an owl of the desert. I watch, and am as a sparrow alone upon the house top." (Psalm 102:6-7, KJV)

The psalmist, afflicted and alone, compares himself to birds of empty places. Later in the same psalm he says the LORD will regard the prayer of the destitute. The lonely owl of the ruins is not forgotten by its Maker, and neither is the one who cries to Him in the night.

Practice: answers

1. Barn owls, with heart-shaped facial discs; and typical owls (such as great horned owls and screech owls), usually with round faces, and many with ear tufts.
2. Because one ear is higher, a sound from above is louder in the higher ear and a sound from below is louder in the lower ear. The owl's brain compares the loudness to judge up and

down, and compares arrival time to judge left and right.

3. Its eyes are tube-shaped and fixed in bony rings, so it cannot move them; it has 14 neck vertebrae to turn its head up to about 270 degrees. Special features in its arteries, such as small blood reservoirs and roomy bony channels, keep blood flowing during the turn.
4. (a) $60 \div 5 = 12$ returns per hour. (b) 36 returns in three hours. (c) Not for certain: White says they returned, and owls usually carry prey back, but some trips may have failed or brought shrews or other prey. It is a reasonable estimate, not an observation.
5. (a) $0.05 \text{ m} \div 343 \text{ m/s} \approx 0.000146 \text{ s} \approx 146 \text{ microseconds}$ (when the sound is straight to one side). (b) $10 \div 146 \approx 0.07$, about one-fifteenth of the maximum. That is why the owl can aim within a few degrees.
6. Low: $1 \text{ pellet} \times 2.5 \times 365 \approx 900$. High: $2 \text{ pellets} \times 2.5 \times 365 \approx 1,800$. Sources of error: pellet counts per day vary with season and food supply; some prey (birds, insects) may not leave skulls; owls feeding young catch more than they eat themselves; a class's pellets may not be typical.

2.3 HUMMINGBIRDS: LIVING ON THE EDGE OF ENERGY

OBJECTIVES

- Explain how a hummingbird hovers, with numbers for wingbeats and the share of lift from each stroke.
- Describe a hummingbird's energy budget and how torpor and fat storage let it survive cold nights and long migrations.
- Explain structural (iridescent) color and the partnership between hummingbirds and the flowers they pollinate.

Warm-up. Tap a pencil on the table as fast as you can for 10 seconds while someone counts. A ruby-throated hummingbird beats its wings about 50 times every second, or about 500 times in those 10 seconds. How close did you come?

Video slot. Video coming. Slow-motion hummingbird hovering and wing motion, hummingbird tongue drinking nectar, Anna's hummingbird courtship dive, hummingbird torpor. Search approved channels (Cornell Lab of Ornithology, Smithsonian, National Park Service, PBS Nature); preview first.

KEY TERMS

hovering

Staying in one place in the air by producing lift on both the forward and backward strokes of the wing.

metabolic rate

The rate at which an animal's body uses energy. Hummingbirds have the highest rate per gram of any bird.

torpor

A deep, short-term sleep-like state in which body temperature and energy use drop sharply, usually overnight.

iridescence

Shimmering color that changes with the angle of view, made by tiny structures that reflect light rather than by pigment.

gorget

The patch of brilliant iridescent throat feathers on many male hummingbirds.

pollination

Carrying pollen from one flower to another so the plant can make seeds; hummingbirds pollinate many flowers while drinking nectar.

CORE IDEAS

Across the Gulf. On a spring evening on the coast of the Yucatán Peninsula, a ruby-throated hummingbird lifts off and heads north over open water. Two weeks ago it weighed about 3 grams, a little more than a penny. Feeding almost without pause, it has added so much fat that it now weighs close to 6 grams. Many ruby-throats cross the Gulf of Mexico in a single nonstop flight of about 500 miles, landing on the Gulf Coast the next day; others follow the coastline around. Either way, a bird smaller than your thumb has made a journey that would challenge a small airplane.

The family. There are about 360 species of hummingbirds, and every one lives in the Americas, most of them in the tropics; the Andean countries have well over a hundred kinds each. The bee hummingbird of Cuba, about 2 grams and 2¼ inches long, is the smallest bird in the world. The giant hummingbird of the Andes is about 20 grams and 8 inches long. East of the Great Plains, only the ruby-throat commonly nests.

How a hummingbird hovers. Most birds get nearly all their lift on the downstroke. A hummingbird's wing is mostly "hand": long finger bones and short arm bones, joined to a shoulder that can swivel almost freely. In hovering, the wing sweeps forward and back in a flattened figure eight, and on the backstroke the wing turns over so it still pushes air downward. A 2005 study of rufous hummingbirds found that about 75 percent of the lift came from the downstroke and about 25 percent from the upstroke; an insect's hovering stroke is closer to even. Ruby-throats beat their wings about 50 times a second; smaller species beat faster. The flight muscles make up roughly a quarter or more of the body weight. Hummingbirds can fly forward, backward and even briefly upside down. And in courtship, a male Anna's hummingbird climbs high and dives past a female at about 60 miles per hour; researcher Christopher Clark calculated that this is about 385 of its own body lengths per second, faster for its size than a falcon's stoop or a jet fighter.

An engine that must keep running. All this costs energy. Per gram of body, a hovering hummingbird uses energy faster than any other bird, and its heart can beat more than 1,000 times a minute in flight. It must feed every few minutes through the day, visiting hundreds of flowers and drinking a large fraction of its own weight in nectar, plus small insects and spiders for protein. Its tongue is a marvel: the forked tip is fringed, and when it dips into nectar the tips spring open and close around the liquid, and the grooves refill like an elastic pump as the tongue flicks in and out many times a second.

Torpor. A small, hot body loses heat fast, and a hummingbird cannot eat in the dark. On cold nights it enters **torpor**. Its body temperature, normally about 104°F (40°C), drops toward the temperature of the air, and its energy use falls by as much as 95 percent. In 2020 researchers in the Peruvian Andes recorded a black metaltail in torpor at about 38°F (3.3°C), the lowest body temperature known for a bird. At dawn the bird shivers its flight muscles to warm up, which takes about 20 minutes, and flies off to feed.

Color made of structure. A male ruby-throat's **gorget** looks black from one angle and flames red from another. The color is not mainly pigment. Inside each feather are layers of

microscopic platelets, filled with tiny air bubbles, that reflect certain wavelengths of light so that they add together, the way a soap bubble or oil film shows colors. Turn the bird, and the reflection is lost. Engineers study such feathers to make colors that never fade.

A partnership. Many flowers in the Americas are shaped for hummingbirds: red or orange tubes, little or no scent (birds have a weak sense of smell), no landing platform, and nectar deep inside. As the bird drinks, pollen dusts its forehead or bill, and it carries the pollen to the next flower. Cardinal flower, trumpet creeper, columbine and many tropical plants depend on these visits. Jesus told His disciples to “behold the fowls of the air,” fed by their heavenly Father. Few creatures live closer to the edge of their energy than a hummingbird, and few show more plainly that the Father feeds them day by day.

PICTURE STUDY



Cattleya Orchid and Three Hummingbirds, Martin Johnson Heade, 1871 · Oil on wood · National Gallery of Art, Washington, D.C.

Wikimedia Commons · Public domain

Martin Johnson Heade, an American painter, traveled to Brazil in 1863 to paint its hummingbirds for a book he planned to call *The Gems of Brazil*. The book was never finished, but for the rest of his life he painted hummingbirds beside orchids and passionflowers in misty forests. Heade often arranged birds and flowers together by his own design, so the scene is a composed picture, not a single moment he witnessed.

Look closely

- Find all three hummingbirds. Which one shows a bright throat or crown, and from what angle?
- Look at the orchid. Is it the kind of flower a hummingbird would pollinate? (Look at its shape and color.)

- Study the background. How did Heade show the damp air of a tropical forest?

Talk about it

1. Heade painted the iridescent feathers with ordinary paint. How might he have tried to show color that changes with angle?
2. Orchids like this are mostly pollinated by bees, not hummingbirds. Why might Heade have put them together anyway, and what does that tell you about reading a painting as evidence?

Safety first. Making nectar uses boiling water on the stove; a parent should supervise, and let the syrup cool completely before filling the feeder.

HANDS-ON: A HUMMINGBIRD ENERGY BUDGET

Work out what it costs to be a hummingbird, then (in season) test your ideas at a feeder. Ruby-throats are in most of the eastern United States from about April to September; in the West, Anna's hummingbirds stay all year in many places. Out of season, do Part A now and Part B in spring.

You will need

- Notebook, calculator and graph paper
- For Part B: a hummingbird feeder (red parts, no red dye needed), white table sugar, water, a saucepan and a timer

Steps

1. **Part A.** Use these assumptions (they are round numbers for practice, not measurements): a 3-gram hummingbird drinks 1.5 times its weight in nectar each day; the nectar is 20 percent sugar by weight; sugar provides 4 Calories per gram. Calculate the grams of nectar, grams of sugar and Calories per day.
2. Now scale up: suppose a 60-kilogram (132-pound) person ate the same amount per kilogram of body weight. How many kilograms of sugar and how many Calories would that be? Compare with a normal human diet of about 2,000–2,500 Calories.
3. Write a paragraph explaining why your scaled-up number is too large to be fair. (Hint: small animals lose heat much faster for their size because they have more surface for their volume.)
4. **Part B.** Make nectar: 1 part white sugar to 4 parts water, boiled briefly and cooled. Do not use honey or red dye. Hang the feeder where you can see it from a window, and change the nectar every two or three days (daily in hot weather).
5. On three days, watch for 20 minutes at the same time of day. Record each visit and how many seconds the bird drinks. Calculate visits per hour and average drinking time, and note any chasing between birds.

Check your work

- I calculated grams of nectar, grams of sugar and Calories per day.
- I scaled the result to a human and explained why the comparison exaggerates.
- In season, I kept a clean feeder and recorded at least three 20-minute watches (or I have scheduled Part B for spring).

FIELD NOTEBOOK

1. **Narration.** Write one paragraph, without looking back, explaining how a hummingbird survives a cold night and how it prepares to cross the Gulf of Mexico. Use the words torpor, metabolic rate and fat. Give it to your parent to keep.
2. Draw a hummingbird hovering seen from the side, with the figure-eight path of the wingtip drawn as a dotted line. Label the downstroke and the upstroke and write the share of lift beside each.
3. Draw a flower shaped for hummingbirds (tube, color, nectar deep inside) and show where pollen touches the bird.

Did you know? Hummingbird nests are about the size of half a walnut shell and are bound together with spider silk, so they stretch as the chicks grow. Hummingbirds have tiny feet and can perch and shuffle, but they cannot walk or hop. And a hummingbird's flight muscles are so rich in energy-burning mitochondria that, gram for gram, they are among the most powerful muscles of any animal.

Go deeper. Cornell Lab of Ornithology, All About Birds: "Ruby-throated Hummingbird" and "Anna's Hummingbird." Sheri L. Williamson, *A Field Guide to Hummingbirds of North America* (Peterson Field Guides, 2001). The National Gallery of Art's online collection, for more of Heade's hummingbird paintings. Second video topic: high-speed video of a hummingbird's tongue drinking from a clear feeder.

Goes deeper in. Life Science, high-school Biology, "Birds" and "Energy in Living Things" units (coming soon); Gardening & Animals, for planting a hummingbird garden of native red tubular flowers.

For families. No suitable public-domain primary source was confirmed for this stop, so it has none; Audubon's chapter on the ruby-throat (in *Ornithological Biography*, vol. 1, 1831, free at Project Gutenberg) is a good optional reading. Figures: about 360 species; 75/25 lift split from Warrick, Tobalske and Powers, *Nature* (2005); the Anna's hummingbird dive from Christopher Clark (2009); the 3.3°C torpor record from Wolf and others, *Biology Letters* (2020). Gulf crossing distance and weight gain are typical values; some birds go around the Gulf. The energy numbers in the project are labeled assumptions for practice. The 1:4 sugar-to-water recipe and the advice against red dye follow the Cornell Lab and the Audubon Society.

PRACTICE

1. **EASY** On which continents do hummingbirds live, and which is the smallest bird in the world?
2. **MEDIUM** Why does a male ruby-throat's gorget look black from some angles and red from others?
3. **MEDIUM** A ruby-throat beats its wings about 53 times per second. How many wingbeats is that per minute? Per hour of hovering?
4. **MEDIUM** Give two features of a flower that suggest it is pollinated by hummingbirds rather than bees, and explain each.
5. **CHALLENGE** Suppose a hummingbird resting overnight at normal body temperature would use 100 units of energy in 10 hours. In torpor its energy use falls by 95 percent. If it spends 2 hours awake (cooling down and warming up) and 8 hours in torpor, how much energy does it use, and what percentage does it save?
6. **CHALLENGE** An Anna's hummingbird dives at about 385 of its own body lengths per second. If a 6-foot person could move at 385 body lengths per second, how fast would that be in feet per second and in miles per hour? What does the comparison show, and what does it leave out?

Make it a game • Flower Hop. Scatter ten paper “flowers” around a yard or large room, each with a bead or a slip of paper underneath for “nectar.” The hummingbird must visit flowers and collect nectar, but every 15 seconds the leader calls “burn!” and the player must hand back one bead. Can the hummingbird stay ahead? Then shorten the time between burns to show a cold day or a hovering bird. Finally, play “night”: the player must sit still holding beads; a player who “goes into torpor” (stays perfectly still) pays only one bead for the whole night.

Scripture. “Behold the fowls of the air: for they sow not, neither do they reap, nor gather into barns; yet your heavenly Father feedeth them. Are ye not much better than they?” (Matthew 6:26, KJV)

A hummingbird stores almost nothing; it must find food every few minutes and lives on what the day provides. Jesus points to such birds to teach His disciples not to be anxious. The Father who feeds them daily cares far more for His children.

Practice: answers

1. Only in the Americas (North and South America and the Caribbean). The smallest is the bee hummingbird of Cuba, about 2 grams.
2. The color is iridescent, made by microscopic platelet layers in the feathers that reflect red light strongly only at certain angles. When the angle is wrong, little red light reaches your eye and the throat looks dark.
3. $53 \times 60 = 3,180$ per minute; $3,180 \times 60 = 190,800$ per hour.
4. Any two: red or orange color (birds see red well; many bees do not); a long tube (fits the bill and keeps out short-tongued insects); little scent (birds smell poorly); no landing platform

(hummingbirds hover); plenty of dilute nectar deep inside.

5. Awake: $2 \text{ hours} \times 10 \text{ units/hour} = 20$. Torpor: $8 \text{ hours} \times (10 \times 0.05) = 8 \times 0.5 = 4$. Total = 24 units, saving 76 units, or 76 percent.
6. $385 \times 6 = 2,310$ feet per second. $2,310 \times 3,600 \div 5,280 \approx 1,575$ miles per hour, about twice the speed of sound. It shows the dive is astonishing for the bird's size. It leaves out that speed relative to body length is not the same as actual speed (the bird is going about 60 mph), and that air resistance and forces do not scale up simply with size.

2.4 PENGUINS: FLYING UNDER THE ICE

OBJECTIVES

- Explain how a penguin's body is designed for "flying" underwater and for keeping warm, including countercurrent heat exchange.
- Describe the emperor penguin's winter breeding cycle with numbers for fasting, weight loss and incubation.
- Tell the story of the 1911 Winter Journey from a primary source and evaluate the scientific reason it was made.

Warm-up. Hold an ice cube in your bare hand for as long as you comfortably can (no more than a minute). Now imagine standing on ice in the dark for two months at forty degrees below zero, with an egg balanced on your feet. Write down three things your body would need to survive.

Video slot. Video coming. Emperor penguin huddles and males incubating eggs on their feet, penguins swimming underwater, gentoo and Adélie penguins porpoising. Search approved channels (BBC Earth, Smithsonian, Australian Antarctic Division, British Antarctic Survey); preview first.

KEY TERMS

flightless

Unable to fly in air. Penguins' wings have become stiff flippers used to "fly" through water.

countercurrent heat exchange

An arrangement of blood vessels in which warm blood flowing out to the feet or flippers passes close to cold blood flowing back, so heat is handed back to the body instead of lost.

brood pouch

A fold of feathered skin on the lower belly of emperor and king penguins that covers the egg as it rests on the parent's feet.

huddle

A tightly packed group of emperor penguins sharing warmth, in which birds slowly shift from the cold edge to the warm center.

crèche

A group of penguin chicks gathered together for warmth and safety while both parents are away fishing.

krill

Small shrimp-like animals that swarm in huge numbers in the Southern Ocean and feed penguins, seals and whales.

CORE IDEAS

The Winter Journey. On June 27, 1911, in the middle of the Antarctic winter, three men of Captain Scott's expedition left their hut at Cape Evans pulling two sledges: Edward Wilson, the expedition's chief scientist; Henry Bowers; and Apsley Cherry-Garrard, the youngest. Their goal was Cape Crozier, about 60 miles away, where Wilson knew emperor penguins bred on the sea ice. They traveled in near-total darkness, at temperatures down to about -77°F , sometimes covering only a mile or two in a day. At Crozier they collected five eggs; a blizzard tore away their tent, and they lay in their sleeping bags in the storm until, by God's mercy, they found it again. They returned on August 1, five weeks after setting out. Three eggs survived. Wilson and Bowers died the next year with Scott on the return from the South Pole, and in 1913 Cherry-Garrard delivered the eggs to the Natural History Museum in London.

Why the eggs? Wilson hoped that early penguin embryos would reveal the history of birds, because some scientists then believed that an embryo passes through stages showing its ancestors. That idea has since been abandoned, and the eggs, when finally studied, settled nothing of the kind. Honest complexity: the reason for the journey was mistaken, but the courage, loyalty and careful observation of the three men were real, and Cherry-Garrard's book about it, *The Worst Journey in the World* (1922), is one of the great true adventure stories.

The penguins. There are about 18 species of penguins, and all live in the Southern Hemisphere; only the Galápagos penguin reaches the equator. The little penguin of Australia and New Zealand stands about a foot tall and weighs about 2 pounds. The emperor is the largest, about 45 inches tall, and a male may weigh up to about 88 pounds when he arrives to breed. Penguins eat fish, squid and **krill**, caught on dives.

Built to fly underwater. A flying bird has light, often hollow bones. A penguin's bones are dense and heavy, which helps it dive instead of bobbing like a cork. The wing bones are flattened and stiffened into a flipper, driven by powerful breast muscles, and the bird literally flies through the water. Its body is a smooth torpedo, and gentoo penguins reach about 20 miles per hour. Emperors dive deepest of all birds: tracking has recorded dives of more than 1,800 feet and lasting more than 20 minutes, with the heart slowing and oxygen stored in blood and muscle. Small, stiff, overlapping feathers, densely packed like shingles, trap a layer of air, and a layer of fat lies beneath the skin.

Countercurrent heat exchange. How do bare feet stand on ice for months without freezing or draining the body of heat? In the legs and flippers, arteries carrying warm blood outward run right alongside veins bringing cold blood back. Heat passes from the outgoing blood to the returning blood, so the feet receive blood that is already cool, just warm enough to keep the tissue alive, and the body keeps its heat. Engineers use the same principle in heat-recovery ventilators.

Fathers in the dark. Emperors are the only birds that breed through the Antarctic winter. They walk as far as 50 miles or more inland over the sea ice in March or April. In May or

June, each female lays a single egg and passes it carefully to her mate's feet, then walks back to the sea to feed. The male balances the egg on his feet under his **brood pouch** for about 65 days through the polar night, in temperatures that can fall to -40°F and winds that can exceed 100 miles per hour. He eats nothing. By the time the chick hatches, a male may have fasted about four months and lost 40 percent or more of his weight. Thousands of males pack into **huddles**, slowly rotating so each takes turns at the cold edge; measurements inside dense huddles have found temperatures well above freezing, at times higher than 70°F . When the female returns, she feeds the chick; if she is late, the father can feed it a protein-rich secretion from his throat. Later the chicks gather in **crèches** while both parents fish.

The first “penguin.” The name “penguin” first belonged to a different bird: the great auk of the North Atlantic, a large flightless swimmer with a black back and white belly. Sailors killed great auks by the thousands for food, feathers and oil, and the last known pair was killed on the island of Eldey, off Iceland, in June 1844. When sailors in the Southern Ocean met similar birds, they used the same name. The two are not closely related, but the Creator gave them a similar design for the same work, and the great auk's loss is a sober lesson in stewardship. Today the Antarctic Treaty (1959) sets aside Antarctica for peaceful scientific study, and penguin colonies are protected.

PICTURE STUDY



Great Auk, Plate 341 of The Birds of America, John James Audubon (engraved by Robert Havell Jr.), Published c. 1836 · Hand-colored engraving and aquatint · From The Birds of America
Wikimedia Commons · CC0

Audubon never saw a living great auk; by his time they were already nearly gone, and he likely painted from a specimen. This is the bird that first carried the name “penguin.” Compare it with a photograph of a modern penguin as you look.

Look closely

- Look at the wings. Are they large enough to fly? What were they used for?
- Compare the black back and white belly with a penguin's coloring. Why might this pattern help a swimmer hide from both above and below?
- Look at how upright the birds stand. Where must the legs be set on the body?

Talk about it

1. Audubon was painting a bird that was disappearing. What responsibility does that give an artist or a scientist?
2. The great auk and the penguins are similar but not closely related. What does it suggest that the Creator used a similar design for birds that do similar work?

Safety first. Use hot tap water, not boiling water, and have a parent help pour it.

HANDS-ON: THE HUDDLE EXPERIMENT

Test whether huddling really saves heat, using jars of warm water as penguins. You will collect real data and graph it.

You will need

- Eight small identical jars or cans with lids (baby food jars or soup cans work)
- Hot tap water
- A thermometer (a cooking or aquarium thermometer is fine)
- A cold place: a refrigerator shelf, a cooler with ice packs, or outdoors on a cold day
- Rubber bands, a timer and graph paper

Steps

1. Fill all eight jars with hot tap water from the same pour and measure the starting temperature of each.
2. Band six jars tightly in a ring around a seventh: the huddle. Set the eighth jar a foot away by itself: the lone penguin.
3. Put the huddle and the lone jar in the cold place. Every 5 minutes for 30 minutes, measure the temperature of the lone jar, one edge jar and the center jar.
4. Graph temperature against time for all three, with a different color for each.
5. Write a paragraph explaining your results using the idea of surface area exposed to cold. Then explain why emperors rotate through the huddle, and why the father must fast to stay in it.

Check your work

- I measured three jars every 5 minutes for 30 minutes.
- My graph has a title, labeled axes with units and a key.

- My paragraph explains why the center stayed warmest and connects it to emperor huddles.

FIELD NOTEBOOK

1. **Narration.** Write one paragraph, without looking back, telling the story of the Winter Journey of 1911: who went, where, why and what happened. Give it to your parent to keep.
2. Draw a penguin's leg with an artery and a vein side by side. Use red and blue arrows and temperatures (for example 100°F leaving the body, 40°F at the foot) to show countercurrent heat exchange.
3. Draw an emperor father with the egg on his feet under the brood pouch, and label the parts.

Did you know? Penguins drink seawater. A gland above each eye removes extra salt from the blood, and the salty liquid drips out through the nostrils, which is why penguins often seem to sneeze or shake their heads. Emperor chicks have gray down and a black-and-white head, and they cannot swim until they grow waterproof adult feathers.

Primary source. *Apsley Cherry-Garrard, The Worst Journey in the World (1922), Introduction, describing the emperor penguin (Project Gutenberg eBook #14363).*

For a reason which was not then understood it lays its eggs upon the bare ice some time during the winter and carries out the whole process of incubation on the sea ice, resting the egg upon its feet pressed closely to a patch of bare skin in the lower abdomen, and protected from the intense cold by a loose falling lappet of skin and feathers.

Underline the parts of this description that are still accepted today. Use it in Practice 3.

Go deeper. Apsley Cherry-Garrard, *The Worst Journey in the World* (1922; free at Project Gutenberg; a long book, best read in the Winter Journey chapters). The Natural History Museum, London (nhm.ac.uk), on the three Cape Crozier eggs, which it still holds. The British Antarctic Survey (bas.ac.uk) on emperor penguins. Second video topic: underwater footage of emperor penguins diving beneath the sea ice.

Goes deeper in. Life Science, high-school Biology, “Birds” and “Homeostasis” units (coming soon); Geography, Antarctica and the Southern Ocean; History, the age of polar exploration.

For families. Dates of the Winter Journey (June 27 to August 1, 1911) and the lowest temperature (about −77°F) are from Cherry-Garrard's account; distance figures are approximate. Wilson and Bowers died with Scott in March 1912; their deaths are stated without detail. Species counts vary from 17 to 19 by authority. Dive figures (over 1,800 ft; over 20 minutes) and huddle temperatures are from published tracking and logger

studies and vary by bird. The embryo theory behind the journey (recapitulation) is now abandoned by scientists of every view; the stop says so plainly and does not use it as a lesson in origins. The great auk's last pair was killed on Eldey in June 1844.

PRACTICE

1. **EASY** In which hemisphere do penguins live, and which species reaches the equator?
2. **MEDIUM** Explain countercurrent heat exchange in a penguin's foot in two or three sentences.
3. **MEDIUM** **Primary source.** According to Cherry-Garrard's description, where does the emperor rest its egg and what protects it? Which phrase shows that some things about the emperor were not understood in 1911?
4. **MEDIUM** Give two reasons why dense, heavy bones help a penguin but would hurt a flying bird.
5. **CHALLENGE** A male emperor arrives at the colony weighing 38 kg and loses 40 percent of his weight over a 115-day fast. (a) What does he weigh at the end? (b) On average, how many grams does he lose per day?
6. **CHALLENGE** Water pressure increases by about 1 atmosphere for every 10 meters of depth, on top of the 1 atmosphere of air at the surface. An emperor dives to 550 meters. (a) What is the total pressure in atmospheres? (b) In pounds per square inch, if 1 atmosphere is about 14.7 psi?

Make it a game • Huddle Up. Players stand close together in a huddle. One player is the wind and stands to one side. Every 20 seconds the wind calls "shift!" and the two players on the windward edge must walk around the outside to the sheltered side and squeeze back in. Count how many shifts it takes for every player to have a turn at the edge. Then talk about it: is the huddle fair? (In real huddles, birds rotate slowly so that all share the cold.)

Scripture. "Out of whose womb came the ice? and the hoary frost of heaven, who hath gendered it? The waters are hid as with a stone, and the face of the deep is frozen." (Job 38:29-30, KJV)

The LORD asked Job questions he could not answer, to show him the greatness of God's works. "The face of the deep is frozen" is the emperor's home. The God who made the ice also made a bird to raise its young upon it.

Practice: answers

1. The Southern Hemisphere. The Galápagos penguin reaches the equator.
2. Warm blood flowing down the leg in the arteries passes right beside cold blood flowing back up in the veins. Heat moves from the outgoing blood to the returning blood, so the foot gets cool blood and loses little heat to the ice, while the heat is carried back into the body.
3. On its feet, pressed against a patch of bare skin on the lower abdomen and covered by a loose fold ("lappet") of skin and feathers, the brood pouch. The phrase "For a reason which was not

then understood” shows that scientists did not yet know why the emperor breeds in winter.

4. They reduce buoyancy, so the penguin can dive deeper with less effort, and they are strong for driving flippers through dense water. A flying bird needs light bones to get airborne cheaply in thin air.
5. (a) $38 \times 0.40 = 15.2$ kg lost; $38 - 15.2 = 22.8$ kg. (b) $15.2 \text{ kg} \div 115 \text{ days} \approx 0.132$ kg, about 132 grams per day.
6. (a) $550 \div 10 = 55$ atmospheres from water, plus 1 from air = 56 atmospheres. (b) $56 \times 14.7 \approx 823$ psi.

2.5 OSTRICHES: “SHE SCORNETH THE HORSE AND HIS RIDER” (JOB 39:13–18)

OBJECTIVES

- Explain how the ostrich’s skeleton, legs and feet are built for running rather than flying, with numbers for speed and stride.
- Compare Job 39:13–18 with modern observations of ostrich nesting and with Xenophon’s eyewitness account from 401 B.C.
- Describe the rise and fall of the ostrich-feather trade as a lesson in economics and stewardship.

Warm-up. Measure your stride: walk ten normal steps, measure the distance and divide by ten. Then run ten strides and do the same. An ostrich’s running stride can reach about 16 feet. How many of your running strides is that?

Video slot. Video coming. Ostriches running in slow motion, ostrich nests with many eggs, male and female ostriches sitting on the nest, ostrich chicks with parents. Search approved channels (BBC Earth, Smithsonian, San Diego Zoo Wildlife Alliance, PBS Nature); preview first.

KEY TERMS

ratite

A flightless bird with a flat breastbone and no keel, such as the ostrich, emu, rhea, cassowary and kiwi.

keel

The tall ridge on the breastbone of flying birds, where the large flight muscles attach.

stride length

The distance covered by one step while running, from one foot touching the ground to the other foot touching.

communal nest

A nest in which several females lay their eggs, as ostriches do.

major hen

The dominant female ostrich who lays first in a nest, incubates it with the male and favors her own eggs.

boom and bust

A rapid rise in a business or price followed by a sudden collapse, as in the ostrich-feather trade before and after 1914.

CORE IDEAS

A soldier's report. In 401 B.C. a Greek army marched east along the Euphrates River to fight for a Persian prince, Cyrus the Younger. One of its officers, Xenophon, wrote an account called the *Anabasis*. Crossing the open country of the Arabian desert, the horsemen tried to run down the wild animals they saw. They could not catch a single ostrich: the bird outran them, "using its wings the while like a sail." Xenophon had never read the book of Job, but he saw what Job's poet saw: "What time she lifteth up herself on high, she scorneth the horse and his rider" (Job 39:18).

The largest bird. A male ostrich may stand about 9 feet tall to the top of the head and weigh up to about 300 pounds. Most authorities now count two species, the common ostrich and the Somali ostrich, both of Africa. Ostriches are **ratites**: the breastbone is flat, with no **keel** to anchor big flight muscles, and the small, soft wings are used for balance, display and shading chicks. Their relatives of the same general kind include the emu of Australia, the rheas of South America, the cassowaries and the little kiwis.

Built to run. An ostrich can sprint at about 43 miles per hour and keep up a speed near 30 miles per hour for a long distance. Its stride can reach about 16 feet. Several design features work together. The heavy muscles sit high on the thigh near the body, so the long lower leg is light and easy to swing. Long tendons stretch and spring back with each step like elastic bands, returning energy. And the ostrich is the only bird with just two toes on each foot; the larger toe bears a thick nail and takes most of the weight, like a hoof. Its forward kick is powerful enough to injure or kill a person or a large predator, so wise keepers stay out of reach. A good horse can match an ostrich in a short sprint, but a horse carrying a rider tires sooner. Job's line is sober fact.

Eyes and eggs. An ostrich's eye is about 2 inches across, the largest of any land animal, and larger than its brain. Its egg is the largest of any living bird: about 6 inches long and about 3 pounds, equal in contents to about two dozen chicken eggs, with a shell about 2 millimeters thick. In the Kalahari, people have long used emptied ostrich eggshells as water canteens, and ostrich-shell beads are among the oldest known ornaments in Africa.

Reading Job closely. Job 39:14-16 says the ostrich "leaveth her eggs in the earth, and warmeth them in dust," forgets "that the foot may crush them," and "is hardened against her young ones." Field studies show what an ancient herdsman might have seen. The male scrapes a shallow nest in the sand. The **major hen** lays her eggs, and several other hens add theirs, so a nest may hold 30 or more eggs, but a pair can cover only about 20. The major hen recognizes her own eggs and rolls extra eggs to the rim, where jackals, vultures or the sun may take them. In the heat of the day the eggs may be left for a time, warmed by the sun and sand. And when danger comes, adults often run off rather than defend the nest. Honest complexity: ostriches do incubate (the female by day, the male by night), and parents guard their chicks. Job is a poem of what is seen, not a full field guide, and its point is in verse 17: God made the ostrich without certain kinds of wisdom, yet gave it speed and strength. God's creatures are not all alike, and He provides for each according to its kind. (In verse 13, the

Hebrew word translated “peacocks” is thought by many scholars to be another name for ostriches.)

The feather boom. Ostrich plumes have been prized since ancient Egypt. In the 1860s, farmers in the Cape Colony of South Africa learned to raise ostriches and clip their plumes without killing the birds. As fashion demanded great feathered hats, the trade boomed; by about 1913 ostrich feathers were among the Cape’s most valuable exports, and farmers around Oudtshoorn built grand “feather palaces.” Then, around 1914, the market collapsed: fashions changed, open automobiles made huge hats impractical, and the First World War cut trade. Many farmers were ruined. It is a classic **boom and bust**: a business built on a single fashionable product, financed by high prices that everyone expected to last.

Stewardship. The ostrich of Job’s own lands, the Arabian ostrich, was hunted until it disappeared during the 20th century, after the arrival of rifles and motor vehicles. Wild ostriches still roam large parts of Africa, and in some places ostriches from North Africa have been brought back to land where their cousins once lived. Ostriches are now farmed around the world for leather, meat and feathers. The bird that scorned the horse could not outrun the rifle and the car; the dominion of Genesis 1:28 calls for wisdom as well as power.

PICTURE STUDY



*The Great Hunt (detail: an ostrich carried aboard a ship), Unknown Roman mosaic workers, probably from North Africa, Early 4th century A.D. · Floor mosaic of small stone pieces (tesserae) · Villa Romana del Casale, near Piazza Armerina, Sicily
Wikimedia Commons · Public domain*

A long corridor in a grand Roman country house in Sicily is paved with a mosaic more than 60 meters long, showing hunters capturing animals in Africa and Asia and loading them onto ships for the arena shows in Rome. In this detail a man carries an ostrich aboard. Ostriches, lions, leopards and antelope were shipped across the Mediterranean in large numbers.

Look closely

- Find the ostrich. How did the artist show its long neck, two-toed feet and soft plumes using only small stones?

- Look at how the man holds the bird. Why would you want to keep away from an ostrich's feet?
- Look at the colors. How did the mosaic makers suggest shading and roundness?

Talk about it

1. This mosaic shows animals being captured for the arena. What does it tell you about how Romans saw wild creatures, and how does Genesis 2:15 offer a different view?
2. Xenophon's horsemen could not catch an ostrich. How do you think the Romans caught them alive?

HANDS-ON: STRIDE, SPEED AND THE HORSE: A RUNNING LAB

Measure your own running and compare it with an ostrich and a horse, then use Xenophon and Job to write a short evidence paragraph.

You will need

- A tape measure (at least 50 feet), chalk or cones, a stopwatch
- A flat, safe running area such as a park path or field
- A helper to time you
- The Primary source box from this stop

Steps

1. Mark a 50-foot course. Run it at full speed three times, counting your strides and timing each run.
2. For each run, calculate your speed in feet per second and miles per hour ($\text{mph} = \text{feet per second} \times 3,600 \div 5,280$), and your average stride length.
3. Make a table comparing you with an ostrich (about 43 mph sprint, stride up to about 16 feet) and a racehorse (about 40–44 mph sprint, but slower with a rider over distance).
4. Calculate how many of your strides fit in one ostrich stride, and how long the ostrich would take to cover your 50-foot course.
5. Read Xenophon's account and Job 39:18. Write a paragraph: does Xenophon's eyewitness report support Job's description? What exactly does each say about wings, legs and horses?

Check your work

- I ran and timed three trials and calculated speed and stride length.
- My table compares me, an ostrich and a horse with units.
- My paragraph quotes both sources accurately and compares them point by point.

FIELD NOTEBOOK

1. **Narration.** Write one paragraph, without looking back, explaining how an ostrich nest works and how it fits Job 39:14–16. Include the major hen and the eggs at the rim. Give it to your parent to keep.
2. Draw an ostrich leg and foot. Label the thigh muscles, the long lower leg, the two toes and the thick nail.
3. Draw a breastbone with a keel (a flying bird's) beside a flat ratite breastbone, and write one sentence explaining the difference.

Did you know? Ostriches do not bury their heads in the sand. The legend may come from the way an ostrich lowers its head and neck flat to the ground to hide, or bends into the nest to turn its eggs. Ostriches also swallow pebbles, which grind food in the gizzard, and a single bird may carry a pound or more of stones.

Primary source. *Xenophon, Anabasis, Book I, chapter 5 (written some years after the march of 401 B.C.), translated by H. G. Dakyns (Project Gutenberg eBook #1170).*

No one was lucky enough to capture an ostrich. Some of the troopers did give chase, but it had soon to be abandoned; for the bird, in its effort to escape, speedily put a long interval between itself and its pursuers; plying its legs at full speed, and using its wings the while like a sail.

Use this in Step 5 of the project and in Practice 3.

Go deeper. Xenophon, *Anabasis* (free at Project Gutenberg; Book I tells the march along the Euphrates). Cornell Lab of Ornithology and San Diego Zoo Wildlife Alliance pages on the ostrich. The Villa Romana del Casale's official site, for photographs of the whole Great Hunt corridor. Second video topic: the ostrich-feather palaces of Oudtshoorn, South Africa, and the history of the feather trade.

Goes deeper in. Life Science, high-school Biology, "Birds" and "Skeletons and Movement" units (coming soon); Small Business & Economics, for the feather boom and bust; History, ancient Greece and Persia, for Xenophon.

For families. Size and speed figures are typical published values and vary by source. Nesting details (major hen, egg rolling, about 20 eggs incubated) follow field studies of common ostriches, especially by Brian Bertram in Kenya. The note on Job 39:13 reflects a common scholarly reading of the Hebrew *renanim*; the KJV says "peacocks," and the stop keeps the KJV text. The Cape feather-trade details are general (a leading export by about 1913, collapse around 1914). The Arabian ostrich is generally considered extinct by the mid-20th century; exact dates are uncertain, so the stop does not give one. The mosaic is usually dated to the early 4th century A.D. Xenophon's text is copied from Project Gutenberg.

PRACTICE

1. **EASY** What makes the ostrich unique among all birds in its feet?
2. **MEDIUM** Why can't an ostrich fly? Use the word keel.
3. **MEDIUM** **Primary source.** List two details in Xenophon's account that match Job 39:18, and one detail Xenophon adds that Job does not mention.
4. **MEDIUM** An ostrich egg holds about 1.2 kg of contents, and a chicken egg about 50 g. How many chicken eggs is one ostrich egg?
5. **CHALLENGE** An ostrich sprints at 43 mph with a 16-foot stride. (a) Convert its speed to feet per second. (b) How many strides per second is it taking? (c) How long would it take to cover a 100-yard football field?
6. **CHALLENGE** Some readers say Job 39:14–16 is unfair because ostriches do care for their young. Write a short answer that uses at least two modern observations and explains what kind of writing Job 39 is.

Make it a game • Long-Stride Race. Mark a start and finish line 20 yards apart. Players race not for speed but for the fewest strides: each must run (not jump with both feet), and a judge counts strides. Record each player's count and work out average stride length. Then compare with an ostrich, which would cover the 20 yards in about four strides.

Scripture. "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 her's: her labour is in vain without fear; Because God hath deprived her of wisdom, neither hath he imparted to her understanding. What time she lifteth up herself on high, she scorneth the horse and his rider." (Job 39:13–18, KJV)

God answers Job by showing him creatures that make no sense by human measures: a bird that seems careless and foolish, yet outruns the warhorse. God made each creature as He chose and provides for each. Job learns to trust the wisdom of the One who made them all.

Practice: answers

1. It has only two toes on each foot (the only bird with two).
2. Its breastbone is flat with no keel, so it has no place to anchor large flight muscles; its wings are also small and its feathers soft, and it is far too heavy. Its strength is in its legs instead.
3. Matches: horsemen chased the ostrich and could not catch it; the bird easily outdistanced them ("she scorneth the horse and his rider"). Added: the bird used its legs at full speed and spread its wings "like a sail" as it ran (Job's "lifteth up herself on high" may picture the same motion).
4. $1,200 \text{ g} \div 50 \text{ g} = 24$ chicken eggs, about two dozen.
5. (a) $43 \times 5,280 \div 3,600 \approx 63$ feet per second. (b) $63 \div 16 \approx 3.9$ strides per second. (c) $300 \text{ ft} \div 63 \text{ ft/s} \approx 4.8$ seconds.

6. A good answer notes that field studies show (1) extra eggs are rolled to the rim of the communal nest and often lost, (2) eggs may be left in the day's heat, warmed by sun and sand, and (3) adults often run from danger rather than defend the nest, all matching Job's description; while also noting that ostriches do incubate and guard chicks. Job 39 is poetry spoken by God to show the variety of His creatures; it describes what is seen and makes a theological point (verse 17), not a complete scientific account. So it is true in what it affirms, not unfair.

2.6 PARROTS: CLEVER VOICES AND STRONG BEAKS

OBJECTIVES

- Describe the parrot’s zygodactyl feet, hinged beak and syrinx, and explain how parrots learn and imitate sounds.
- Evaluate the evidence from Irene Pepperberg’s work with Alex the African grey, separating observation from interpretation.
- Compare the extinction of the Carolina parakeet with the recovery of the kākāpō as lessons in stewardship.

Warm-up. Say “hello” in your normal voice, then try to say it without moving your lips at all. Parrots have no lips and no larynx voice box like ours, yet some say “hello” clearly. Write a guess: what part of their body do they use instead?

Video slot. Video coming. Alex the African grey parrot with Irene Pepperberg, wild macaws at a clay lick, kea solving puzzles, the kākāpō recovery program. Search approved channels (Smithsonian, BBC Earth, New Zealand Department of Conservation, PBS Nature); preview first.

KEY TERMS

zygodactyl

Having two toes pointing forward and two pointing back, as parrots, woodpeckers and owls (sometimes) do; good for climbing and grasping.

syrinx

The sound-making organ of birds, at the place where the windpipe splits toward the lungs.

vocal learning

The ability to learn new sounds by hearing and copying them. Parrots, songbirds and hummingbirds have it; most animals do not.

mimicry

Copying the sounds of other animals, people or machines.

hinged (kinetic) beak

A beak whose upper half can move on a joint with the skull, giving parrots great crushing and prying power.

captive breeding

Raising animals under human care, either for pets (so wild birds are not taken) or to restore rare species.

CORE IDEAS

Alex. In 1977, a young scientist named Irene Pepperberg bought a year-old African grey parrot in a Chicago pet store. She named him Alex and set out to test what a parrot could

learn. She used a “model and rival” method: two people would talk about an object, one asking and one answering, while Alex watched and competed for the attention. Over three decades, Alex learned to name about 50 objects, seven colors and five shapes, to count small groups up to six, and to answer “What’s same?” and “What’s different?” about two objects (color, shape or material). When Alex died in 2007 at about 31 years old, his reported last words to Dr. Pepperberg as she left the lab for the night were his usual “You be good. I love you. See you tomorrow.”

What did Alex understand? Here an Expert must think carefully. The observations are clear: Alex gave correct answers to new combinations of questions far more often than chance. The interpretation is debated. Pepperberg argued that Alex understood categories like color and number. Some critics argued he had learned many trained responses without understanding words the way a person does. Pepperberg designed her tests to answer such objections, using objects Alex had never seen and testers who did not know the answers. A fair conclusion: Alex showed real abilities to sort and label his world, which tells us God made some birds far cleverer than people once assumed; but a parrot’s speech is not human language, which carries reasoning, promises and worship.

The parrot family. There are about 400 species of parrots, including true parrots, macaws, cockatoos, lovebirds and budgerigars, and the strange parrots of New Zealand. Most live in the tropics and the Southern Hemisphere. They range from pygmy parrots weighing about a third of an ounce to the hyacinth macaw, about 3 feet long, and the flightless kākāpō, the heaviest parrot, which may weigh up to about 9 pounds.

Feet, beak and tongue. A parrot’s feet are **zygodactyl**: two toes forward and two back. They grip branches firmly and can lift food to the beak like a hand, and most individual parrots favor one foot, as people favor one hand. The **hinged beak** moves on a joint at the skull, giving tremendous force; a hyacinth macaw can crack palm nuts that a person needs a hammer to open. Parrots also use the beak as a third foot when climbing. The tongue is thick and muscular, used to turn seeds and, in speech, to shape sounds.

How parrots talk. Birds have no voice box like ours; they sing and call with the **syrinx**, deep in the chest where the windpipe divides. Parrots change the sound further with the tongue and throat, which may be why they imitate human speech so well. Parrots are **vocal learners**. In the wild they learn the calls of their flock; studies of small green-rumped parrotlets in Venezuela suggest that chicks learn individual “signature” calls from their parents, something like names. In captivity, with no flock of parrots to copy, they copy the sounds of their human “flock”: words, whistles, doorbells and microwaves.

A long life to care for. Large parrots can live 50 years or more. Cookie, a Major Mitchell’s cockatoo at Chicago’s Brookfield Zoo, lived to about 83 and died in 2016. A parrot is a lifelong commitment: it needs company, daily chewing material, room to climb and a will that names its next owner. Many wild parrots were taken from their homes for the pet trade; today international trade in most parrots is controlled by treaty (CITES), and a responsible family buys only birds bred in captivity.

Lost and found. The Carolina parakeet, green with a yellow-and-orange head, was the only parrot native to the eastern United States, flocking along rivers from the Gulf Coast north toward the Great Lakes region. Farmers shot it as a pest in orchards and fields, hunters took its feathers for hats, and its forests were cleared. Its habit of circling back to fallen flock members made whole flocks easy to shoot. The last known Carolina parakeet, a male named Incas, died at the Cincinnati Zoo on February 21, 1918, and the species was declared extinct in 1939. The kākāpō of New Zealand nearly followed: rats, cats and stoats brought by settlers ate its eggs and young, and by 1995 only 51 were known. Rangers moved every bird to predator-free islands, named and monitored each one, and fed and guarded their nests. After a record breeding season in 2026 there are 325. Genesis 2:15 put man in the garden “to dress it and to keep it”; these two stories show what neglect costs and what patient keeping can do.

PICTURE STUDY



Hyacinthine Macaw, from Illustrations of the Family of Psittacidae, or Parrots, Edward Lear, 1832 · Hand-colored lithograph · From Lear's book of parrot plates, published in London 1830-1832
Wikimedia Commons · Public domain

Edward Lear began this book of life-size parrot portraits when he was only 18, drawing living birds at the London Zoological Society's gardens and in private collections, and drawing directly on the lithographic stones himself. It was one of the first English bird books devoted to a single family. Lear later became famous for nonsense poems such as “The Owl and the Pussy-cat.”

Look closely

- Find the zygodactyl feet. How many toes point forward and how many back?
- Study the beak. Where would the hinge be, and what tells you it is powerful?
- Look at the eye. How did Lear make the bird look alive and alert?

Talk about it

1. Lear drew living parrots, not dead specimens. What could he show that a specimen could not?
2. Compare this plate with an Audubon plate from this trail. Which artist shows more action, and which shows more of the bird's character?

HANDS-ON: SEEING SOUND: COMPARING A PARROT'S VOICE WITH YOURS

Scientists study bird sounds with spectrograms, pictures of sound that show pitch from bottom to top and time from left to right. You will make spectrograms of your own voice and a parrot's and compare them.

You will need

- A computer with free sound software that shows spectrograms (for example Audacity, or Cornell Lab's free Raven Lite)
- A microphone or phone to record yourself
- A recording of a talking parrot and of a wild parrot call, from the Macaulay Library (macaulaylibrary.org) or a parent-approved video

Steps

1. Record yourself saying "hello" and whistling a short tune. Open each in the software and switch to spectrogram view.
2. Open a recording of a parrot saying "hello" (or another word) and make its spectrogram.
3. Compare: Where is most of the sound energy in each (low or high pitch)? Are the shapes similar? Sketch both spectrograms side by side.
4. Now open a recording of a wild parrot's flock call. How is it different from the imitated word?
5. Write a paragraph: what does your comparison show about how well a parrot imitates human speech, and what can a spectrogram not tell you about whether the parrot understands?

Check your work

- I made and sketched at least three spectrograms (my voice, a parrot word, a wild call).
- I described at least two differences and one similarity.
- My paragraph separates what the spectrogram shows (observation) from what it means (interpretation).

FIELD NOTEBOOK

1. **Narration.** Write one paragraph, without looking back, telling the story of the Carolina parakeet and the kākāpō and what they teach about stewardship. Give it to your parent to keep.

2. Draw a parrot foot gripping a branch, and beside it a robin's foot (three toes forward, one back). Label each toe arrangement.
3. Make a two-column table about Alex: "What was observed" and "How it was interpreted," with at least three rows.

Did you know? The kea, a mountain parrot of New Zealand, is famous for curiosity: it pulls apart rubber on cars, opens backpacks and has solved puzzle boxes in experiments. Many macaws in the Amazon gather at riverbank "clay licks" to eat mud, which may supply sodium and help them cope with bitter compounds in seeds.

Go deeper. Irene M. Pepperberg, *Alex and Me* (2008), her own account (preview for families; it includes some personal material). Audubon's chapter "The Carolina Parrot" in *Ornithological Biography*, vol. 1 (1831; free at Project Gutenberg), with his eyewitness account of the flocks. New Zealand Department of Conservation (doc.govt.nz) on the kākāpō recovery. Second video topic: wild macaws at a Peruvian clay lick.

Goes deeper in. Life Science, high-school Biology, "Birds" and "Animal Behavior" units (coming soon); Art, for Edward Lear's plates and lithography; Gardening & Animals, for caring for pet birds responsibly.

For families. No public-domain primary source excerpt was confirmed from the approved collections for this stop, so none is quoted; Audubon's Carolina Parrot chapter (Project Gutenberg eBook #56989) is recommended reading. Alex's abilities and his reported last words follow Pepperberg's published accounts; scholars still debate how to interpret them, and the stop says so. Kākāpō numbers are from New Zealand's Department of Conservation (51 in 1995; 325 after the 2026 breeding season). Incas died February 21, 1918; the Carolina parakeet was declared extinct in 1939. Cookie the cockatoo died in 2016 at an estimated 83 years. The parrotlet "name" research is by Karl Berg and colleagues; it is suggestive, not settled.

PRACTICE

1. **EASY** What does zygodactyl mean, and how does it help a parrot?
2. **MEDIUM** How is the way a parrot makes sound different from the way a person does?
3. **MEDIUM** Sort each statement as observation or interpretation: (a) Alex said "blue" when shown a blue key he had never seen. (b) Alex understood the idea of color. (c) Alex answered "same/different" questions correctly far more often than chance.
4. **MEDIUM** Give three causes of the Carolina parakeet's extinction.
5. **CHALLENGE** The kākāpō grew from 51 birds in 1995 to 325 in 2026. (a) By what factor did it grow? (b) What average yearly growth rate is that? (c) Why is an average misleading for kākāpō?
6. **CHALLENGE** James 3:7-8 says every kind of bird "is tamed, and hath been tamed of mankind," but the tongue "can no man tame." A parrot can be taught to speak. Write

three or four sentences explaining what a human tongue does that a parrot's cannot, and why that makes the human tongue harder to tame.

Make it a game • Parrot Chain. The first player makes a short sound: a whistle, click or word. The next player repeats it exactly and adds one new sound. Keep going around the circle until someone misses the order or the sound. Then talk about it: vocal learning means hearing, remembering and copying. How long a chain could your family manage?

Scripture. “For every kind of beasts, and of birds, and of serpents, and of things in the sea, is tamed, and hath been tamed of mankind: But the tongue can no man tame; it is an unruly evil, full of deadly poison.” (James 3:7-8, KJV)

A parrot can be trained to say kind words or rude ones without knowing the difference. People know the difference and still stumble. James calls us to guard our speech and to ask God for the wisdom from above that is “pure, then peaceable” (James 3:17).

Practice: answers

1. Two toes point forward and two back. It gives a strong grip for climbing and lets the parrot hold food like a hand.
2. A person uses the larynx (voice box) in the throat and shapes sound with lips, tongue and mouth. A parrot uses the syrinx, deep in the chest where the windpipe branches, and shapes sound with its thick tongue and throat; it has no lips.
3. (a) Observation. (b) Interpretation. (c) Observation (a measured result).
4. Any three: shooting as a crop pest; hunting for feathers for hats; capture for the pet trade; clearing of the forests it lived in; its habit of returning to fallen flock members, which made whole flocks easy to kill. (Disease may also have played a part.)
5. (a) $325 \div 51 \approx 6.4$ times. (b) Over 31 years: $\ln 6.4 \approx 1.85$; $1.85 \div 31 \approx 0.060$; $e^{0.060} \approx 1.062$, so about 6 percent per year. (c) Kākāpō breed only in years when certain trees (such as rimu) fruit heavily, every two to four years, so the population jumps in breeding years and stays flat or dips in between.
6. A strong answer: a parrot repeats or labels, but a person uses words to reason, promise, bless, curse, deceive or worship; human words come from the heart (Luke 6:45) and carry moral weight. Training can shape what a parrot says, but only God can change a heart, so the human tongue cannot be tamed by outside training alone. Accept any answer that distinguishes imitation from responsible speech.

2.7 MIGRATION: “THE STORK IN THE HEAVEN KNOWETH HER APPOINTED TIMES”

OBJECTIVES

- Explain why birds migrate and give record distances with numbers (Arctic tern, bar-tailed godwit).
- Describe the experiments that revealed birds’ sun, star and magnetic compasses, and what is still unknown.
- Trace how people learned that birds migrate, from ancient guesses to Gilbert White, the 1822 “arrow stork,” banding and modern radar.

Warm-up. Where do the robins, swallows or hummingbirds in your area go in winter? Write your best guess before you read. Then write: how could someone in 1750, with no radios or trackers, find out?

Video slot. Video coming. Bird migration on weather radar, the Arctic tern’s pole-to-pole journey, the bar-tailed godwit’s nonstop flight, sandhill cranes on the Platte River. Search approved channels (Cornell Lab of Ornithology, BirdCast, U.S. Geological Survey, National Park Service, BBC Earth); preview first.

KEY TERMS

migration

A regular, round-trip seasonal journey between breeding grounds and wintering grounds.

Zugunruhe

German for “migration restlessness”: the hopping and wing-fluttering of a caged migratory bird at the season and in the direction it would migrate.

magnetoreception

The ability to sense Earth’s magnetic field and use it for direction.

flyway

A broad route used by many migrating birds; North America has four: Atlantic, Mississippi, Central and Pacific.

stopover

A place where migrating birds rest and refuel for days or weeks on their journey.

banding (ringing)

Placing a small numbered band on a bird’s leg so it can be identified if it is caught or found again.

CORE IDEAS

The arrow stork. In May 1822, near the village of Klütz in northern Germany, a hunter shot a white stork and found something astonishing: a wooden spear about 30 inches long through its neck. The spear was African. The stork had been wounded somewhere in Africa, survived, and flown thousands of miles back to Germany. The bird, stuffed with its spear, is still kept at the University of Rostock. Germans call it the *Pfeilstorch*, the “arrow stork,” and it settled a question people had argued about for two thousand years: where do the birds go in winter?

Old answers. Aristotle thought some birds changed into other kinds with the seasons and that swallows and others hid in holes. In 1555 the Swedish churchman Olaus Magnus reported that fishermen pulled swallows out of lake mud in winter, and around 1700 one English writer even suggested that birds flew to the moon. Gilbert White, the careful naturalist of Selborne, watched swallows gather each autumn and still could not decide whether some hid in England over winter (see the Primary source). Jeremiah, writing more than 2,500 years ago in a land where storks pass overhead by the hundreds of thousands every spring and fall, simply said what was plain: the stork, the turtle (turtledove), the crane and the swallow “observe the time of their coming” (Jeremiah 8:7).

Why go? In the northern summer, long days and an explosion of insects, seeds and fish make an ideal nursery. In winter that food disappears or freezes. Many birds therefore raise their young in the north and spend the winter where food is easy to find. Roughly one bird species in five makes regular long-distance migrations. Most songbirds migrate at night, when the air is cooler and calmer and hawks are asleep, and feed during the day at **stopovers**. Before leaving, a bird may eat so much that it nearly doubles its weight in fat, its fuel.

Record holders. In 2010, scientists fitted Arctic terns nesting in Greenland with tiny geolocators. The birds flew south to the edge of Antarctica and back, averaging about 44,000 miles (71,000 km) a year, the longest known animal migration; a later study of terns from England’s Farne Islands recorded nearly 60,000 miles. An Arctic tern can live 30 years. In October 2022 a young bar-tailed godwit tagged in Alaska flew about 8,400 miles (13,560 km) to Tasmania in 11 days without landing, eating, drinking or, as far as anyone can tell, stopping to sleep. Before such flights, godwits shrink their digestive organs and enlarge their hearts and flight muscles. Some birds can rest one half of the brain at a time; frigatebirds have been recorded sleeping in short bursts while flying.

Three compasses. In the 1950s, Gustav Kramer showed that caged starlings with Zugunruhe faced their migration direction by the sun; when he shifted the apparent sun with mirrors, the birds shifted too. They also allowed for the sun’s movement through the day. In the 1960s, Stephen Emlen placed young indigo buntings in a planetarium. Birds raised under a sky that turned around the North Star learned to use it; birds raised under a sky turning around a different star used that one instead. Also in the 1960s, Wolfgang and Roswitha Wiltschko showed that European robins in closed rooms oriented by the Earth’s magnetic field. How birds sense the field is still being studied; one leading idea involves light-sensitive proteins called cryptochromes in the eye. Honest complexity: a compass gives direction, but

a bird also needs a “map” to know where it is, and scientists still do not fully know how birds solve that. Many young birds migrate alone on their first trip, guided by an inborn direction and calendar.

How we know. In 1804, John James Audubon tied silver threads to the legs of young phoebes at his Pennsylvania farm and found marked birds back the next spring, the first known bird banding in America. In 1899 the Danish teacher Hans Christian Mortensen began putting numbered aluminum rings on birds, and modern banding was born; the U.S. Bird Banding Laboratory has kept records since 1920. Today light geolocators and GPS tags follow single birds across oceans, and weather radar shows great clouds of birds lifting off at dusk on spring and fall nights. Projects such as BirdCast forecast these nightly flights, and cities that dim their lights on peak nights help prevent collisions with tall buildings.

Appointed times. Jeremiah’s point was not mainly about birds. The stork knows its appointed times and keeps them; “but my people know not the judgment of the LORD.” A bird obeys the pattern its Creator built into it, by sun, star and field. People, made in God’s image, are called to know Him and to keep His ways willingly. The faithful migrant shames the faithless heart.

PICTURE STUDY



Wild Geese Descending at Katata (Katata rakugan), from Eight Views of Ōmi, Utagawa Hiroshige, 1833–1837 · Color woodblock print · Rijksmuseum, Amsterdam (many other impressions survive in museum collections)

Wikimedia Commons · Public domain

Hiroshige was one of the great Japanese printmakers of the 1800s. The “Eight Views of Ōmi” are famous scenes around Lake Biwa, near Kyoto, each tied to a season and time of day. Wild geese arriving in autumn were a traditional sign of the changing season in Japan, as storks

and cranes were in the lands of the Bible. The square box at the upper left holds a short poem about the scene.

Look closely

- Follow the geese across the sky. Are they in lines, a V or scattered? Why might geese fly in formation?
- Find the small hall standing on stilts over the water at the left, and the sailboat in front. How do they help you judge the size of the lake and the mountains?
- Look at the colors of the sky and water. What time of day is it, and what season?

Talk about it

1. Many cultures marked the seasons by the arrival of migrating birds. Why would that be useful to farmers before printed calendars?
2. How does this quiet print express the same idea as Jeremiah 8:7?

Safety first. Night listening and watching should be done with a parent, in a safe place such as your own yard, porch or a familiar park.

HANDS-ON: TRACKING A NIGHT MIGRATION

Use free radar-based migration maps and your own ears to collect a week of migration data, then test a hypothesis about wind. Spring (April–May) and fall (September–October) are the best seasons.

You will need

- Internet access to BirdCast live migration maps and forecasts (birdcast.info)
- A weather source showing nightly wind direction and speed for your area
- A notebook and graph paper
- Optional: a phone app or recorder for night flight calls

Steps

1. Write a hypothesis: “In fall, more birds will migrate over my county on nights with winds from the north than on nights with winds from the south” (reverse it for spring). Explain why you think so.
2. For seven nights in a row, record from BirdCast the estimated number of birds that crossed your county or state, along with the wind direction, wind speed and any rain.
3. On at least two clear nights, go outside with a parent for 15 minutes after dark and listen for the high “seep” and “tsip” flight calls of migrating songbirds. Record how many you hear.
4. Graph the nightly bird numbers as bars and mark each bar with its wind direction.
5. Write a paragraph: was your hypothesis supported? Name at least one other factor that could explain your results and one way to improve the study.

Check your work

- I wrote a hypothesis with a reason.
- I recorded seven nights of migration and weather data.
- My graph is labeled and shows wind direction.
- My conclusion is honest about what the data do and do not show.

FIELD NOTEBOOK

1. **Narration.** Write one paragraph, without looking back, explaining how scientists discovered that birds have sun, star and magnetic compasses. Name at least two of the experimenters. Give it to your parent to keep.
2. Draw a world map and trace the Arctic tern's route from Greenland to Antarctica and back, and the bar-tailed godwit's flight from Alaska to Tasmania. Label the distances.
3. Draw the arrow stork with its spear and write the date and place.

Did you know? Israel lies on a land bridge between three continents, and it is one of the world's great migration bottlenecks: hundreds of millions of birds pass over it each year, including huge flocks of white storks, cranes and birds of prey. Jeremiah's hearers would have seen them every spring and fall.

Primary source. *Gilbert White, The Natural History of Selborne, letters to Thomas Pennant: Letter X (August 4, 1767) and Letter XII (November 4, 1767) (Project Gutenberg eBook #20933).*

I acquiesce entirely in your opinion—that, though most of the swallow kind may migrate, yet that some do stay behind and hide with us during the winter.

It is well known, at least, that the swallows and the fieldfares do congregate with a gentle twittering before they make their respective departure.

White was a careful observer, yet here he agrees with a theory that later proved wrong. Use this in Practice 3.

Go deeper. Scott Weidensaul, *Living on the Wind: Across the Hemisphere with Migratory Birds* (1999). BirdCast (birdcast.info) for live migration maps. U.S. Geological Survey Bird Banding Laboratory (usgs.gov) on how to report a banded bird. Second video topic: half a million sandhill cranes gathering on Nebraska's Platte River each March.

Goes deeper in. Life Science, high-school Biology, "Birds" and "Animal Behavior" units (coming soon); Earth Science, "Earth's Magnetic Field" and "Weather and the Atmosphere"; Geography, for flyways and the Middle East land bridge.

For families. The Pfeilstorch was shot in 1822 near Klützig, Mecklenburg, and is held by the University of Rostock. Arctic tern figures are from Egevang and others, *PNAS* (2010), and the Farne Islands tracking (2016). The godwit flight (tag 234684, October 2022,

about 13,560 km in 11 days) was reported by researchers and Guinness World Records. Experimenters: Gustav Kramer (sun compass), Stephen Emlen (star compass), Wolfgang and Roswitha Wiltschko (magnetic compass). The cryptochrome idea is a leading hypothesis, not settled. The “moon” essay is usually credited to Charles Morton, about 1700. Audubon’s 1804 phoebe threads are from his own account. White’s words are copied from Project Gutenberg.

PRACTICE

1. **EASY** Give two reasons birds migrate north in spring to nest.
2. **MEDIUM** Name the three compasses birds use and the scientist(s) who demonstrated each.
3. **MEDIUM** **Primary source.** What did Gilbert White believe about swallows in winter in 1767, and what did he observe correctly? What evidence later settled the question?
4. **MEDIUM** Why was the Pfeilstorch of 1822 such strong evidence for migration?
5. **CHALLENGE** An Arctic tern flies about 71,000 km a year and lives 30 years. The moon is about 384,400 km from Earth. How many round trips to the moon equal its lifetime of flying?
6. **CHALLENGE** The bar-tailed godwit flew 13,560 km in about 11 days. (a) What was its average speed in km per hour? (b) In miles per hour (1 km $\approx$ 0.621 mi)? (c) Why might its actual air speed have been different from this average?

Make it a game • Stopover. Lay out hula hoops or rope circles across a yard as stopover sites, with one “breeding ground” at one end and one “wintering ground” at the other. All players (birds) must cross from end to end, and they may rest only inside a stopover, where no more than three birds fit; a bird caught resting outside a hoop is out. After each crossing, the leader removes one hoop (a drained wetland or a cleared woodlot). How many birds still make it? Talk about why stopovers matter as much as nesting grounds.

Scripture. “Yea, the stork in the heaven knoweth her appointed times; and the turtle and the crane and the swallow observe the time of their coming; but my people know not the judgment of the LORD.” (Jeremiah 8:7, KJV)

The “turtle” is the turtledove. The birds keep the times God built into them, by sun, star and magnetic field. Jeremiah grieved that God’s people, who had His Word, did not keep His ways. Obedience that the stork shows by instinct, God asks of us by faith.

Practice: answers

1. Long summer days give more hours to feed young; there is an abundance of insects, seeds and other food; there may be more nesting space and fewer competitors than in the crowded tropics.
2. Sun compass: Gustav Kramer (starlings, 1950s). Star compass: Stephen Emlen (indigo buntings in a planetarium, 1960s). Magnetic compass: Wolfgang and Roswitha Wiltschko (European robins, 1960s).

3. He agreed that most swallows migrate but believed some stay behind and hide in England over winter. He correctly observed that swallows gather with twittering before departing. Later evidence, such as the arrow stork of 1822, banding returns and recoveries of banded swallows in Africa, and modern tracking, showed that swallows migrate to Africa and do not hibernate.
4. The spear through its neck was African, so the bird must have been in Africa (where it was wounded) and then flown back to Germany. It could not have spent the winter hiding in Europe.
5. Lifetime: $71,000 \times 30 = 2,130,000$ km. One round trip: $2 \times 384,400 = 768,800$ km. $2,130,000 \div 768,800 \approx 2.8$ round trips to the moon.
6. (a) $11 \times 24 = 264$ hours; $13,560 \div 264 \approx 51$ km/h. (b) $51 \times 0.621 \approx 32$ mph. (c) The average is ground speed over the whole route; tailwinds would push it faster over the ground than its air speed, and headwinds or detours would slow it. The route was also not a perfectly straight line.

2.8 NESTS: BUILT BY DESIGN

OBJECTIVES

- Classify nests by type (scrape, cup, platform, cavity, mud, pendant, mound) and explain how each fits the bird's eggs, young and dangers.
- Explain incubation, the brood patch, and the difference between altricial and precocial young.
- Apply Deuteronomy 22:6-7 and the Migratory Bird Treaty Act to how a family studies nests, and build a monitored nest box.

Warm-up. Using only one hand and a clothespin for a “beak,” try to weave a few strands of yarn or grass into a cup that will hold a marble. Give yourself three minutes. What was hardest?

Video slot. Video coming. Birds building nests: American robin cup nest with mud, Baltimore oriole weaving a hanging nest, cliff swallows building mud nests, woodpecker excavating a cavity, malleefowl tending its mound. Search approved channels (Cornell Lab of Ornithology and NestWatch, BBC Earth, National Park Service); preview first.

KEY TERMS

incubation

Keeping eggs at the right temperature, usually by sitting on them, until they hatch.

brood patch

A patch of bare skin, rich in blood vessels, that develops on a parent bird's belly so it can warm eggs directly.

altricial

Hatched naked or nearly so, with eyes closed and helpless, needing long care in the nest (robins, eagles, songbirds).

precocial

Hatched with down and open eyes, able to walk and follow the parents within hours (ducks, killdeer, quail).

cavity nester

A bird that nests inside a hole in a tree, cliff, bank or box, either digging it or using one already made.

brood parasite

A bird that lays its eggs in other birds' nests and builds none of its own, such as the brown-headed cowbird.

CORE IDEAS

A robin builds. In April a female American robin chooses a fork in a tree, a ledge or a porch beam. Over several days she carries in coarse grass and twigs for the outer wall. Then she brings beakfuls of mud and presses them in, turning round and round and pushing with her breast and wings to shape a smooth, round cup. Finally she lines it with soft, fine grass. The result is a cup just the size of her body, strong enough to last through spring storms, insulated against cool nights, and deep enough that the eggs cannot roll out.

A gallery of nests. Nests come in many types, each suited to its builder. A *scrape* is a shallow hollow on the ground (killdeer, ostrich), relying on camouflage. A *cup* (robin, most songbirds) holds eggs and small young. A *platform* of sticks carries heavy birds; one bald eagle nest near St. Petersburg, Florida, was measured at about 9½ feet across and 20 feet deep and estimated at two tons. A *cavity* is a hole, dug by woodpeckers and later used by bluebirds, chickadees and owls. *Mud* nests are stuck to cliffs and barns by swallows, or shaped like little ovens by the hornero of South America. A *pendant* nest hangs like a bag, woven of plant fibers by orioles. Swiftlets in Southeast Asia glue nests of their own hardened saliva to cave walls. The malleefowl of Australia builds a great *mound* of sand and rotting leaves; the heat of decay warms the eggs, and the male tests the temperature with his bill and adds or removes sand to keep it near 33°C (about 91°F). Some birds build nothing: emperor penguins hold the egg on their feet, the fairy tern balances its egg on a bare branch, and the brown-headed cowbird, a **brood parasite**, lays its eggs in the nests of more than 200 other species.

Engineering. A nest is a structure built under limits: a beak for a hand, materials gathered one load at a time, and a deadline set by the coming eggs. Woven fibers resist pulling; mud resists squeezing once dry; sticks lock together by friction; spider silk, used by hummingbirds and many small birds, binds and stretches. Placement matters as much as material: shade, shelter from wind and rain, height above predators. In general, birds that nest in cavities lose fewer nests to predators than birds in open cups, and their young can stay longer in the nest before flying.

Eggs and young. Before incubation a parent develops a **brood patch**: belly feathers drop out and blood vessels multiply, so the warm skin touches the eggs. Most bird eggs develop best at about 99–100°F (37–38°C), and parents turn them regularly. Incubation takes about 12 to 14 days in many songbirds, about 35 days in bald eagles and about 65 days in emperor penguins. Young hatch in two broad patterns. **Altricial** chicks, like robins, hatch naked and blind and need a deep, safe nest for about two weeks. **Precocial** chicks, like ducklings and killdeer, hatch downy and walking, so a simple ground scrape is enough; they follow their parents within a day.

Instinct and practice. A young bird building its first nest has never been taught. Birds raised by hand, with no chance to watch adults build, still make nests of the type their own kind makes. This inborn pattern is a mark of design: each kind builds “after his kind.” Yet studies of weaverbirds and zebra finches have shown that birds become neater and faster builders with experience and choose materials better after trial and error. Honest

complexity: nest building is not pure instinct or pure learning, but an inborn pattern that skill improves. The Creator gave birds both.

Law and stewardship. Moses gave Israel a law about nests: if you find a bird's nest, you may take the young or eggs, but you must let the mother go, "that it may be well with thee" (Deuteronomy 22:6-7). The breeding bird is kept so that birds continue. In the United States, the Migratory Bird Treaty Act of 1918 protects nearly all native birds, their eggs and their nests; without a permit it is illegal to take, keep or collect them, even a nest that looks empty. (Three common non-native birds, the house sparrow, European starling and rock pigeon, are not covered.) So a student of nests should observe, photograph, sketch and record, not collect. Cornell's NestWatch program teaches a code: check a nest no more than every three or four days, stay only a minute, do not visit during building or just before the young fly, and never lead a predator to the nest.

A house for her young. The psalmist, longing for the courts of the LORD, noticed that "the sparrow hath found an house, and the swallow a nest for herself," even at the altars of God (Psalm 84:3). The small bird nesting safely at the place of worship pictures the believer's rest in God's presence. Jesus, by contrast, said that the birds of the air have nests, but the Son of man had nowhere to lay His head (Matthew 8:20): He gave up His own rest to bring us home.

PICTURE STUDY



Baltimore Oriole, Plate 12 of The Birds of America, John James Audubon, 1827 (engraving) · Hand-colored engraving and aquatint · From The Birds of America
Wikimedia Commons · CC BY-SA 4.0

In this early plate, Audubon showed a family of Baltimore orioles at their hanging nest in a tulip tree. The oriole weaves its bag nest from plant fibers, hair and string, hanging it from the tip of a slender branch where squirrels and snakes cannot easily reach.

Look closely

- Find the nest. Where is it attached, and how is it shaped?
- Compare the male (bright orange and black) and the female and young (duller). Which bird would be better hidden while sitting on the nest?
- Look at the flowers and leaves. Why might Audubon have painted the nest in a flowering tree?

Talk about it

1. Why is a nest hanging from a thin branch tip a good defense? What danger might it still face?
2. Audubon often painted birds with their nests. What does a nest tell a viewer that the bird alone does not?

Safety first. Building a nest box uses a saw and a drill. Work with a parent, wear safety glasses, clamp the wood before cutting or drilling, and use only untreated wood. Mount boxes from a sturdy ladder with an adult holding it.

HANDS-ON: BUILD AND MONITOR A NEST BOX

Build a nest box for cavity nesters such as bluebirds, chickadees, tree swallows or wrens, put it up before nesting season (late winter is best), and keep careful records through spring. Read Gilbert White's observations of the house martin first, and copy his habit of patient, dated notes.

You will need

- One untreated 1×6-inch pine or cedar board, about 5 feet long
- Galvanized screws or nails, a hinge or pivot nail for a side door
- A saw, a drill with a 1½-inch hole saw or spade bit, and a ¼-inch bit for drainage and air holes
- A pole or post with a predator baffle (cone or stovepipe) if possible
- A free plan for a bluebird box from NestWatch (nestwatch.org) or the North American Bluebird Society

Steps

1. Follow a tested plan: an inside floor about 4×4 to 5×5 inches, an entrance hole 1½ inches across set about 6 inches above the floor, no perch, a sloping roof, drainage holes in the floor and air gaps under the roof.
2. Make one side open on a pivot so the box can be checked and cleaned.
3. Mount the box 4–6 feet high on a pole with a baffle, facing open ground, away from feeders.
4. Through spring, check the box every three to four days following the NestWatch code. Record date, time, nest materials, number of eggs or young, and what the adults are

doing. Do not open the box when the young are about 12 days old or older, or they may leave too early.

5. When the young have flown, clean out the old nest so the box is ready for a second brood. Compare your notes with White's method in the Primary source and write a summary of the season.

Check your work

- My box matches the plan's measurements and has drainage, air holes and an opening side.
- I mounted it safely with an adult and, if possible, a baffle.
- I kept dated records following the NestWatch code.
- I wrote a season summary (or, if no birds came, an explanation of what I would change).

FIELD NOTEBOOK

1. **Narration.** Write one paragraph, without looking back, comparing an altricial and a precocial bird: their nests, their chicks at hatching and how long they stay. Give it to your parent to keep.
2. Draw a chart of seven nest types (scrape, cup, platform, cavity, mud, pendant, mound) with one bird for each and one sentence on why that nest suits it.
3. Draw a cross-section of a robin's nest showing the outer twigs, the mud layer and the soft lining.

Did you know? Sociable weavers in southern Africa build huge shared nests of grass, with many separate chambers, that can house dozens to more than a hundred birds and last for decades. Their story belongs to Trail F, "Animal builders." And some woodpeckers drum on dead wood not only to dig but to announce their territory, choosing wood that rings loudly.

Primary source. *Gilbert White, The Natural History of Selborne, Letter XVI to the Hon. Daines Barrington, November 20, 1773, on the house martin (Project Gutenberg eBook #20934).*

About the middle of May, if the weather be fine, the martin begins to think in earnest of providing a mansion for its family. ... by building only in the morning, and by dedicating the rest of the day to food and amusement, gives it sufficient time to dry and harden. ... About half an inch seems to be a sufficient layer for a day. Thus careful workmen, when they build mud-walls (informed at first, perhaps, by this little bird), raise but a moderate layer at a time, and then desist, lest the work should become top-heavy, and so be ruined by its own weight.

Use this in Practices 3 and 5.

Go deeper. Cornell Lab of Ornithology's NestWatch (nestwatch.org) for nest box plans, the nest-monitoring code and a free way to report your data. Gilbert White, *The Natural History of Selborne* (free at Project Gutenberg); read all of Letter XVI on the house martin. Peter Goodfellow, *Avian Architecture: How Birds Design, Engineer, and Build* (Princeton University Press, 2011). Second video topic: Baltimore orioles or weaverbirds weaving a hanging nest, filmed close up.

Goes deeper in. Life Science, high-school Biology, "Birds" and "Reproduction and Development" units (coming soon); Gardening & Animals, for nest boxes and bird-friendly yards.

For families. The St. Petersburg eagle nest dimensions are the record listed by Guinness World Records (usually given as reported in 1963). The cowbird host count (over 200 species) and malleefowl mound temperature are standard published figures. The Migratory Bird Treaty Act protects nests of native species; the U.S. Fish and Wildlife Service advises against collecting even empty nests without a permit. Nest-box measurements follow NestWatch and North American Bluebird Society plans. White's text is copied from Project Gutenberg; the ellipses mark omitted words and sentences. The tools in the project call for adult help.

PRACTICE

1. **EASY** What is the difference between altricial and precocial chicks? Give one example of each.
2. **MEDIUM** Why can a killdeer get by with a simple scrape on the ground while a robin needs a deep cup?
3. **MEDIUM** **Primary source.** According to White, why does the house martin build only in the morning and only about half an inch a day? What does he say human builders learned?
4. **MEDIUM** What does Deuteronomy 22:6-7 command about a bird's nest, and what modern law in the U.S. protects nests? How do the two differ?
5. **CHALLENGE** A house martin builds about $\frac{1}{2}$ inch of mud wall a day. If a finished nest wall is about 5 inches tall, how many building days does it need? If the bird skips rainy days (mud dries badly) and 1 day in 4 is rainy, about how many calendar days will it take?
6. **CHALLENGE** Model the record St. Petersburg eagle nest as a cylinder 9.5 feet across and 20 feet deep. (a) Find its volume. (b) If it weighed 2 tons (4,000 pounds), what was its average density in pounds per cubic foot? (c) Water weighs about 62 pounds per cubic foot. What does your answer tell you about the nest?

Make it a game • Beak Builders. Give each player a pile of materials (yarn, grass, small twigs, paper strips, a bit of play dough for "mud") and a clothespin for a beak. Players may use the clothespin and one hand only. In five minutes, build a nest that will hold three marbles when gently shaken. Then test them: which design held best, and why? Swap materials and try a different nest type.

Scripture. “Yea, the sparrow hath found an house, and the swallow a nest for herself, where she may lay her young, even thine altars, O LORD of hosts, my King, and my God.” (Psalm 84:3, KJV)

Small birds nested in the Temple courts, safe near God’s altars. The psalmist envied them. A nest is a picture of home and safety, and the believer’s true home is in the presence of the LORD.

Practice: answers

1. Altricial chicks hatch naked, blind and helpless (robin, eagle). Precocial chicks hatch with down and open eyes and can walk soon after (duck, killdeer, quail).
2. Killdeer chicks are precocial and leave the nest within hours of hatching, and the speckled eggs are camouflaged among stones. Robin chicks are altricial and must stay safe, warm and contained in the nest for about two weeks.
3. So each layer of mud has the rest of the day to dry and harden; otherwise the wet wall would become top-heavy and collapse under its own weight. He suggests that builders of mud walls also raise a moderate layer at a time and then stop, perhaps having learned it first from the martin.
4. Deuteronomy 22:6-7 allows taking the eggs or young but commands letting the mother go, so the birds continue. The Migratory Bird Treaty Act (1918) protects nearly all native birds, eggs and nests, forbidding collection without a permit. The ancient law protected the breeding adult in a world where people ate wild birds; the modern law protects the whole nest because many species have become scarce.
5. $5 \div 0.5 = 10$ building days. If 1 day in 4 is lost, only 3 of every 4 days are working days: $10 \div 0.75 \approx 13.3$, so about 13 or 14 calendar days.
6. (a) Radius 4.75 ft; $V = \pi \times 4.75^2 \times 20 \approx 3.14 \times 22.56 \times 20 \approx 1,417$ cubic feet. (b) $4,000 \div 1,417 \approx 2.8$ lb per cubic foot. (c) That is far lighter than water, so the nest is mostly air spaces among sticks, like a loosely packed brush pile; it is huge but not solid.

2.9 JOHN JAMES AUDUBON AND THE BIRDS OF AMERICA

OBJECTIVES

- Tell the story of Audubon's life and the making of *The Birds of America* (1827–1838), with its dates, size and methods.
- Read Audubon's own account of a disaster and evaluate what it shows about his character.
- Weigh Audubon's achievements and his real wrongs honestly, judging him by the truth rather than by slogans.

Warm-up. Imagine you had spent years drawing every bird you could find, and you came home to find your drawings shredded. What would you do next? Write two sentences. You will read what Audubon did.

Video slot. Video coming. John James Audubon and *The Birds of America*: the double elephant folio, how the plates were engraved and hand-colored, a page-turning of an original volume. Search approved channels (National Audubon Society, Smithsonian, the New-York Historical Society, university library special collections); preview first.

KEY TERMS

double elephant folio

One of the largest sizes of paper used for printed books, about 39½ by 29½ inches; chosen by Audubon to show birds life-size.

engraving and aquatint

Printmaking methods in which lines are cut into a copper plate and tones are etched by acid through a grainy resin; the inked plate is pressed onto paper.

hand-coloring

Painting color onto each printed sheet by hand, done for every plate of *The Birds of America* by a team of colorists.

subscription

A way of publishing in which buyers sign up in advance and pay for each part as it is delivered.

specimen

A real animal, or part of one, collected for study. Audubon usually painted from freshly collected birds.

naturalist

A person who studies living things in nature by careful observation, collection and description.

CORE IDEAS

The rats. Around 1812, John James Audubon packed his bird drawings in a wooden box and left them with a relative in Henderson, Kentucky, while he traveled to Philadelphia on business. When he came home months later and opened the box, he found that a pair of Norway rats had nested in it and shredded the work of years. He tells the story himself in the Primary source. After several sleepless nights, he picked up his gun, notebook and pencils and went back to the woods. He later said the new drawings were better than the old.

Early life. Audubon was born on April 26, 1785, in Les Cayes on the French colony of Saint-Domingue (now Haiti), the son of a French sea captain and planter, Jean Audubon, and a young Frenchwoman, Jeanne Rabin, who died a few months after his birth. He was raised in Nantes, France, by his father and his father's wife. In 1803, at 18, he was sent to his father's farm, Mill Grove, near Philadelphia, partly to keep him out of Napoleon's armies. There he roamed the woods, drew birds, and in 1804 tied threads to young phoebes' legs to see if they returned (Stop B7). He married Lucy Bakewell in 1808.

Failure and a great plan. Audubon tried business in Louisville and Henderson, Kentucky. He was a poor businessman, and a large steam mill he invested in failed; in the Panic of 1819 he lost nearly everything, was briefly jailed for debt and declared bankruptcy. He drew portraits and stuffed specimens for a museum to earn money, while Lucy taught school and often supported the family. Then he set a goal that seemed reckless: to paint every bird in America, life-size, in its natural setting. In 1820 he floated down the Mississippi with a 13-year-old assistant, Joseph Mason, who painted many of the plant backgrounds.

Making the book. No American publisher would take on such a project, so in 1826 Audubon sailed to Britain. In Edinburgh the engraver William Home Lizars began the plates; the London engraver Robert Havell Jr. soon took over and finished almost all of them. Each of Audubon's watercolors was copied onto a copper plate by engraving and aquatint, printed on huge **double elephant folio** sheets, and colored by hand. The book was sold by **subscription** in sets of five plates. From 1827 to 1838 Audubon issued 435 plates showing roughly 1,065 individual birds of nearly 500 species, while he traveled to find subscribers and more birds. Fewer than 200 complete sets were made; about 120 survive. In 2010 one sold at auction in London for about 11.5 million dollars. To go with the plates he wrote the *Ornithological Biography* (five volumes, 1831-1839), with the Scottish naturalist William MacGillivray supplying much of the scientific detail.

How he painted. There were no cameras for wildlife and no modern binoculars. Audubon shot fresh **specimens**, then pushed wires through them into a board marked with a grid of squares, bending the birds into lifelike poses. He drew them on paper ruled with the same grid, using watercolor, pastel, graphite and sometimes oil and gouache. Earlier bird art, even the good work of Alexander Wilson, usually showed stiff birds in profile; Audubon showed them hunting, fighting, feeding young and twisting in flight. Some poses are too dramatic for real birds, but many showed behavior no one had painted before.

Honest complexity. Audubon killed many birds, as every naturalist of his day did, and he described the vast passenger pigeon flocks and the Carolina parakeets that would later vanish. He sometimes exaggerated his adventures and invented a romantic past for himself. He once played a prank on the naturalist Constantine Rafinesque, describing imaginary fishes that Rafinesque then published. Most seriously, while living in Kentucky Audubon owned several enslaved people and sold them when his business failed. Owning and selling human beings is a grave wrong, against the truth that every person is made in the image of God (Genesis 1:27), and Christians in his own day said so. Naming this plainly does not erase his art. It reminds us that gifts and sins can live in the same man, and that only Christ is without fault.

Legacy. Audubon's later years produced a smaller, cheaper edition of the birds (1840-1844) and a great work on North American mammals with his friend, the Lutheran pastor and naturalist John Bachman. Audubon died in New York on January 27, 1851. Years later George Bird Grinnell, who as a boy had known Lucy Audubon, founded the first Audubon Society in 1886 to protect birds, and the National Audubon Society followed in 1905. Many birders today first fall in love with birds by turning Audubon's pages. Psalm 111:2 says the works of the LORD are "sought out of all them that have pleasure therein"; whatever his faults, Audubon sought them out with a lifetime's labor.

PICTURE STUDY



Wild Turkey, Plate 1 of The Birds of America, John James Audubon (first engraved by William Home Lizars), 1827 · Hand-colored engraving and aquatint · From *The Birds of America*; Audubon's watercolor is at the New-York Historical Society
Wikimedia Commons · Public domain

Audubon chose the wild turkey, the great American bird Benjamin Franklin had praised (Stop B1), to open his book. The male fills almost the whole huge sheet: Audubon wanted the very first plate to show that every bird would be life-size.

Look closely

- Find how the bird fits the page. Where is its tail? Its head? How did Audubon fit a big bird on the sheet?
- Look at the feathers. How did the colorists show their metallic shine?
- Study the background plants. What kind of place is the turkey walking through?

Talk about it

1. Why do you think Audubon chose the wild turkey for Plate 1 instead of the bald eagle?
2. This plate was printed from a copper plate and colored by hand. How might a hand-colored print differ from one copy to the next?

HANDS-ON: COPY A PLATE BY AUDUBON'S GRID

Learn Audubon's grid method by copying one of his plates, then write a museum label for it. Free, high-quality images of every plate are available online from the National Audubon Society and several university libraries.

You will need

- A printed image of one Audubon plate (choose a bird you have seen)
- Drawing or watercolor paper, a ruler and a pencil
- Watercolors or colored pencils
- The Primary source box from this stop

Steps

1. Print the plate and rule a grid of 1-inch squares over it.
2. On your paper, rule a grid with the same number of squares, larger (1½ or 2 inches) to enlarge, or the same size to copy exactly.
3. Copy the bird square by square, lightly in pencil, paying attention to where each line crosses the grid. Then add color, matching the plate as closely as you can.
4. Write a museum label: bird name, plate number, date, artist, engraver, medium, and two or three sentences on what the plate shows about the bird's behavior.
5. Read the Primary source. Add a short note to your label about what the rat story tells you about the man who made this picture.

Check your work

- My grid on the copy matches the grid on the plate in number of squares.
- My copy keeps the bird's proportions and pose.
- My label has all the information and an accurate description.

FIELD NOTEBOOK

1. **Narration.** Write one paragraph, without looking back, telling how *The Birds of America* was made: where, by whom, how big, how many plates, and over what years. Give it to your parent to keep.
2. Make a timeline of Audubon's life with at least eight dated events from 1785 to 1851.
3. Write a fair, three-sentence summary of Audubon's character: one strength, one fault and one lesson.

Did you know? Audubon arrived in Britain in 1826 wearing his hair long and sometimes a wolfskin coat, and played up the image of the "American woodsman," which helped make him famous in Edinburgh and London. The Scottish painter John Syme painted his portrait that year; it now belongs to the White House collection.

Primary source. *John James Audubon, Ornithological Biography, vol. 1 (1831), Introduction (Project Gutenberg eBook #56989).*

I left the village of Henderson, in Kentucky, situated on the bank of the Ohio, where I resided for several years, to proceed to Philadelphia on business. ... I looked to all my drawings before my departure, placed them carefully in a wooden box, and gave them in charge to a relative, with injunctions to see that no injury should happen to them. ... The box was produced, and opened;—but, reader, feel for me—a pair of Norway rats had taken possession of the whole, and had reared a young family amongst the gnawed bits of paper, which, but a few months before, represented nearly a thousand inhabitants of the air! The burning heat which instantly rushed through my brain was too great to be endured, without affecting the whole of my nervous system. I slept not for several nights, and the days passed like days of oblivion,—until the animal powers being recalled into action, through the strength of my constitution, I took up my gun, my notebook, and my pencils, and went forth to the woods as gaily as if nothing had happened.

Use this in Step 5 of the project and in Practice 3.

Go deeper. Audubon, *Ornithological Biography*, vol. 1 (free at Project Gutenberg): read "The Wild Turkey" and one of his "episodes" of frontier life. The National Audubon Society's online *Birds of America* (audubon.org) with every plate. Richard Rhodes, *John James Audubon: The Making of an American* (2004), a full biography for older readers. Second video topic: how copperplate engraving and aquatint printing were done.

Goes deeper in. Art, "Printmaking" and "Drawing from Nature" (coming soon); History, the early American republic and the frontier; Life Science, high-school Biology, "Birds."

For families. Dates: born April 26, 1785; to America 1803; married 1808; bankruptcy 1819; to Britain 1826; plates 1827–1838; died January 27, 1851. Counts of birds and

species on the plates vary by source (about 1,065 birds; about 489–497 species), so the stop rounds. The 2010 sale was at Sotheby's, London (£7.3 million). Audubon's slaveholding in Kentucky is documented by his biographers (for example Gregory Nobles and Richard Rhodes); the stop names it plainly and without slogans. The rat story is usually dated to about 1812. The quotation is copied from Project Gutenberg; the ellipses mark omitted sentences. The Rhodes biography is long and frank; preview it.

PRACTICE

1. **EASY** Why did Audubon print *The Birds of America* on such enormous sheets?
2. **MEDIUM** Describe Audubon's method of posing and drawing birds.
3. **MEDIUM** **Primary source.** What did Audubon find in the box, how did he react at first, and what did he do afterward? Name one virtue his response shows.
4. **MEDIUM** Who were William Home Lizars and Robert Havell Jr., and what did each do?
5. **CHALLENGE** The 435 plates were issued in parts of 5 plates each between 1827 and 1838. (a) How many parts were there? (b) On average, how many parts and how many plates came out per year over those 11 years? (c) A double elephant folio sheet is about $39\frac{1}{2} \times 29\frac{1}{2}$ inches. How many times larger in area is it than a sheet of $8\frac{1}{2} \times 11$ paper?
6. **CHALLENGE** Write a fair judgment of Audubon in four to six sentences. Include at least two achievements, at least two faults, and a principle for judging people of the past.

Make it a game · Name That Plate. Print or display eight Audubon plates (for example the wild turkey, bald eagle, Carolina parakeet, Baltimore oriole, ruby-throated hummingbird, great blue heron, flamingo and snowy owl). One player strikes the pose of one bird; the others guess which plate. Then reverse it: show a plate for five seconds, hide it, and have everyone list as many details as they can remember. Audubon trained his memory the same way.

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

This verse was carved over the door of the Cavendish Laboratory at Cambridge University. Studying birds, as Audubon did, is a way of seeking out God's works with delight. The greatness belongs to the LORD, not to the one who paints or studies them.

Practice: answers

1. To show every bird life-size.
2. He collected fresh birds, pushed wires through them into a board ruled with a grid, bent them into lifelike poses, and drew them on paper ruled with the same grid, using watercolor, pastel and other media.
3. A pair of Norway rats had nested in the box and gnawed his drawings to bits. At first he was overwhelmed: a burning heat in his brain, sleepless nights, days of "oblivion." Then he took up his gun, notebook and pencils and went back to the woods "as gaily as if nothing had happened." Virtues: perseverance, resilience, diligence.

4. They were the engravers. Lizars, in Edinburgh, engraved the first plates; Havell, in London, took over and engraved, printed and supervised the coloring of nearly all the rest.
5. (a) $435 \div 5 = 87$ parts. (b) $87 \div 11 \approx 7.9$ parts and $435 \div 11 \approx 40$ plates per year. (c) $39.5 \times 29.5 \approx 1,165$ sq in; $8.5 \times 11 = 93.5$ sq in; $1,165 \div 93.5 \approx 12.5$ times larger.
6. A strong answer names achievements (the life-size Birds of America, new behaviors observed, perseverance after failure and the rats, the Ornithological Biography, inspiring bird study and protection) and faults (owning and selling enslaved people, exaggerating and inventing stories, the prank on Rafinesque). It states a principle such as: judge by the truth that applies in every age (slavery was wrong then as now, and people of his time said so), while understanding the customs of the time (collecting birds by shooting was normal science), and recognize that gifts and sins coexist in all people.

2.10 THE BACKYARD BIRD COUNT: COUNTING GOD'S SPARROWS

OBJECTIVES

- Explain the history and purpose of the Christmas Bird Count (1900) and the Great Backyard Bird Count (1998), with numbers.
- Count birds by a sound method: timed effort, field marks and the “highest number seen at once” rule.
- Evaluate the strengths and weaknesses of community science data, and submit or record a real count.

Warm-up. Look out a window for exactly five minutes and write down every bird you see or hear, even “small brown bird.” Then ask: did you count any bird twice? How would you know?

Video slot. Video coming. How to take part in the Great Backyard Bird Count, using eBird and the Merlin app, how to count a large flock, the history of the Christmas Bird Count. Search approved channels (Cornell Lab of Ornithology, National Audubon Society, Birds Canada); preview first.

KEY TERMS

community (citizen) science

Scientific research in which ordinary volunteers collect data, such as bird counts, that scientists then combine and analyze.

field mark

A visible feature that helps identify a bird, such as a wing bar, eye ring, bill shape or tail pattern.

checklist

A record of the birds seen at one place in one period of time, with the date, start time, duration and distance.

complete checklist

A checklist that reports every species identified, so a species left off can be read as “not detected.”

sampling effort

How much looking was done (minutes, distance, number of observers); more effort usually finds more birds, so effort must be recorded.

double counting

Counting the same individual bird more than once, the most common error in bird counts.

CORE IDEAS

From the side hunt to the census. In the late 1800s, a Christmas tradition in parts of America was the “side hunt”: hunters chose sides and went into the fields, and the side that shot the biggest pile of birds and animals won. Frank M. Chapman, a young ornithologist at the American Museum of Natural History and an early leader of the Audubon movement, proposed something different in his magazine *Bird-Lore*: a “Christmas Bird-Census,” in which people would count birds instead of shooting them. On Christmas Day 1900, 27 observers held 25 counts, from Toronto, Ontario, to Pacific Grove, California, and tallied about 18,500 birds. The Christmas Bird Count has run every winter since. Each count today covers a circle 15 miles across, sometime between December 14 and January 5, and tens of thousands of volunteers take part; the 2025–26 season was the 126th count.

The Great Backyard Bird Count. In 1998 the Cornell Lab of Ornithology and the National Audubon Society started a simpler count: anyone, anywhere, could watch birds for at least 15 minutes on any of four days in February and report what they saw. Birds Canada joined later, and since 2013 the count has been worldwide, with reports sent through eBird or the Merlin app. In 2025, an estimated 838,000 people took part and reported 8,078 species, roughly three-quarters of the world’s known bird species, in a single weekend.

Why count? One family’s list from one morning tells little. But millions of lists, gathered the same way year after year, show patterns no single scientist could see. Christmas Bird Count records helped document the bald eagle’s comeback (Stop B1). Project FeederWatch volunteers tracked the spread of an eye disease through house finches in the 1990s. Counts reveal “irruptions,” winters when crossbills, redpolls or snowy owls move far south in search of food. A 2019 study combining long-term surveys and weather radar estimated that the United States and Canada had about 2.9 billion fewer breeding birds than in 1970, about a 29 percent drop, while also showing that some groups, such as ducks, geese and birds of prey, had increased, helped by wetland protection and other conservation. Counts are how good stewards know what is happening to the creatures in their care.

How to count well. Choose a place and record the date, start time and how long you watched; that is your **sampling effort**. Identify by **field marks**: size and shape first, then color pattern, bill, behavior, habitat and voice. For each species, record the *highest number you saw at one time*, not the total of every sighting; if three chickadees keep visiting the feeder for an hour, you may have seen the same three birds twenty times. For big flocks, count ten birds, judge what fraction of the flock that block is, and multiply. When you are unsure, write “sparrow species” rather than guessing. Report every species you identified, so the list is a **complete checklist**.

Honest complexity. Community science has weaknesses. More people count near cities and roads than in wilderness. Feeders draw some species and not others. Beginners misidentify birds, and experts find more birds than beginners in the same time. Statisticians answer these problems: eBird uses regional filters that flag unusual reports for volunteer reviewers to check, and analysts adjust for effort, location and observer skill. Every count is an

estimate with some uncertainty, and good scientists say so. Large, careful, honest data sets are still among the best tools ornithologists have.

Watching without a gun. In 1889 Florence Merriam (later Florence Merriam Bailey), a young naturalist from New York, published *Birds Through an Opera-Glass*, often called the first modern American field guide. Most ornithologists of that era identified birds by shooting them; Merriam urged readers to watch living birds with an opera glass, patiently, and to learn them by their habits and marks. Her book *A-Birding on a Bronco* (1896) tells of a spring in a California valley, riding out each morning and writing up her notes each night. Every backyard counter follows in her steps.

Not one forgotten. Jesus said that two sparrows were sold for a farthing, one of the smallest coins, and yet “one of them shall not fall on the ground without your Father.” A bird count is a small act of attention to creatures God already knows by number. It trains the eye, it serves good stewardship, and it reminds us that we are “of more value than many sparrows.”

PICTURE STUDY



The Goldfinch, Carel Fabritius, 1654 · Oil on wood panel · Mauritshuis, The Hague, Netherlands
Wikimedia Commons · Public domain

Carel Fabritius was a gifted Dutch painter and a student of Rembrandt. He painted this small picture in Delft in 1654, the year he died in the explosion of the town’s gunpowder store. Goldfinches were popular pets in the Netherlands, trained to draw up a tiny bucket of water on a chain. The painting is a perfect field-mark exercise.

Look closely

- List every field mark you can see: face color, head pattern, wing color and any bars or patches.
- Find the chain. What does it tell you about how this bird lived?
- Look at the shadow and the brushstrokes. How did Fabritius make a small bird look real with so few strokes?

Talk about it

1. Using only the field marks you listed, write a description someone could use to identify a European goldfinch. How would it differ from the American goldfinch (bright yellow male, black cap and wings)?
2. This bird was kept on a chain. How does counting wild birds free in the yard reflect a different way of enjoying them?

HANDS-ON: RUN A REAL BIRD COUNT

Do a careful, documented count, analyze it, and if a parent agrees, submit it to science. The Great Backyard Bird Count takes place over four days each February (dates at birdcount.org), but eBird accepts checklists any day of the year, so you can begin now and count again during the GBBC.

You will need

- A notebook or printed tally sheet with columns for species, highest number at once, and notes
- Binoculars if available, and a field guide or the free Merlin Bird ID app
- A watch or timer
- With a parent: a free eBird account (a parent should set it up and submit for students under the age eBird requires)

Steps

1. Choose one spot (yard, porch, park bench). Do four counts of at least 15 minutes each on different days or times. Record date, start time, minutes and weather for each.
2. For each species, record only the highest number seen at one time. Write “unknown” or a group name (“sparrow species”) rather than guessing.
3. After the four counts, make a table: species, highest count in each session, and the number of sessions in which it appeared. Calculate total species (richness) and which species appeared most often.
4. Graph the number of species found against minutes watched for one session (note the minute each new species appeared). Describe the shape of the curve.
5. With a parent, submit at least one complete checklist to eBird (or to the GBBC in February). Then write a paragraph on two sources of error in your count and how you tried to reduce them.

Check your work

- I did four timed counts and recorded effort for each.
- I used the highest-number-at-once rule and did not guess identifications.
- My table and species-over-time graph are complete and labeled.
- I submitted (or prepared) a complete checklist and wrote about sources of error.

FIELD NOTEBOOK

1. **Narration.** Write one paragraph, without looking back, telling how the Christmas Bird Count began in 1900 and why it replaced the side hunt. Give it to your parent to keep.
2. Start a **Life List** page: every species you have identified with certainty, with the date and place you first saw it.
3. Choose your three most common yard birds. Draw each and label three field marks.

Did you know? eBird, launched in 2002 by the Cornell Lab of Ornithology and the National Audubon Society, has gathered more than a billion bird observations from around the world, and scientists use it to make weekly maps of where each species is. The Merlin app can suggest an identification from a photo or a recording of a song, but it can be wrong; always check its suggestion against field marks.

Primary source. *Florence A. Merriam, A-Birding on a Bronco (1896), chapter I, "Our Valley" (Project Gutenberg eBook #33410).*

Every morning, right after breakfast, my horse was brought to the door and I set out to make the rounds of the valley. ... After dinner I would take my camp-stool and stroll, through the oaks at the head of the valley, for a quiet study of the nearer nests. ... at night I would identify my new birds and write up the notes of the day.

Notice her routine: regular rounds, quiet sitting and nightly notes. Use this in Practice 3.

Go deeper. Florence Merriam Bailey, *A-Birding on a Bronco* (free at Project Gutenberg). The Great Backyard Bird Count (birdcount.org) and eBird (ebird.org) for how-to guides and live results maps. The National Audubon Society's history of the Christmas Bird Count (audubon.org). Second video topic: how to estimate the size of a large flock of blackbirds or shorebirds.

Goes deeper in. Arithmetic and statistics, for estimation, sampling and graphing (coming soon); Life Science, high-school Biology, "Ecology" and "Birds"; Gardening & Animals, for feeders and a bird-friendly yard.

For families. Christmas Bird Count origins (27 observers, 25 counts, Christmas Day 1900) are from the National Audubon Society. GBBC 2025 figures (about 838,000 estimated participants; 8,078 species) are from birdcount.org's 2025 final results. The 2019 study is Rosenberg and others, *Science*; the stop reports both losses and gains without alarm. The Merriam quotation is copied from Project Gutenberg; the ellipses

mark omitted sentences, and the last line begins mid-sentence. eBird has a minimum age for its own accounts; a parent should create the account and submit for younger students. Posting a checklist makes the location public on eBird, so choose a general location (such as a park or a nearby road) rather than a home address if you prefer.

PRACTICE

1. **EASY** What was the Christmas “side hunt,” and who proposed counting birds instead?
2. **MEDIUM** Why should you record the highest number of a species seen at one time instead of adding up every sighting?
3. **MEDIUM** **Primary source.** Name three habits in Merriam’s routine that a good bird counter still uses today.
4. **MEDIUM** In 2025 the Great Backyard Bird Count reported 8,078 species. If the world has about 11,000 known bird species, what percentage was reported?
5. **CHALLENGE** Family A counted 12 species in 30 minutes. Family B counted 20 species in 120 minutes. (a) Calculate species per hour for each. (b) Can you conclude Family A’s yard has more kinds of birds? Explain using the idea of effort.
6. **CHALLENGE** A flock of blackbirds passes. You count a block of 10 birds and judge that the block is about one-twentieth of the flock. A friend judges it is one-fifteenth. (a) What does each estimate? (b) Report a single number with a range, and explain why ranges are honest.

Make it a game · Count the Flock. One player scatters a handful of dried beans or rice on a dark tray (between 100 and 400). Others get five seconds to look, then write an estimate using the block method: picture ten beans, judge how many blocks of ten fill the tray. Then count them exactly. The closest estimate wins and scatters the next flock. Play several rounds and see if your estimates improve.

Scripture. “Are not two sparrows sold for a farthing? and one of them shall not fall on the ground without your Father. But the very hairs of your head are all numbered. Fear ye not therefore, ye are of more value than many sparrows.” (Matthew 10:29–31, KJV)

We count birds to learn and to care well for them, and our counts are always estimates. God’s knowledge is complete: He numbers every sparrow and every hair. Jesus gives this as a reason not to fear, because His people are of more value than many sparrows.

Practice: answers

1. A holiday contest in which teams shot as many birds and animals as they could; the side with the biggest pile won. Frank M. Chapman proposed the Christmas Bird Census in 1900.
2. To avoid double counting: the same birds may come and go many times. The highest number seen at once is the smallest number you can be sure were present.
3. Regular, repeated rounds at the same time (morning); sitting quietly in one place to watch closely; identifying birds and writing up notes the same day. (Also: studying nests and birds alive, without collecting them.)

4. $8,078 \div 11,000 \approx 0.73$, about 73 percent, roughly three-quarters.
5. (a) A: $12 \div 0.5 = 24$ species per hour. B: $20 \div 2 = 10$ species per hour. (b) No. New species are found quickly at first and then more slowly (the species-over-time curve flattens), so a long count always has a lower rate per hour. B found more species in total. To compare fairly, compare counts of equal length, or compare how many species each found in the first 30 minutes.
6. (a) You: $10 \times 20 = 200$ birds. Friend: $10 \times 15 = 150$ birds. (b) Report about 175 birds (range 150-200) or record the lower number to be conservative, as eBird encourages. A range admits the real uncertainty in an estimate rather than pretending to precision you do not have.

TRAIL 2 BADGE QUIZZES

The badge quizzes are optional. The student answers in writing, showing work for calculations; a parent checks answers with the key. Four right out of five earns each badge. Badges and the certificate are earned by doing the stops, not by scores.

Badge quiz 1 (Stops 1–5)

1. Explain how DDT caused bald eagle numbers to fall to 417 nesting pairs by 1963, using the word biomagnification.
2. Name two features that let a barn owl catch a mouse in total darkness.
3. What is torpor, and how does it help a hummingbird?
4. Describe the emperor penguin father's role in winter, with one number.
5. How does Xenophon's account of the ostrich (401 B.C.) agree with Job 39:18?

Badge quiz 2 (Stops 6–10)

6. Give one cause of the Carolina parakeet's extinction and one action that helped the kākāpō recover.
7. Name the three compasses birds use to migrate, and explain why the 1822 "arrow stork" mattered.
8. Explain the difference between altricial and precocial young and how it affects the nest.
9. Give three facts about how *The Birds of America* was made.
10. Why do bird counters record the highest number seen at one time and the minutes spent counting?

TRAIL CERTIFICATE: MY BIRD FIELD NOTEBOOK AND TRAIL B CERTIFICATE

Gather the Field Notebook pages from all ten stops into one bound notebook titled "My Bird Field Notebook," with your name and the dates you began and finished. Put your Life List (Stop B10) at the front.

Include the ten narration paragraphs, kept by your parent, in order behind the stop pages.

Include at least two pages of real data: your soaring flap counts (B1), huddle experiment (B4), migration graph (B7), nest box records (B8) or bird count tables (B10).

Include your Audubon grid copy with its museum label (B9). When the notebook is complete, a parent signs the Trail B certificate.

- **Completeness:** A titled, dated page for every stop, plus the ten narration paragraphs.
- **Data and analysis:** At least two projects with recorded data, labeled graphs and a written conclusion that names sources of error.
- **Use of sources:** Primary sources and Scripture are quoted accurately, and the student separates what a writer observed from what he or she believed.

- **Observation and care:** Drawings and records are made from real birds or close study of plates, labeled carefully, and the student followed the safety and nest-watching rules.

Answer key

1. DDT (as DDE) built up in larger amounts at each step of the food chain, from water to small fish to large fish to eagles (biomagnification). It interfered with eggshell formation, so shells were thin and broke during incubation, and few young hatched.
2. Any two: the facial disc that funnels sound; asymmetrical ear openings that let it judge up/down and left/right; nearly silent flight from serrated, velvety, fringed feathers.
3. A deep overnight state in which body temperature and energy use drop sharply (by up to about 95 percent), so the bird does not run out of energy on a cold night when it cannot feed.
4. He holds the single egg on his feet under his brood pouch for about 65 days through the Antarctic winter, fasting for about four months in all and losing about 40 percent of his weight, huddling with other males for warmth.
5. Both say horsemen could not catch the ostrich: Xenophon's troopers gave up the chase as the bird ran off at full speed with its wings spread like a sail; Job says "she scorneth the horse and his rider."
6. Cause (any one): shooting as a crop pest, the feather trade, capture for pets, forest clearing, or its habit of returning to fallen flock mates. Recovery (any one): moving birds to predator-free islands, monitoring and naming every bird, guarding and supporting nests.
7. Sun, star and magnetic compasses. The stork was shot in Germany with an African spear in its neck, proving that storks fly to Africa for the winter rather than hiding in Europe.
8. Altricial chicks hatch helpless and stay in the nest for a long time, so they need a deep, safe nest (a cup or cavity). Precocial chicks hatch downy and walking and leave within hours, so a simple scrape can be enough.
9. Any three: Audubon painted birds life-size in watercolor and other media from posed specimens; the plates were engraved and aquatinted in copper (first by Lizars in Edinburgh, then by Robert Havell Jr. in London); every print was hand-colored; it was printed on double elephant folio sheets; it was sold by subscription in parts of five; there were 435 plates issued from 1827 to 1838.
10. The highest number at once avoids counting the same birds twice; recording minutes (effort) lets scientists compare counts fairly, since longer counts find more birds.

ANIMALS TRAIL C: REPTILES AND AMPHIBIANS

The third trail of the Animals track visits the reptiles and amphibians: crocodiles and the leviathan of Job 41, the Komodo dragon, snakes and the bronze serpent, sea turtles, chameleons, the giant tortoises of the Galápagos, frogs and the plague of Exodus 8, salamanders and the old legend of the fire salamander, poison dart frogs, and the Gila monster whose venom led to a medicine. Each stop studies how these creatures are designed for their lives, what people have believed about them, and how we can care for them well.

This is the  **Expert** level, for students 14 and up, written at a high-school level. Each stop takes 35 to 50 minutes and gives real measurements and dates, honest notes where scientists still disagree, and, where one exists, a primary source copied exactly from Herodotus, Cellini or the King James Bible. Students work independently: they read the core ideas, study the picture, do the project and the practice (including two challenge problems), and write one narration paragraph that the parent keeps. Creation is taught as God's handiwork "after his kind" (Genesis 1); conservation is taught as stewardship (Genesis 2:15).

Five stops earn the **Herpetologist badge, part 1**, and ten stops earn part 2 and the **Trail C certificate**. The two badge quizzes at the end are optional; badges are earned by doing the stops and keeping the notebook pages and narrations.

BEFORE YOU BEGIN

- Read a page of high-school nonfiction and write a clear paragraph summarizing it.
- Work with percentages, unit conversions (metric and U.S.) and simple line or bar graphs.

MASTERY CHECKLIST

- ☐ I can explain the differences between reptiles and amphibians (skin, eggs, breathing, life cycle) and give two examples of each from this trail.
- ☐ I can explain at least three designs on this trail with real numbers, such as a crocodile's bite, a chameleon's tongue, a sea turtle's magnetic sense or a wood frog's freezing.
- ☐ I can separate observation from legend in an old source (Herodotus on the crocodile, Cellini on the salamander) and explain how a legend may have begun.
- ☐ I can tell the story of at least two recoveries (the American alligator, the Kemp's ridley, the Española tortoise) and what people did to help.
- ☐ I can connect at least four stops to specific passages of Scripture, quoted from the King James Version, and explain what each teaches.

OPTIONAL BOOKS AND RESOURCES

- **AmphibiaWeb** (<https://amphibiaweb.org>): A free University of California database with a page for every amphibian species: photos, range maps and life histories. Use it for Stops C7–C9.
- **The Reptile Database** (<https://reptile-database.reptarium.cz>): A free scholarly catalog of every reptile species, with names, ranges and references. Use it for species counts and to check identifications.
- **Biodiversity Heritage Library** (<https://www.biodiversitylibrary.org>): Free scans of old natural-history books: Merian, Seba, Günther’s tortoise plates and Cope’s North American reptiles, for the picture studies.
- **Project Gutenberg** (<https://www.gutenberg.org>): Free public-domain texts used on this trail: Herodotus’ *An Account of Egypt* (#2131), Cellini’s *Autobiography* (#4028) and Darwin’s *Voyage of the Beagle* (#944).

3.1 CROCODILES: ARMOR, AMBUSH AND LEVIATHAN

OBJECTIVES

- Explain how a crocodilian's head, heart and senses are built for ambush in the water, using real measurements.
- Read Herodotus' account of the Nile crocodile and sort what he got right from what he got wrong.
- Describe how the American alligator went from endangered to recovered, and connect it to the dominion and stewardship of Genesis.

Warm-up. Fill a sink or tub and float a ping-pong ball, then lay your hand flat just under the surface. Have someone drop a single drop of water on the far side. Can you feel the ripple? A crocodile's face is covered with hundreds of tiny domes that feel ripples far smaller than that. Keep that in mind as you read.

Video slot. Video coming. Crocodilians hunting from the water's edge; Nile crocodiles at a river crossing; a mother alligator carrying hatchlings in her mouth; how to tell an alligator from a crocodile. Search approved channels (Smithsonian's National Zoo, San Diego Zoo Wildlife Alliance, BBC Earth, National Geographic, St. Augustine Alligator Farm Zoological Park); preview first.

KEY TERMS

crocodilian

Any member of the order Crocodylia: true crocodiles, alligators and caimans, and gharials. About 27 living species are usually recognized.

ectotherm

An animal whose body heat comes mainly from its surroundings rather than from burning food. Reptiles bask to warm up and seek shade or water to cool down.

palatal valve

A fold of tissue at the back of a crocodilian's mouth that seals off the throat, so it can open its jaws underwater without flooding its lungs or stomach.

integumentary sensory organs (ISOs)

Small dark domes in a crocodilian's skin, packed most thickly around the jaws, that sense pressure and tiny ripples in water.

temperature-dependent sex determination

A pattern, found in crocodilians and many turtles, in which the temperature of the nest during incubation decides whether a hatchling is male or female.

leviathan

The great creature described by God in Job 41. Many readers identify it with the crocodile; others think it is a larger sea creature. The KJV keeps the Hebrew name.

CORE IDEAS

One order, three families. The crocodilians are a small group of large reptiles, about 27 species in all: the true crocodiles, the alligators and caimans, and the gharials of India and Southeast Asia. A quick field rule: a crocodile has a narrower, V-shaped snout, and when its mouth is shut the big fourth tooth of the lower jaw sticks up outside the upper lip; an alligator has a broad, U-shaped snout, and its lower teeth disappear when it closes its mouth. The gharial has a long, thin snout lined with needle teeth, built for snapping sideways at fish. South Florida is the only place on earth where wild alligators and crocodiles live side by side.

The largest reptile. The saltwater crocodile of Australia and Southeast Asia is the largest living reptile. Big males commonly reach 4.5 to 5 meters (15 to 17 feet). The longest one ever measured carefully, a captured male named Lolong in the Philippines (2011), was 6.17 meters (20 feet 3 inches) long and weighed about 1,075 kilograms. Yet every crocodile starts small: a hatchling saltwater crocodile is only about 30 centimeters long. Few land animals grow so much from so small a beginning, a fact you will see an ancient Greek writer noticed too.

Built for ambush. A crocodilian's eyes, ears and nostrils sit in a line along the top of its head, so it can see, hear and breathe while the rest of its body lies hidden. A clear third eyelid slides across the eye underwater. The palatal valve seals the throat, so it can grab prey with an open mouth beneath the surface. The tiny domes on its jaws (ISOs) are so sensitive that in laboratory tests alligators turned toward a single drop falling into a dark tank. When it strikes, the jaws close with tremendous force: a 2012 study led by Gregory Erickson measured a large saltwater crocodile biting with about 16,400 newtons, roughly 3,700 pounds-force, the strongest bite ever measured in a living animal. Strangely, the muscles that *open* the jaws are weak, which is why a trained handler can hold a closed mouth shut with tape.

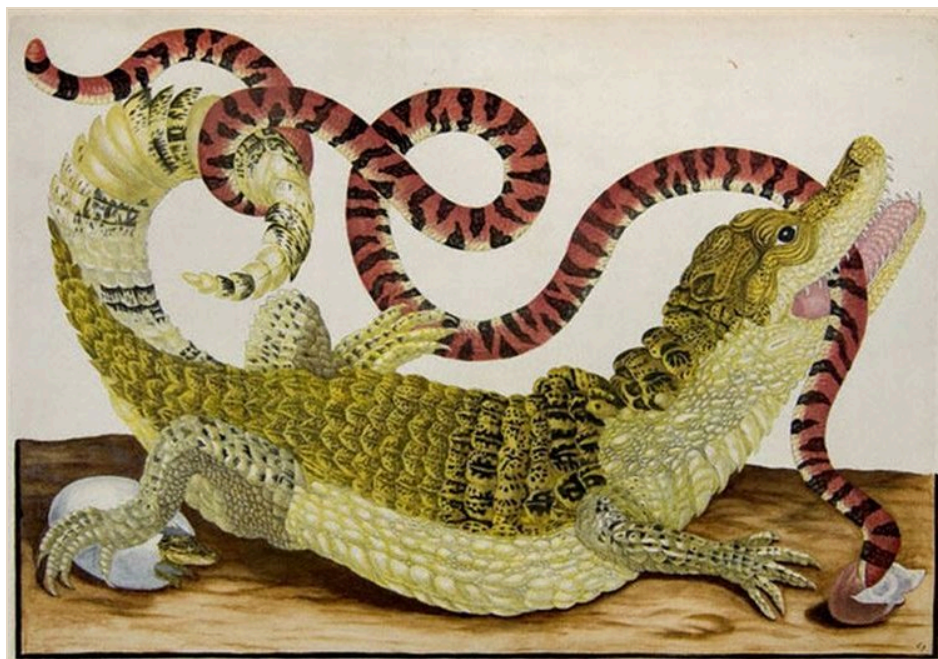
A thrifty body. Because crocodilians are ectotherms, they spend little energy keeping warm, and a large crocodile may eat only a few dozen big meals in a year. Their heart is unusual: it has four chambers like a bird's, but also a small opening (the foramen of Panizza) and a toothed valve that let it send blood around the lungs during a long dive. A resting crocodile commonly stays under for 15 minutes or more, and a still, cool animal can stay down for over an hour. Scientists still debate exactly how much this heart arrangement helps; it is an area of live research.

Nest and family. Crocodilians are more careful parents than most reptiles. Alligators and saltwater crocodiles heap up mounds of plants and mud; Nile crocodiles dig holes in sandbanks. The temperature of the nest decides the sex of each hatchling: in the American alligator, nests cooler than about 30°C (86°F) produce mostly females and those warmer than about 34°C (93°F) mostly males. The mother guards the nest for two to three months. When the young chirp inside their eggs, she digs them out and carries them gently to the water in the same jaws that can crush a turtle shell. Even so, most hatchlings are eaten by birds, fish, raccoons and other crocodiles before they are a year old.

Old reports, honest corrections. Around 440 B.C. the Greek traveler Herodotus described the Nile crocodile (see the primary source). He was right that it lays eggs not much bigger than a goose's and grows enormous, and that it fasts in the coolest months. He was wrong that it has no tongue (its tongue is fixed to the floor of its mouth) and that it moves only its upper jaw. His story of the trochilus bird picking leeches from the crocodile's mouth has been repeated for 2,400 years, but modern naturalists have never documented it. A careful student keeps both kinds of statement apart: what has been checked, and what has only been repeated.

Dominion and stewardship. The American alligator was hunted heavily for its hide, and in 1967 it was placed on the federal list of endangered species. With protection, careful study of nesting and later regulated harvests, it recovered, and in 1987 the U.S. Fish and Wildlife Service declared it fully recovered. Today there are millions in the southeastern states. Respect still matters: Nile and saltwater crocodiles kill people every year. In Job 41, God asks Job whether he can draw out leviathan with a hook. Whatever leviathan was exactly, the point is clear: man is given dominion (Genesis 1:28) and the charge to "dress" and "keep" creation (Genesis 2:15), but the animal's strength belongs to its Maker.

PICTURE STUDY



Caiman and False Coral Snake, from Metamorphosis insectorum Surinamensium, After Maria Sibylla Merian, 1719 (second edition; Merian died in 1717) · Hand-colored etching · University Library, Groningen, the Netherlands (from the 1719 Amsterdam edition)
Wikimedia Commons · Public domain

Maria Sibylla Merian sailed to Suriname in South America in 1699 at the age of 52 and spent nearly two years drawing its plants and animals from life. Her book on Surinam's insects came out in 1705. After her death, an enlarged edition of 1719 added twelve more plates from her work, including this one of a caiman, a South American relative of the alligator, locked in a struggle with a snake, with eggs at its feet.

Look closely

- Find the caiman's eyes and nostrils. Are they placed where this stop says a crocodilian's are?
- Look at the teeth along the jaw. Can you tell whether this is a crocodile-type or an alligator-type snout?
- Find the eggs. Why might the artist have shown them beside the caiman, and what does this stop say about crocodilian nests?

Talk about it

1. Merian was known for drawing from life. What parts of this picture look carefully observed, and what parts might be arranged for drama?
2. Why might an artist in 1719 choose to show two animals fighting rather than one resting?

Safety first. Never approach a wild alligator or crocodile, even one that looks asleep, and never feed one (feeding wild alligators is illegal in Florida and other states). Stay several car lengths away, follow posted park rules, and keep small children and pets well back from the water's edge in alligator country.

HANDS-ON: FACT-CHECKING HERODOTUS

Herodotus is called the "Father of History," but he wrote down what he saw and what he was told side by side. In this project you will check each of his claims about the crocodile against modern observation, the way a historian or scientist weighs an old source.

You will need

- The Herodotus excerpt in the "Primary source" box
- Your Field Notebook and two colored pencils
- A library book or museum web page on crocodilians (see "Go deeper")

Steps

1. Read the excerpt aloud slowly. Underline every separate claim it makes about the crocodile (you should find at least ten).
2. Make a three-column table: *Herodotus says* / *Modern observation* / *Verdict* (Right, Wrong, Partly right, or Unconfirmed).
3. Fill in the table using this stop and one other source. For each "Wrong" verdict, suggest how Herodotus might have made the mistake (for example, watching a crocodile lift its head to open its mouth).
4. Count your verdicts. Write two sentences: How trustworthy is Herodotus on crocodiles? What does this teach about using old sources?

Check your work

- My table has at least ten claims, each with a verdict.
- I used at least one source besides this stop and named it.
- I explained at least one of Herodotus' errors, not just marked it wrong.

FIELD NOTEBOOK

1. Draw a crocodile's head from the side and from above. Label the eyes, nostrils, ear slit, ISOs, and the fourth lower tooth. Beside it, draw an alligator's head from above and label the difference in snout shape.
2. **Narration.** In one written paragraph, explain how a crocodilian is designed to hunt from the water. Use at least three body parts and one number from this stop. Your parent keeps this paragraph.

Did you know? A crocodilian replaces its teeth again and again. Each tooth has a replacement growing beneath it, and an American alligator may go through two to three thousand teeth in its life. Crocodiles also swallow stones (gastroliths), which may help grind food or adjust their balance in the water; scientists still argue over which.

Primary source. *Herodotus, The History, Book II (An Account of Egypt), section 68, translated by G. C. Macaulay (1890). Project Gutenberg eBook #2131.*

Of the crocodile the nature is as follows:--during the four most wintry months this creature eats nothing; she has four feet and is an animal belonging to the land and the water both; for she produces and hatches eggs on the land, and the most part of the day she remains upon dry land, but the whole of the night in the river, for the water in truth is warmer than the unclouded open air and the dew. Of all the mortal creatures of which we have knowledge this grows to the greatest bulk from the smallest beginning; for the eggs which she produces are not much larger than those of geese and the newly-hatched young one is in proportion to the egg, but as he grows he becomes as much as seventeen cubits long and sometimes yet larger. He has eyes like those of a pig and teeth large and tusky, in proportion to the size of his body; but unlike all other beasts he grows no tongue, neither does he move his lower jaw, but brings the upper jaw towards the lower, being in this too unlike all other beasts. He has moreover strong claws and a scaly hide upon his back which cannot be pierced; and he is blind in the water, but in the air he is of a very keen sight. Since he has his living in the water he keeps his mouth all full within of leeches; and whereas all other birds and beasts fly from him, the trochilus is a creature which is at peace with him, seeing that from her he receives benefit; for the crocodile having come out of the water to the land and then having opened his mouth (this he is wont to do generally towards the West Wind), the trochilus upon that enters into his mouth and swallows down the leeches, and he being benefited is pleased and does no harm to the trochilus.

Go deeper. Charles A. Ross, ed., *Crocodiles and Alligators* (Facts on File, 1989), a well-illustrated survey by specialists; the St. Augustine Alligator Farm Zoological Park (alligatorfarm.com), which keeps every living crocodilian species, and its research pages; Smithsonian's National Zoo pages on crocodilians; and the rest of Herodotus Book II (Project Gutenberg #2131) for his whole account of Egypt's animals. Second video topic: how a mother alligator opens her nest and carries her young.

Goes deeper in. Life Science, high-school Biology, unit "Reptiles and Amphibians" (coming soon); and History, Ancient World, for Herodotus and Egypt.

For families. Species counts vary (25 to 28) as scientists split or lump species; "about 27" is a common figure. Lolong's measurements are from the 2011 capture as recognized by Guinness World Records. The bite figure is Erickson et al., *PLoS ONE* (2012). The ISO ripple study is Daphne Soares, *Nature* (2002). Alligator status: listed endangered in 1967, declared recovered in 1987 (USFWS). The identity of leviathan is debated among faithful Bible readers (crocodile, a great sea creature, or a now-unknown animal); the stop says so. Herodotus' trochilus is usually identified with the Egyptian plover; no reliable modern observation of the leech-cleaning behavior exists. The 1719 Merian plate was published after her death and engraved from her work; check the Commons image before printing.

PRACTICE

1. **EASY** Give two ways to tell an American crocodile from an American alligator by looking at its head.
2. **EASY** What does the palatal valve let a crocodilian do?
3. **MEDIUM** In an alligator nest, what decides whether a hatchling is male or female? Give the approximate temperatures.
4. **MEDIUM** Herodotus says a crocodile grows to "seventeen cubits." A cubit is about 18 inches (46 cm). How long is that in feet and in meters? Is it believable?
5. **CHALLENGE** Using the primary source, list two things Herodotus got right, two he got wrong, and one that remains unconfirmed. For one error, suggest how an honest observer might have made it.
6. **CHALLENGE** A saltwater crocodile's bite force was measured at about 16,400 newtons. One newton is about 0.225 pounds-force. Convert the bite to pounds-force, then explain why a person can still hold a crocodile's mouth closed with hands or tape.

Make it a game · Ripple Detector. One player sits blindfolded with a hand resting just under the surface of a tub of still water. Another player silently drops a single bead or drop of water somewhere in the tub. The "crocodile" points to where the ripple came from. Score a point for pointing within a hand's width. Switch roles and see who has the sharpest ISOs.

Scripture. "Who can open the doors of his face? his teeth are terrible round about. His scales are his pride, shut up together as with a close seal." (Job 41:14-15, KJV)

God points Job to leviathan's jaws and armor to humble him. A crocodile's scales really are set with bony plates (osteoderms) that act like mail. The more closely we study such a creature, the more we see that its strength and design come from the One who asks, "Canst thou draw out leviathan with an hook?"

Practice: answers

1. The crocodile's snout is narrower and V-shaped and its large fourth lower tooth shows when the mouth is closed; the alligator's snout is broad and U-shaped and its lower teeth are hidden when the mouth is closed.
2. Open its mouth underwater to seize prey without water flooding its throat, lungs or stomach.
3. The incubation temperature: below about 30°C (86°F) mostly females; above about 34°C (93°F) mostly males (temperature-dependent sex determination).
4. $17 \times 18 \text{ in} = 306 \text{ in} = 25.5 \text{ feet}$; $17 \times 0.46 \text{ m} \approx 7.8 \text{ m}$. It is longer than any crocodile reliably measured (Lolong was 6.17 m, about 20 feet), so it is an exaggeration, though not wildly so, and Herodotus may have been reporting hearsay or a different cubit.
5. Right (any two): it eats little in the coldest months; it lays eggs on land; the eggs are about goose-sized; it grows hugely from a small egg; it has strong claws and a tough, scaly back; it often spends days on land and nights in water. Wrong: it has a tongue (fixed to the floor of the mouth); it moves its lower jaw (it often lifts its whole head while opening, so the upper jaw seems to move); ("blind in the water" is only partly right: studies suggest crocodiles see blurrily underwater and rely on touch there, while seeing keenly in air, as Herodotus says). Unconfirmed: the trochilus cleaning leeches from its mouth. The jaw error likely came from watching a basking crocodile tip its head back to gape.
6. $16,400 \times 0.225 \approx 3,690$ pounds-force (about 3,700). The muscles that close the jaws are massive, but the muscles that open them are small and weak, so little force is needed to keep the mouth shut. (Only trained handlers should ever do this.)

3.2 KOMODO DRAGONS: THE LAND CROCODILE OF THE LESSER SUNDAS

OBJECTIVES

- Tell how the Komodo dragon became known to science between 1910 and 1926, and why early reports were doubted.
- Explain how a Komodo dragon finds, kills and eats large prey, and weigh the evidence in the “bacteria or venom” debate.
- Calculate meal sizes and population figures, and describe how the dragon is protected today.

Warm-up. Lay a tape measure or string on the floor and mark 3 meters (about 10 feet). Lie down beside it. A big male Komodo dragon is that long, and may weigh as much as a grown man. Now ask: if you heard a sailor’s story of a 10-foot lizard that eats deer, would you believe it?

Video slot. Video coming. Komodo dragons on Komodo and Rinca islands; how a Komodo dragon uses its forked tongue; Komodo National Park rangers. Search approved channels (Smithsonian’s National Zoo, San Diego Zoo Wildlife Alliance, BBC Earth, National Geographic); preview first.

KEY TERMS

monitor lizard

A lizard of the genus *Varanus*: long-necked, long-tailed, active hunters with forked tongues. The Komodo dragon (*Varanus komodoensis*) is the largest.

Jacobson’s organ (vomeronasal organ)

A pair of scent-sensing pits in the roof of the mouth. The forked tongue gathers scent particles from the air and delivers them here.

anticoagulant

A substance that keeps blood from clotting, so a wound keeps bleeding.

parthenogenesis

Reproduction in which a female produces young from unfertilized eggs. It has been recorded in captive Komodo dragons.

endemic

Found naturally in only one place. The Komodo dragon is endemic to a few islands of eastern Indonesia.

CORE IDEAS

A rumor becomes a species. For generations the people of Komodo and Flores knew a giant lizard they called *ora*. Pearl divers and traders told stories of “land crocodiles,” but outsiders thought the tales were exaggerated. Around 1910 a Dutch colonial officer, Lieutenant J. K. H. van Steyn van Hensbroek, went to Komodo, shot one, and sent a photograph and its skin to Peter Ouwens, director of the zoological museum at Buitenzorg (now Bogor) on Java. Ouwens sent a collector, obtained more specimens, and in 1912 published the scientific description, naming it *Varanus komodoensis*. In 1926 the American naturalist W. Douglas Burden led an expedition for the American Museum of Natural History and returned with preserved specimens and two live dragons. His book *Dragon Lizards of Komodo* (1927) made the animal famous.

Where and how big. Komodo dragons live wild on only five islands of the Lesser Sunda chain in eastern Indonesia: Komodo, Rinca, Flores, Gili Motang and Gili Dasami. They are the largest living lizards. Adult males commonly reach about 2.5 meters and may grow to 3 meters (10 feet); wild males often weigh 70 to 90 kilograms, though a few captive or just-fed animals have weighed much more. Females are smaller. The islands are hot, dry grassland and monsoon forest, and the dragons bask in the morning, hunt, and shelter in burrows during the worst of the midday heat.

Finding food. A Komodo dragon “smells” with its tongue. It flicks its long yellow forked tongue in and out, picking up scent particles, then presses the two tips into the Jacobson’s organ in the roof of its mouth. Because the tongue is forked, the dragon can compare the scent on the left and right and swing its head toward the stronger side. It can follow the smell of a carcass across several kilometers. Its eyesight is good for movement, but its hearing is limited.

The bite and the debate. Dragons ambush deer, wild pigs and even water buffalo along game trails. They have about 60 serrated, backward-curving teeth like a shark’s, constantly replaced. For decades textbooks said that a dragon’s bite killed by infection, because its saliva swarmed with deadly bacteria; the idea came largely from the field studies of Walter Auffenberg in the 1970s. In 2009 a team led by Bryan Fry reported venom glands in the dragon’s lower jaw that release proteins which keep blood from clotting and lower blood pressure. A 2013 study found that the bacteria in dragon mouths were ordinary, much like those of other meat-eaters. Most researchers now think a dragon kills mainly by deep cutting wounds and blood loss, with the venom adding to the bleeding and shock. Others still argue about how much the venom matters. This is a good example of science correcting itself.

Huge meals, slow life. A dragon can eat up to 80 percent of its own body weight at one meal. Its lower jaw is loosely hinged and its skull flexible, so it can gulp large chunks or even a whole small goat. Afterward it may rest for days while it digests. Females lay about 20 eggs (often in the old mound nest of a megapode bird) and the eggs take some seven to eight months to hatch. The young spend their first years mostly in trees, partly because adult dragons will eat young ones.

A surprise in the zoo. In 2006 two female dragons in English zoos, Flora at Chester and Sungai at London, laid eggs that hatched although neither had been with a male. This was parthenogenesis. In Komodo dragons the young produced this way are male. Scientists think the ability may help a single female start a new population on an empty island. It reminds us that the Creator built remarkable flexibility into living things.

Stewardship. Indonesia set aside Komodo National Park in 1980, and UNESCO named it a World Heritage Site in 1991. The wild population is estimated at a few thousand animals, including perhaps 1,300 to 1,400 adults, and in 2021 the IUCN listed the species as Endangered. Threats include poaching of the deer and pigs that dragons eat, wildfire and farming on Flores, and the small size of each island population. Park rangers guide visitors with forked sticks. Protecting the dragon means protecting its prey and its islands, which is the kind of careful keeping Genesis 2:15 asks of us.

PICTURE STUDY



Photograph of a Komodo dragon from the first scientific description, Photograph sent to P. A. Ouwens (photographer not recorded; probably from the van Steyn van Hensbroek specimens), 1912 · Black-and-white photograph, published as a plate · P. A. Ouwens, "On a large Varanus species from the island of Komodo," Bulletin du Jardin botanique de Buitenzorg, 1912

Wikimedia Commons · CC BY-SA 4.0

When Peter Ouwens described the Komodo dragon in 1912, he had to convince other scientists that such an animal was real. Photographs of the first specimens were part of his evidence. Look at this picture as a scientist of 1912 would: does it prove the size of the animal?

Look closely

- Find something in the picture you can use as a scale: a person, a tool or a ruler. Estimate the lizard's length.
- Look at the head, the legs and the tail. What proportion of the total length is tail?
- Look at the setting. Is the animal alive, dead, posed? What clues tell you?

Talk about it

1. Why were a skin and a photograph together stronger evidence than either one alone?
2. What would a skeptical scientist in 1912 want to see before believing in a 3-meter lizard?

HANDS-ON: LIFE-SIZE DRAGON AND THE 80 PERCENT MEAL

Turn the numbers in this stop into something you can see and weigh.

You will need

- Sidewalk chalk or a long rope
- A tape measure
- A bathroom scale
- Your Field Notebook and a calculator

Steps

1. Outdoors, chalk a life-size outline of a 3-meter Komodo dragon. Make the tail about half the total length, the head about 30 cm long, and mark where the four legs attach.
2. Have each family member lie beside it. Measure and record each person's height as a fraction of the dragon's length.
3. Weigh yourself (or use a family member's weight). Calculate 80 percent of a 75 kg dragon's weight. Then calculate 80 percent of your own weight, the meal you would eat if you ate like a dragon. Write both in kilograms and pounds.
4. Estimate: if an adult dragon ate one such meal a month, how many deer of 40 kg would it eat in a year? Write a sentence about why protecting deer matters to protecting dragons.

Check your work

- My outline is 3 meters long with the tail about half.
- I worked out both meal sizes with units.
- I connected the dragon's food needs to its protection.

FIELD NOTEBOOK

1. Draw a Komodo dragon's head with its tongue out. Label the forked tongue, the nostril, the serrated teeth and the position of the venom glands in the lower jaw. Draw an arrow showing how the tongue carries scent to the Jacobson's organ.

2. **Narration.** In one written paragraph, tell how scientific thinking about the dragon's bite changed from the 1970s to 2013, and what that shows about how science works. Your parent keeps this paragraph.

Did you know? The dragon's skin is armored with tiny bones called osteoderms, like chain mail under the scales. Researchers who examined dragon teeth under the microscope in 2024 also found that the tips of their teeth are coated with iron, which gives the cutting edges an orange color and may keep them sharp.

Go deeper. W. Douglas Burden, *Dragon Lizards of Komodo* (1927), the first popular account of the 1926 expedition; James B. Murphy, Claudio Ciofi, Colomba de La Panouse and Trooper Walsh, eds., *Komodo Dragons: Biology and Conservation* (Smithsonian Institution Press, 2002); Smithsonian's National Zoo page on the Komodo dragon; UNESCO World Heritage page for Komodo National Park. Second video topic: the 2006 virgin births at Chester and London zoos.

Goes deeper in. Life Science, high-school Biology, unit "Reptiles and Amphibians" (coming soon); Geography, unit on Southeast Asia and Indonesia (coming soon).

For families. Discovery details follow standard accounts (Ouwens, 1912; Burden, 1927). The Burden expedition is often said to have helped inspire the film *King Kong* (1933); that link is commonly repeated but loosely documented, so it is left out of the stop. Venom: Fry et al., *PNAS* (2009); bacteria: Goldstein et al., *Journal of Clinical Microbiology* (2013). Parthenogenesis: Watts et al., *Nature* (2006). Iron-coated teeth: LeBlanc et al., *Nature Ecology & Evolution* (2024). IUCN uplisted the species to Endangered in 2021. Population estimates vary by survey; the stop uses rounded figures. The 1912 photograph's exact source should be checked on Commons or in the Biodiversity Heritage Library before printing.

PRACTICE

1. **EASY** Name three of the five islands where Komodo dragons live wild.
2. **EASY** Why is a Komodo dragon's tongue forked?
3. **MEDIUM** Who first described the Komodo dragon scientifically, in what year, and what did he name it?
4. **MEDIUM** What is parthenogenesis, and where was it seen in Komodo dragons?
5. **CHALLENGE** State the old "bacteria" explanation for how a dragon's bite kills and the newer "venom" explanation. What evidence in 2009 and 2013 moved scientists' thinking, and why is the question not fully closed?
6. **CHALLENGE** A 75 kg dragon eats 80 percent of its body weight in one meal. (a) How many kilograms is that? (b) If Komodo Island had 1,300 dragons averaging 40 kg each eating the equivalent of 12 such 80 percent meals a year, how many tonnes of food would they need yearly? (c) What does that suggest about poaching of deer?

Make it a game · Follow the Scent. Hide a cotton ball dabbed with vanilla or peppermint somewhere in a room. One blindfolded “dragon” moves slowly, sniffing to the left and the right before each step, and must turn toward the stronger side each time. A helper keeps the dragon safe from furniture. Time how long it takes to find the “carcass.”

Scripture. “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.” (Genesis 1:25, KJV)

The Komodo dragon was hidden from most of the world until 1910, but it was never hidden from God, who made every creeping thing “after his kind” and called it good. Discovery is our privilege; creation is His work.

Practice: answers

1. Any three: Komodo, Rinca, Flores, Gili Motang, Gili Dasami.
2. The two tips pick up scent on the left and right; comparing them tells the dragon which direction the smell is coming from.
3. Peter Ouwens, director of the zoological museum at Buitenzorg (Bogor), Java, in 1912; he named it *Varanus komodoensis*.
4. Reproduction from unfertilized eggs by a female alone. It was recorded in 2006 in two captive females, Flora at Chester Zoo and Sungai at London Zoo.
5. Old: deadly bacteria in the saliva caused fatal infection. 2009 (Fry et al.): venom glands in the lower jaw secreting anticoagulant and blood-pressure-lowering proteins. 2013 (Goldstein et al.): the mouth bacteria were ordinary, like other carnivores'. Most now think deep wounds and blood loss kill, helped by venom. It is not fully closed because researchers still disagree about how strong the venom's effect is compared with the wounds themselves.
6. (a) $0.8 \times 75 = 60$ kg. (b) One 80 percent meal for a 40 kg dragon = 32 kg; $32 \times 12 = 384$ kg per dragon per year; $384 \times 1,300 = 499,200$ kg, about 500 tonnes. (c) The dragons depend on a large, healthy population of deer and pigs; poaching their prey threatens the dragons even if no one harms a dragon. (Accept work shown; the scenario is simplified.)

3.3 SNAKES: WISE AS SERPENTS

OBJECTIVES

- Explain how a snake moves, swallows large prey and senses heat and scent, correcting the “unhinged jaw” myth.
- Use real numbers to describe venomous snakes and snakebite, and identify the venomous snakes of your own region.
- Trace the bronze serpent from Numbers 21 through 2 Kings 18 to John 3, and explain what each passage teaches.

Warm-up. Put your hand flat on a table and try to push yourself forward without lifting it or using your fingers. Hard, isn’t it? Now lay a long scarf in an S-shape on a rough rug and push the curves backward. Snakes move by pushing the backs of their curves against the ground.

Video slot. Video coming. How snakes move (lateral undulation, concertina, rectilinear, sidewinding); how a snake swallows an egg; a rattlesnake’s heat-sensing pits shown with a thermal camera. Search approved channels (Smithsonian’s National Zoo, San Diego Zoo Wildlife Alliance, BBC Earth, National Geographic, a state wildlife agency); preview first.

KEY TERMS

scute

One of the wide, overlapping scales across a snake’s belly. Their edges catch on rough ground and help the snake push forward.

quadrate bone

A movable bone that links a snake’s lower jaw to its skull, letting the jaw swing wide open.

pit organ

A heat-sensing pit between the eye and nostril of pit vipers (rattlesnakes, copperheads, cottonmouths); boas and pythons have similar pits along their lips.

venom

A mixture of proteins made in a gland and injected by a bite or sting. Venom is injected; poison is eaten or touched.

antivenom

A medicine made from antibodies (usually raised in horses or sheep) that binds and neutralizes a particular snake venom.

Nehushtan

The name given to Moses’ bronze serpent when King Hezekiah destroyed it because the people had made it an idol (2 Kings 18:4).

CORE IDEAS

A body of backbones. More than 4,000 kinds of snakes are known, living on every continent except Antarctica (though islands such as Ireland, Iceland and New Zealand have no native land snakes). They range from the Barbados threadsnake, about 10 centimeters long, to the reticulated python, which can pass 6 meters, and the green anaconda, which can weigh over 90 kilograms. A snake's body is mostly backbone: 200 to more than 400 vertebrae, each with a pair of ribs. Snakes move in four main ways. In *lateral undulation* the body pushes the backs of its S-curves against rocks and stems. In *concertina* motion it bunches up and stretches out, like an accordion, in tunnels and on branches. Heavy snakes such as pythons creep in a straight line by rippling their belly *scutes* (rectilinear motion), and desert sidewinders throw their bodies sideways in loops so that only two short sections touch the hot sand at once.

The jaw that does not unhinge. People often say a snake “unhinges” its jaw. It does not. The two halves of the lower jaw are joined at the chin only by a stretchy ligament, so they can spread apart, and each half hangs from the skull on a swinging quadrate bone. The snake then “walks” its jaws over its prey, left side, then right side, the backward-curving teeth gripping like ratchets. A tube-like windpipe slides forward along the floor of the mouth so the snake can breathe during a long swallow. An African egg-eating snake can swallow a bird's egg several times wider than its own head and crack it with bony spikes inside its throat.

Seeing heat, tasting the air. Like the Komodo dragon, a snake flicks its forked tongue to carry scent to the Jacobson's organ. Snakes have no outer ears, but they feel vibration through their jaws and body. Pit vipers carry a sense we lack: two pits between eyes and nostrils lined with a thin membrane that detects infrared heat. Experiments suggest the membrane responds to temperature changes of a few thousandths of a degree, and the brain blends this heat picture with sight, so a rattlesnake can strike a warm mouse in total darkness.

Venom: the honest numbers. Only around 600 species are venomous, and perhaps 200 of those are dangerous to people. Cobras, mambas and coral snakes (elapids) have short fixed front fangs; vipers fold long hollow fangs against the roof of the mouth. Venoms are complex mixtures: some attack nerves, others blood and tissue. Worldwide, the World Health Organization estimates 81,000 to 138,000 deaths from snakebite each year, mostly among rural farm workers in South Asia and Africa who have little access to antivenom. In the United States roughly 7,000 to 8,000 people are bitten by venomous snakes yearly and only about five die. The first antivenom was made in the 1890s by Albert Calmette, a French physician working at the Pasteur Institute, from the blood of animals immunized against cobra venom.

Constrictors and myths. Boas, pythons, rat snakes and kingsnakes kill by coiling. For a long time people said constrictors suffocated their prey. Experiments published in 2015 showed that the squeeze stops blood flow so quickly that the prey loses consciousness within

seconds, much faster than suffocation. Other common myths fail too: snakes are not slimy (their scales are dry), and a baby snake's venom is not reliably "stronger" than an adult's.

Serpents in Scripture. The serpent appears at the Fall (Genesis 3), and the Bible never pretends that snakebite is harmless. In Numbers 21, when Israel complained against God, "fiery serpents" bit the people. God told Moses to make a serpent and set it on a pole; whoever looked to it lived. Centuries later, King Hezekiah broke that same bronze serpent into pieces because the people were burning incense to it and called it Nehushtan (2 Kings 18:4). A good gift had become an idol. Jesus took up the story again: "as Moses lifted up the serpent in the wilderness, even so must the Son of man be lifted up" (John 3:14). The healing came by looking in faith to what God provided, not from the brass itself.

Wise and harmless. Jesus told His disciples to be "wise as serpents, and harmless as doves" (Matthew 10:16). For a student, wisdom about snakes means knowing which local species are dangerous, leaving all wild snakes alone, and valuing the work they do. A single rat snake may eat dozens of rodents a year, and farmers have long welcomed them in barns. Killing every snake on sight is neither wise nor good stewardship.

PICTURE STUDY



Plate 62 (Tab. LXII) of the *Thesaurus (Locupletissimi rerum naturalium thesauri)*, Engravers working for Albertus Seba, 1700s (Seba's *Thesaurus* appeared in four volumes, 1734-1765) · Engraving · Albertus Seba's natural history "cabinet," published in Amsterdam; copies in many libraries, viewable in the Biodiversity Heritage Library
Wikimedia Commons · Public domain

Albertus Seba (1665-1736) was a Dutch pharmacist who collected thousands of specimens from sailors returning to Amsterdam. He hired artists to engrave them in four great volumes, the first published in 1734. Many plates are full of snakes, arranged in loops and knots like

decorations, and some add birds or other creatures to make a scene. Some specimens were mislabeled, and a few pictures were imagined, so his book is beautiful but must be checked.

Look closely

- Count the snakes on the plate. How many different patterns can you see?
- Look at the heads. Can you find any with the broad, triangular head of a viper, or the slender head of a colubrid?
- Find the two birds. What is the long-legged bird doing, and does the whole scene look like real animal behavior or like an arrangement for the page?

Talk about it

1. Seba's artists drew mostly from preserved specimens, not living animals. What might an artist get wrong working that way?
2. Why would beautiful decoration help and also hinder a scientific picture?

Safety first. Never touch, pick up or corner a wild snake, even one you think is harmless, and never handle a dead venomous snake (a severed head can still bite by reflex). If someone is bitten by a venomous snake, call 911 at once, keep the person calm and still, remove rings and tight items, and keep the bitten limb about level with the heart. Do not cut, suck, ice, or apply a tourniquet.

HANDS-ON: FIELD GUIDE PAGE: VENOMOUS SNAKES OF MY REGION

Being “wise as serpents” starts with knowing which snakes near you are dangerous and which are helpers. In this project you will make a one-page field card from reliable sources.

You will need

- Your state wildlife agency's snake page, or a Peterson field guide to reptiles and amphibians
- A sheet of card stock and colored pencils
- A sheet protector (to keep the card in a hiking pack)

Steps

1. Find out which venomous snakes live in your state or county. (Many states have none or only one or two.)
2. For each, draw the snake and write three field marks, its habitat, and its typical length.
3. Add two common harmless snakes that are often confused with the venomous ones, with the mark that tells them apart. (Warning: color-rhyme tricks for coral snakes work only in parts of North America, so learn the real field marks.)
4. On the back, write the first-aid rules from this stop's safety line, and the poison control number (1-800-222-1222 in the U.S.).
5. Have a parent check the card against a second source.

Check your work

- My card lists every venomous species found in my state, or says clearly that there are none.
- I included at least two harmless look-alikes.
- First-aid steps are correct and match a reliable source.

FIELD NOTEBOOK

1. Draw a snake skull from the side with its mouth wide open. Label the quadrate bone, the stretchy chin ligament, the teeth and (for a viper) the folding fang. Beside it, draw the four ways snakes move with small arrows.
2. **Narration.** In one written paragraph, tell the story of the bronze serpent from Numbers 21 to 2 Kings 18 to John 3:14, and explain what it teaches about faith and about idols. Your parent keeps this paragraph.

Did you know? Snakes have no eyelids. A clear scale called the spectacle (or brille) covers each eye, and it is shed with the rest of the skin. A few days before shedding, the old spectacle clouds over, and the snake is nearly blind and often hides. A shed skin is longer than the snake, because it stretches as the snake crawls out.

Primary source. *Numbers 21:6-9, King James Version (1611).*

6 And the LORD sent fiery serpents among the people, and they bit the people; and much people of Israel died.

7 Therefore the people came to Moses, and said, We have sinned, for we have spoken against the LORD, and against thee; pray unto the LORD, that he take away the serpents from us. And Moses prayed for the people.

8 And the LORD said unto Moses, Make thee a fiery serpent, and set it upon a pole: and it shall come to pass, that every one that is bitten, when he looketh upon it, shall live.

9 And Moses made a serpent of brass, and put it upon a pole, and it came to pass, that if a serpent had bitten any man, when he beheld the serpent of brass, he lived.

Go deeper. Robert Powell, Roger Conant and Joseph T. Collins, *Peterson Field Guide to Reptiles and Amphibians of Eastern and Central North America* (4th ed., 2016), or Robert C. Stebbins' Peterson guide for the West; Raymond L. Ditmars, *Snakes of the World* (1931), by the Bronx Zoo's first reptile curator; the CDC's workplace safety page on venomous snakes; the Biodiversity Heritage Library's scans of Seba's *Thesaurus*. Second video topic: how antivenom is made.

Goes deeper in. Life Science, high-school Biology, unit "Reptiles and Amphibians" (coming soon); Gardening & Animals, for snakes on the farm and in the garden.

For families. Species counts follow the Reptile Database (over 4,000 snakes). Snakebite figures: WHO fact sheet (81,000–138,000 deaths a year); U.S. figures from the CDC/NIOSH. Calmette produced his first antivenom in the mid-1890s. Constriction study: Boback et al., *Journal of Experimental Biology* (2015). The fiery serpents are often identified with venomous desert vipers; Scripture does not name a species. First-aid guidance follows current U.S. poison control and CDC advice; it is not a substitute for medical care. The Seba plate number is left open on purpose: choose any snake plate from Volume II on Commons or BHL.

PRACTICE

1. **EASY** Name the four main ways snakes move.
2. **EASY** What is the difference between venom and poison?
3. **MEDIUM** Correct this sentence: “A snake unhinges its jaw to swallow big prey.”
4. **MEDIUM** How does a pit viper find a mouse in complete darkness?
5. **CHALLENGE** Read Numbers 21:6–9 (primary source), 2 Kings 18:4 and John 3:14. (a) What did the people have to do to live? (b) Why did Hezekiah later destroy the serpent? (c) What does Jesus say the serpent pictured? (d) Write one sentence on what the three passages together teach.
6. **CHALLENGE** In the U.S., about 7,500 venomous snakebites and about 5 deaths occur each year. (a) What percentage of bites are fatal? (b) Worldwide, about 100,000 die yearly from snakebite. Give two reasons the risk is so much higher in some countries.

Make it a game · Snake or Not?. The leader reads statements: “Snakes are slimy.” “Snakes have eyelids.” “A rattlesnake can sense heat.” “All snakes lay eggs.” Players stand tall for true and coil down on the floor for false. After each, the leader gives the reason. (False, false, true, false: many vipers and boas bear live young.)

Scripture. “Behold, I send you forth as sheep in the midst of wolves: be ye therefore wise as serpents, and harmless as doves.” (Matthew 10:16, KJV)

Jesus commends the serpent’s alertness and caution, not its malice. A wise Christian learns the real dangers of the world, avoids needless risk, and stays gentle and innocent toward others.

Practice: answers

1. Lateral undulation (S-curves), concertina, rectilinear (straight-line creeping) and sidewinding.
2. Venom is injected (by a bite or sting); poison is harmful when eaten or touched.
3. The jaw does not come unhinged. The two halves of the lower jaw are joined at the chin by a stretchy ligament and hang from movable quadrate bones, so the mouth spreads wide; the snake then “walks” its jaws over the prey.
4. Its pit organs, between eye and nostril, sense the mouse’s infrared heat; the brain combines this heat image with other senses to aim the strike.

5. (a) Look at the bronze serpent on the pole (verse 8: “when he looketh upon it, shall live”). (b) The people had begun burning incense to it as an idol and called it Nehushtan. (c) The Son of man being “lifted up,” His crucifixion, by which those who believe have life. (d) Healing comes from God through the means He appoints and is received by faith; even a God-given object becomes sin if it is worshiped in His place.
6. (a) $5 \div 7,500 \approx 0.0007 =$ about 0.07 percent (fewer than 1 in 1,000). (b) Any two: many people work barefoot in fields where dangerous species are common; hospitals and antivenom are far away or too expensive; antivenom may not exist for local species or is poorly stored; very dangerous species (saw-scaled vipers, kraits, Russell’s vipers, cobras) live close to farms and homes.

3.4 SEA TURTLES: NAVIGATORS OF THE GREAT AND WIDE SEA

OBJECTIVES

- Name the seven sea turtle species and describe how their bodies are built for life at sea.
- Explain natal homing and the magnetic-map research that helps account for it.
- Tell the story of the Kemp's ridley's decline and recovery and the practical stewardship that helped it.

Warm-up. Turn off the lights in a room at night and open the curtains. Which way is brightest? Now switch on a lamp on the other side of the room. Which way would a hatchling turtle crawl? Newly hatched sea turtles head for the brightest horizon, which on a natural beach is over the sea.

Video slot. Video coming. Sea turtle hatchlings emerging at night and crawling to the sea; a leatherback nesting; a Kemp's ridley arribada at Rancho Nuevo, Mexico. Search approved channels (NOAA Fisheries, U.S. Fish and Wildlife Service, Sea Turtle Conservancy, National Park Service at Padre Island National Seashore); preview first.

KEY TERMS

carapace and plastron

The upper shell (carapace) and lower shell (plastron) of a turtle. Both are bone, fused with the ribs and backbone, and covered with horny plates called scutes.

natal homing

The return of an adult animal to the area where it was born in order to breed. Female sea turtles return to nest near their home beach.

salt gland

A gland beside each eye that removes extra salt from the blood, producing thick, salty "tears."

arribada

Spanish for "arrival": a mass nesting in which thousands of ridley turtles come ashore together over a few days.

turtle excluder device (TED)

A grid of bars fitted in a shrimp net that lets shrimp through but guides larger animals such as turtles out of an escape flap.

CORE IDEAS

Seven kinds. Seven species of sea turtle are usually recognized: the green, loggerhead, hawksbill, Kemp's ridley, olive ridley, flatback and leatherback. Six wear a hard shell of bony plates covered by scutes. The leatherback is different: its back is a mosaic of tiny bones

under thick, oily skin, with seven ridges running from front to back. It is also the giant: adults are commonly 1.5 to 2 meters long and 300 to 600 kilograms, and the largest on record, a male stranded in Wales in 1988, weighed about 916 kilograms. Unlike land turtles, sea turtles cannot pull their heads or flippers into their shells. Their front flippers are long wings, and they “fly” through the water with them.

Built for the sea. Each species has its own tools. The leatherback dives deeper than 1,000 meters after jellyfish and swallows them past hundreds of backward-pointing spines in its throat. The hawksbill uses its narrow, bird-like beak to pick sponges from crevices in coral reefs. The adult green turtle is a grazer of seagrass and algae, and its name comes from the greenish color of its fat, not its shell. All sea turtles drink seawater with their food and get rid of the extra salt through salt glands beside their eyes, which is why a nesting turtle seems to cry.

Coming home. A female sea turtle may not breed until she is 20 or 30 years old, depending on species. Then she returns to nest on or near the beach where she hatched, often after crossing an ocean. Kenneth and Catherine Lohmann at the University of North Carolina showed that loggerhead hatchlings can sense both the strength and the angle (inclination) of the earth’s magnetic field, which differ from place to place. Each coastline has its own magnetic “address,” and turtles seem to imprint on it. In a 2015 study, the Lohmanns found that as the earth’s field slowly shifted along the Florida coast, nesting loggerheads shifted with it. Turtles probably use sight and smell as well near shore, so the magnetic map is only part of the answer.

The nest. At night the female hauls herself up the beach, digs a body pit with all four flippers, then scoops out a flask-shaped egg chamber with her hind flippers alone, one side and then the other. She lays about 100 leathery eggs the size of ping-pong balls, covers them, scatters sand to hide the spot, and returns to the sea. She may nest several times in one season. The eggs incubate about two months. As in crocodilians, temperature decides sex, but the other way round: warmer sand produces mostly females, cooler sand mostly males, with the pivot near 29°C (84°F). The hatchlings dig out together, usually at night, and sprint for the brightest horizon. Perhaps only one in a thousand lives to adulthood, though no one knows the figure exactly.

Food for sailors. For centuries sea turtles fed sailors, because a turtle could be kept alive on its back on deck for weeks. Columbus named islands for them, and Caribbean and Florida ports shipped thousands. At Key West, green turtles caught off Cuba and Nicaragua were held in sea-water pens called kraals until they were sold or butchered for soup; a turtle cannery there worked into the early 1970s. Winslow Homer painted one of those pens in 1898. Overharvest, eggs taken from nests, and drowning in fishing nets drove several species into steep decline.

The Kemp’s ridley comeback. The Kemp’s ridley is the smallest and was once the rarest. In 1947 a Mexican engineer, Andrés Herrera, filmed an arribada at Rancho Nuevo, Tamaulipas, in which an estimated 40,000 females came ashore in a single day. Scientists did not see that film until the early 1960s, and by then the nesting had collapsed. In 1985 only

about 700 nests were counted. Mexico and the United States then worked together: guarding the beach and its nests, starting a second nesting colony at Padre Island National Seashore in Texas, and requiring shrimp trawlers to use turtle excluder devices. Nests climbed above 20,000 in good years after 2009, though the numbers still rise and fall and the species is not yet safe.

Keeping the shore. Ordinary choices matter. Beachfront lights draw hatchlings inland to die, so many coastal towns now require shielded, low, amber lighting in nesting season. Volunteers mark nests and report stranded turtles. Fishermen fit TEDs and circle hooks. This is the stewardship of Genesis 2:15 lived out on a sandy beach: using the sea for food and work while keeping its creatures for the generations to come.

PICTURE STUDY



The Turtle Pound, Winslow Homer, 1898 · Translucent and opaque watercolor over graphite on paper (about 38 × 54 cm) · Brooklyn Museum, New York
Wikimedia Commons · Public domain

Winslow Homer (1836–1910) spent winters painting in Florida and the Caribbean. In Key West, green turtles were kept alive in wooden pens in the sea until they were shipped north or made into soup. Homer shows two men handling a huge turtle in the clear water of a turtle pound. He paints the work plainly, as he saw it.

Look closely

- Find the turtle. Which flippers can you see, and what are they doing?
- Look at the color of the water and the light on the men's skin and shirts. How does Homer make the water look clear and bright?
- Look at the wooden stakes of the pen. Why would a turtle pen be built of stakes rather than solid boards?

Talk about it

1. What does this painting tell you about how people used sea turtles in 1898?
2. Homer shows the work without judging it. What can a painting of everyday labor teach a historian?

Safety first. On a nesting beach, never touch a nesting turtle, hatchlings or a marked nest, and never use a flashlight or phone light near them; in the U.S. it is illegal to disturb sea turtles or their nests. Report a stranded or injured turtle to the local wildlife hotline. Fill in holes and flatten sandcastles before you leave the beach.

HANDS-ON: HATCHLING LIGHT TEST AND LIGHTING AUDIT

Test how light direction steers a hatchling, then check your own home's outdoor lights as if you lived on a nesting beach.

You will need

- A long shallow box or a hallway
- A small toy car or marble to stand for the hatchling
- Two flashlights, one covered with red or amber cellophane
- Your Field Notebook

Steps

1. In a dark room, set the "hatchling" in the middle of the box. At one end place a dim, wide light (a white sheet lit softly: the ocean horizon). At the other place a bright white flashlight (a beach house).
2. Ask several people, one at a time and without telling them why, to "point to the brightest way out." Record how many choose each end. Then switch the bright flashlight for the amber one and test again.
3. Explain your results: hatchlings move toward the brightest, lowest horizon. What does a bright white porch light do?
4. Walk around your home at night. List every outdoor light: color, whether it is shielded, and whether it shines toward the ground or outward. Write one change a beachfront family could make.

Check your work

- I recorded results for white and amber light.
- I explained the results using what hatchlings sense.
- My lighting list includes at least three lights and one practical change.

FIELD NOTEBOOK

1. Draw a leatherback and a green turtle side by side. Label the carapace, front flipper, rear flipper, beak and salt gland. Write one feeding fact under each.

2. Draw a cross-section of a nest: body pit, flask-shaped egg chamber, eggs, sand. Mark the temperatures that produce males and females.
3. **Narration.** In one written paragraph, tell the story of the Kemp's ridley from the 1947 film to today, with at least three dates or numbers. Your parent keeps this paragraph.

Did you know? Young loggerheads from Florida ride the Gulf Stream and the great clockwise current of the North Atlantic, sometimes for years, before returning to the coast. The Lohmanns' experiments showed that hatchlings placed in the magnetic field of a spot along that route turned to swim in the direction that would keep them in the current.

Go deeper. Archie Carr, *The Windward Road* (1956) and *So Excellent a Fishe* (1967), classic field accounts by the University of Florida naturalist who led sea turtle research in the Caribbean; the Sea Turtle Conservancy (conserveturtles.org), which Carr helped found; NOAA Fisheries' sea turtle species pages; Padre Island National Seashore's Kemp's ridley program (nps.gov/pais). Second video topic: how a turtle excluder device works.

Goes deeper in. Life Science, high-school Biology, unit "Reptiles and Amphibians" (coming soon); Earth Science, unit on Earth's magnetic field and ocean currents (coming soon).

For families. Some scientists treat the black turtle of the eastern Pacific as an eighth species; most count seven. The 916 kg leatherback is the record from Harlech, Wales (1988). Magnetic studies: Lohmann et al., many papers; the 2015 shifting-field study is Brothers and Lohmann, *Current Biology*. The "1 in 1,000" survival figure is a widely used rough estimate. Kemp's ridley numbers come from the U.S. Fish and Wildlife Service and NOAA recovery documents; nest counts vary from year to year. No primary source is excerpted here, because an exact public-domain text could not be checked for this stop.

PRACTICE

1. **EASY** Name the seven sea turtle species. Which one has no hard shell?
2. **EASY** Why does a nesting sea turtle look as if it is crying?
3. **MEDIUM** Sea turtle nests incubated warmer than about 29°C produce mostly which sex? How is this the reverse of alligators?
4. **MEDIUM** What two features of the earth's magnetic field can loggerhead turtles detect, and how could that help them find home?
5. **CHALLENGE** In 1947, about 40,000 Kemp's ridleys nested in a single day; in 1985, about 700 nests were counted for the whole year. (a) What percentage of the 1947 one-day number is 700? (b) Give three human causes of the collapse and three actions that helped the recovery.
6. **CHALLENGE** A loggerhead lays 4 nests in a season, each with 110 eggs, and nests every 3 years for 20 years. If 1 hatchling in 1,000 reaches adulthood, about how many adult

offspring will she leave? What does that number teach about protecting adults?

Make it a game • Hatchling Dash. At dusk outdoors, “hatchlings” crouch at a start line with eyes closed. A leader stands far off holding a dim light low (the sea horizon); a helper on another side switches a bright flashlight on and off (a beach house). On “Go!” hatchlings open their eyes and walk toward what they judge to be the sea. Afterward, talk about which light pulled them and why towns dim their lights.

Scripture. “So is this great and wide sea, wherein are things creeping innumerable, both small and great beasts.” (Psalm 104:25, KJV)

The psalmist marveled at the sea’s crowds of creatures without knowing how a turtle finds its way across it. We now know a little of how, and the wonder only grows: the God who made the great and wide sea also wrote its directions into a hatchling no bigger than a cookie.

Practice: answers

1. Green, loggerhead, hawksbill, Kemp’s ridley, olive ridley, flatback and leatherback. The leatherback has leathery skin over a mosaic of small bones instead of a hard, scute-covered shell.
2. Salt glands beside its eyes are getting rid of extra salt from the seawater it takes in.
3. Mostly females. In alligators, warm nests (above about 34°C) produce mostly males and cool ones mostly females.
4. Its strength (intensity) and its angle (inclination). Each stretch of coast has a particular combination, so a turtle that remembers its home beach’s values can steer toward them.
5. (a) $700 \div 40,000 = 0.0175$, about 1.75 percent (less than one-fiftieth). (Note: the 1947 figure counts females in one day; the 1985 figure counts nests in a season, so the comparison is rough.) (b) Causes: collecting eggs, killing adults for meat and leather, drowning in shrimp nets. Recovery: protecting the Rancho Nuevo beach and its nests, a second colony at Padre Island, Texas, and required turtle excluder devices in shrimp trawls.
6. Seasons: $20 \div 3 \approx 6$ (accept 6 or 7). Eggs: $6 \times 4 \times 110 = 2,640$ (7 seasons gives 3,080). Adults: about 2.6 to 3. Because each female leaves only a few adults over a long life, every adult turtle lost (for example, drowned in a net) is a heavy blow; protecting large adults matters as much as protecting nests.

3.5 CHAMELEONS: TURRET EYES, CATAPULT TONGUE, CRYSTAL SKIN

OBJECTIVES

- Explain how a chameleon’s eyes, tongue, feet and tail work together to catch insects, with real measurements.
- Describe how chameleons change color using pigment cells and nanocrystals, and correct the “matches its background” myth.
- Read Leviticus 11:29–30 and explain why translators are unsure which animals some Hebrew words name.

Warm-up. Hold a pencil at arm’s length. Close one eye and try to touch its tip quickly with the tip of another pencil. Now try with both eyes open. Two eyes make judging distance easier. A chameleon scans with each eye separately, then swings both forward together at the moment it aims its tongue.

Video slot. Video coming. Chameleon tongue strike in slow motion; a panther chameleon changing color; chameleon eyes moving independently. Search approved channels (Smithsonian’s National Zoo, San Diego Zoo Wildlife Alliance, BBC Earth, National Geographic); preview first.

KEY TERMS

zygodactyl feet

Feet whose toes are split into two opposing groups. A chameleon’s toes are fused into bundles of two and three, gripping a branch like tongs.

prehensile tail

A tail that can grasp and hold, like a fifth hand.

ballistic tongue

A tongue launched like a projectile, powered by stored elastic energy rather than by muscle pulling during the strike.

iridophore

A skin cell containing tiny reflective crystals of guanine. By changing the spacing of these crystals, a chameleon changes which colors of light its skin reflects.

structural color

Color produced by the physical arrangement of tiny structures that reflect certain wavelengths of light, rather than by pigment. Peacock feathers and soap bubbles show structural color.

CORE IDEAS

Where they live. About 220 species of chameleon are known, and close to half live only on the island of Madagascar. Others live in mainland Africa, around the Mediterranean (including southern Spain), the Arabian peninsula, India and Sri Lanka. They range from Parson's chameleon of Madagascar, which can reach about 68 centimeters, to *Brookesia nana*, described in 2021, whose adult male has a body only about 13.5 millimeters long, small enough to sit on a fingertip. Many species live in a tiny area, sometimes a single mountain forest.

Turret eyes. Each eye sits in a cone-shaped turret of fused eyelid with only a pinhole opening, and each can swivel on its own, so a chameleon can watch nearly all the way around itself, forward with one eye and backward with the other. When it spots an insect, it turns its head and swings both eyes forward onto the target. Experiments in the 1990s found that chameleons judge the distance of prey largely by how much they must focus each eye's lens, much like a camera's autofocus, using a lens that bends light unusually strongly.

The catapult tongue. At rest the tongue is bunched on a bone (the entoglossal process) at the back of the mouth. A ring-shaped accelerator muscle squeezes around elastic sheaths of collagen, loading them like a stretched spring. When the chameleon releases, the stored energy flings the tongue forward far faster than muscle alone could. In small species the tongue can stretch about twice the length of the body, and a 2016 study by Christopher Anderson measured a tiny chameleon's tongue accelerating at more than 260 times the force of gravity. The tongue tip is a sticky pad coated in mucus hundreds of times thicker than human saliva, and it can hold prey a third of the chameleon's weight. The whole strike takes a fraction of a second.

Tongs and a fifth hand. A chameleon's toes are fused into two bundles on each foot, two on one side and three on the other, so each foot clamps a twig like tongs. Its tail curls around branches as an anchor. It moves slowly and often rocks back and forth as it walks, which some researchers think makes it look like a leaf stirred by the breeze. Every part fits a life on thin branches: sharp sight, a long reach, a firm grip and a quiet approach.

How color really changes. The old saying is that a chameleon changes color to match whatever it sits on. That is mostly a myth. A chameleon's skin has layers. Near the surface are pigment cells with yellow and red pigments; beneath them are iridophores packed with a lattice of guanine nanocrystals. In 2015 a team at the University of Geneva led by Jérémie Teyssier and Michel Milinkovitch showed that panther chameleons change color by actively tightening or relaxing this lattice. Close-packed crystals reflect short wavelengths such as blue, which combine with yellow pigment to look green; spread out, they reflect longer wavelengths such as orange and red. A deeper layer of crystals reflects infrared light, which may help keep the animal cool.

Why change? Chameleons change color mainly to communicate and to manage temperature. Males flush bright colors to warn rivals or court females; a female already carrying eggs may show dark, blotchy colors that say "not interested." A chilled chameleon

darkens to absorb sunlight. Their resting colors do blend with leaves, and some species pale at night, so camouflage is part of the story, but it is not the whole story. Good science keeps the true part of an old belief and corrects the rest.

A word in Leviticus. The King James Version lists “the chameleon” among the creeping things in Leviticus 11:30. The Hebrew word there is *koach*, which elsewhere means “strength,” and scholars are not sure which animal it names; some modern translations render it “land crocodile” or “monitor lizard.” Several of the small creatures in that list are uncertain. Hebrew animal names did not always match our scientific categories, and honest translators note when they are guessing. What the passage clearly teaches is that God gave Israel distinctions to keep, and that He knew every creature by name, even the ones we struggle to identify.

PICTURE STUDY



A Chameleon, Ustad Mansur, c. 1612 · Brush and ink with watercolor on paper (about 11 × 14 cm) · Royal Collection Trust, United Kingdom (RCIN 912081)
Wikimedia Commons · Public domain

Ustad Mansur was the leading animal painter at the court of the Mughal emperor Jahangir in India, who gave him the title “Wonder of the Age.” Jahangir loved to study animals and had his painters record new arrivals. This chameleon, painted about 1612, may have been one of the animals brought to the court that year. Mansur dotted the skin with tiny points of green to show its bumpy texture, and on very close inspection a touch of gold makes the eye glint.

Look closely

- Find the feet. Can you see how the toes are grouped to hold the branch?
- Follow the tail. What is it doing?
- Look at the eye. Which way is it looking compared with the head?

Talk about it

1. Mansur painted this four centuries ago without a camera. Which details show he watched a living chameleon carefully?
2. Compare this careful painting with Seba's decorative snakes (Stop C3). Which is more useful to a scientist, and why?

HANDS-ON: COLOR WITHOUT PAINT: TESTING STRUCTURAL COLOR

A chameleon's brilliant blues and greens come partly from the spacing of tiny crystals, not only from pigment. You can see the same physics with things in your house.

You will need

- An old CD or DVD
- A flashlight or sunny window
- Bubble solution and a wand
- A green leaf and a sheet of green paper
- Your Field Notebook

Steps

1. Shine light on the shiny side of the CD and tilt it slowly. Record the order of colors you see. The CD's tiny, evenly spaced tracks reflect different colors at different angles: structural color.
2. Blow a bubble and watch the colors swirl as the bubble's skin thins. Thinner films reflect different colors from thicker ones. Write how this is like a chameleon's crystals moving closer together or farther apart.
3. Now tilt the green paper and the leaf in the same light. Does their color change with angle? Explain why not (their color is pigment).
4. Write a short paragraph: How do chameleons use both pigment and structure to make their colors?

Check your work

- I recorded the color order on the CD.
- I compared structural color (CD, bubble) with pigment color (paper, leaf).
- My paragraph mentions guanine crystals and their spacing.

FIELD NOTEBOOK

1. Draw a chameleon on a branch with its tongue fully extended toward an insect. Label the turret eye, the accelerator muscle and entoglossal bone (inside the mouth), the sticky tongue pad, the grouped toes and the prehensile tail.
2. Draw two small boxes of "crystals," one tightly packed and one spread apart, and color the light each reflects.

3. **Narration.** In one written paragraph, explain how a chameleon catches an insect, from first sighting to swallowing, using at least two numbers from this stop. Your parent keeps this paragraph.

Did you know? In 2018 German researchers shone ultraviolet light on chameleons and found that bony bumps on many species' heads glow blue, because the bone fluoresces through thin skin. Old writers also believed chameleons lived on air, since they were seen to eat so seldom; Shakespeare's Hamlet jokes that he eats "the chameleon's dish."

Primary source. *Leviticus 11:29–30, King James Version (1611).*

29 These also shall be unclean unto you among the creeping things that creep upon the earth; the weasel, and the mouse, and the tortoise after his kind,
30 And the ferret, and the chameleon, and the lizard, and the snail, and the mole.

Go deeper. Krystal A. Tolley and Anthony Herrel, eds., *The Biology of Chameleons* (University of California Press, 2014), a scholarly survey with many photographs; Petr Nečas, *Chameleons: Nature's Hidden Jewels* (1999); the Royal Collection Trust's online entry for Ustad Mansur's *A Chameleon*; Smithsonian's National Zoo pages on reptiles. Second video topic: high-speed footage of a chameleon tongue strike.

Goes deeper in. Life Science, high-school Biology, unit "Reptiles and Amphibians" (coming soon); Art, for Mughal painting and natural-history illustration (coming soon).

For families. Species counts (about 220) follow the Reptile Database. *Brookesia nana*: Glaw et al., *Scientific Reports* (2021). Tongue acceleration: Anderson, *Scientific Reports* (2016), measured in *Rhampholeon spinosus*. Mucus viscosity: Brau et al., *Nature Physics* (2016). Color change: Teyssier et al., *Nature Communications* (2015). Fluorescent bones: Prötzel et al., *Scientific Reports* (2018). The Shakespeare line is *Hamlet*, Act 3, Scene 2. The Hebrew animal names in Leviticus 11:29–30 are uncertain, as the stop says; the KJV wording is quoted exactly.

PRACTICE

1. **EASY** About what share of the world's chameleon species live only on Madagascar?
2. **EASY** How are a chameleon's toes arranged, and why does that help?
3. **MEDIUM** What powers a chameleon's tongue strike, and why is that faster than muscle alone?
4. **MEDIUM** True or false: "A chameleon changes color to match whatever it sits on." Explain.
5. **CHALLENGE** A chameleon 10 cm long (body without tail) shoots its tongue 2 body lengths. Its tongue tip accelerates at 260 g. (a) How far does the tongue reach in centimeters? (b) If $1\text{ g} = 9.8\text{ m/s}^2$, what is 260 g in m/s^2 ? (c) A sports car accelerates from 0 to 100 km/h in about 3 seconds, roughly 9 m/s^2 . About how many times greater is the chameleon's acceleration?

6. **CHALLENGE** Read Leviticus 11:29-30 in the primary source. (a) Which of the eight animals named does the KJV call by names we would class as reptiles? (b) The Hebrew word translated “chameleon” is *koach*, meaning “strength.” Why might some translators prefer “land crocodile” or “monitor lizard”? (c) What should an honest reader conclude?

Make it a game • Chameleon Tongue Toss. Players stand behind a line holding a party blower (the kind that unrolls) with a small piece of tape stuck sticky-side-out on the tip. Paper “insects” hang from strings at different distances. Each player has one blow to touch and pick up an insect. Keep one eye closed for round one and both eyes open for round two. Which round scored better, and why?

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 chameleon gathers into one small body a telescope, a catapult, a pair of tongs and a color-changing crystal coat. Each was made “in wisdom,” and studying them teaches us to praise the Maker.

Practice: answers

1. Close to half.
2. They are fused into two opposing bundles (two and three), so each foot clamps a branch like tongs.
3. Elastic collagen sheaths around the tongue bone are loaded (stretched) by the accelerator muscle before the strike; releasing that stored energy at once, like a catapult, launches the tongue much faster than a muscle contracting during the strike could.
4. Mostly false. Chameleons change color mainly to signal (to rivals and mates) and to manage body temperature. Their usual colors do help them blend in, so camouflage is part of the story, but they do not copy their background.
5. (a) 20 cm. (b) $260 \times 9.8 = 2,548 \text{ m/s}^2$ (about 2,500). (c) $2,548 \div 9 \approx 283$, so roughly 280 times greater.
6. (a) The tortoise, the chameleon and the lizard. (Many scholars think several more Hebrew words in this list also name lizards: modern versions often render the “ferret” as gecko, the “snail” as sand lizard or skink, and even the “tortoise” as a great lizard.) (b) A name meaning “strength” suits a large, powerful lizard such as a desert monitor better than a slow, small chameleon. (c) Some ancient Hebrew animal names are uncertain; we hold the text’s teaching firmly while admitting where identifications are a best guess.

3.6 TORTOISES OF THE GALÁPAGOS: GIANTS LOST AND RESTORED

OBJECTIVES

- Describe the Galápagos giant tortoise's size, lifespan and two main shell shapes, and explain how each shape fits its island.
- Explain how sailors, whalers and introduced animals reduced the tortoises, with numbers.
- Tell how the Española breeding program, the removal of goats and the stories of Lonesome George, Diego and Fernanda show both loss and recovery.

Warm-up. Walk at your normal pace for exactly one minute and have someone measure how far you went. In 1835 Charles Darwin timed a giant tortoise walking 60 yards in 10 minutes. How long would it take the tortoise to cover the distance you just walked?

Video slot. Video coming. Galápagos giant tortoises in the wild on Santa Cruz island; saddleback and domed tortoises compared; the Española tortoise breeding program and Diego's return home in 2020. Search approved channels (Galápagos Conservancy, Charles Darwin Foundation, San Diego Zoo Wildlife Alliance, BBC Earth, National Geographic); preview first.

KEY TERMS

archipelago

A group or chain of islands. The Galápagos archipelago lies on the equator about 1,000 kilometers (600 miles) west of Ecuador.

saddleback

A tortoise shell raised high at the front like a saddle, letting the neck stretch upward. Common on dry, low islands.

domed

A rounded, high-backed shell that covers the neck closely. Common on higher, wetter islands with ground plants.

introduced species

An animal or plant brought by people to a place where it did not live before, such as goats, pigs and rats on the Galápagos.

captive breeding and repatriation

Raising young animals in protected pens and then returning them to the wild places their kind once lived.

CORE IDEAS

Islands named for tortoises. The Galápagos Islands sit on the equator in the Pacific, about 1,000 kilometers west of Ecuador. In 1535 Tomás de Berlanga, Bishop of Panama, drifted there by accident when his ship was becalmed and carried off course, and he reported huge tortoises. *Galápagos* is an old Spanish word for a tortoise (it may also have meant a kind of saddle), and the islands were named for their most famous animal. Today scientists recognize about a dozen living kinds of Galápagos giant tortoise. Some treat them as separate species and others as subspecies of one; everyone agrees they belong to a single tortoise kind with remarkable variety from island to island.

Giants built for patience. The largest adults have shells over 1.5 meters long, and big males can weigh well over 200 kilograms; a few in captivity have passed 400. They are among the longest-lived of all animals: many live more than 100 years, and some in zoos are believed to have lived 150 or more, though exact ages are hard to prove. They graze grass, leaves and cactus pads and fruit, can store water in their bladders, and can live for months without food or drink because their metabolism is so slow. Darwin, visiting in 1835, timed one walking 60 yards in 10 minutes, which he reckoned at about four miles a day, allowing for rest and feeding.

Domes and saddles. On the higher, wetter islands such as Santa Cruz, where grass and low plants grow, tortoises have *domed* shells. On low, dry islands such as Española, where the best food is the pads of tall tree cactus, tortoises have *saddleback* shells raised at the front, longer necks and longer legs, so they can stretch upward. In 1835 the islands' vice-governor, Nicholas Lawson, told Darwin he could tell which island a tortoise came from by its shell. This variety within the tortoise kind fits its many island homes, a picture of the richness the Creator built into living things.

Fresh meat for sailors. Because a tortoise could live a year in a ship's hold without food or water, buccaneers, whalers and sealers carried them off by the thousands as a supply of fresh meat. Charles Haskins Townsend studied the logbooks of American whaling ships and found that just 79 ships took more than 13,000 tortoises between 1831 and 1868. Altogether, historians estimate that well over 100,000 tortoises, and perhaps as many as 200,000, were removed in the 1800s. Sailors and settlers also brought goats, pigs, donkeys, cattle, rats and dogs. Pigs and rats ate eggs and hatchlings; goats stripped the plants tortoises needed. Several island kinds vanished, and by the 1970s perhaps 15,000 tortoises were left in all.

The fourteen of Española. Ecuador made most of the islands a national park in 1959, and the Charles Darwin Research Station opened in 1964. On Española, searchers found only 14 tortoises left: 12 females and 2 males, too scattered to find each other. They were brought to Santa Cruz to breed. In 1976 a third male, Diego, who had been taken to the San Diego Zoo decades before, joined them. Between 1965 and 2020 the program returned about 2,000 young tortoises to Española, and Diego is thought to have fathered a large share of them. In 2020 the program ended and Diego went home. Over the same years, rangers and hunters removed tens of thousands of goats from Española, Santiago and northern Isabela, letting the plants grow back.

The last and the lost-and-found. Not every story ended well. Lonesome George, found on Pinta Island in 1971, was the last known Pinta tortoise; despite years of effort he left no offspring and died on June 24, 2012. Then in 2019 rangers on Fernandina Island, an active volcano, found a female tortoise, later named Fernanda. Only one other Fernandina tortoise had ever been seen, a male collected in 1906, and many assumed the kind was gone. In 2022 genetic tests confirmed that Fernanda belongs to it. Searchers are still looking for a mate.

Darwin and the honest reader. Darwin later cited the Galápagos, including its tortoises and finches, in arguing for his theory that all living things descend from common ancestors. Christians agree with what he observed: real variation, real adaptation to each island, real differences that can be inherited. Christians read those facts as variety within created kinds, not as proof that every creature arose without a Maker. Either way, the tortoises' recent history is a plain lesson in stewardship: careless taking can nearly wipe out a kind in a lifetime, and patient, careful keeping (Genesis 2:15) can bring it back.

PICTURE STUDY



Lonesome George, the last Pinta Island tortoise, Arturo de Frias Marques, 2008 · Color photograph (CC BY-SA 3.0) · Taken on Santa Cruz Island, Galápagos, where George lived at the Charles Darwin Research Station

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Lonesome George was found on Pinta Island in 1971 and spent the rest of his life at the Charles Darwin Research Station on Santa Cruz, where visitors from all over the world came to see him. This photograph was taken in October 2008, less than four years before he died in 2012 as the last known Pinta tortoise. Look at him as a naturalist would.

Look closely

- Look at the front edge of the shell. Is it domed low over the neck, or raised like a saddle? What does that suggest about the kind of island he came from?
- Look at the front legs and feet. How are they built to carry a heavy shell over rough lava rock?
- Find the scutes (the plates on the shell). How many can you count, and how worn do they look?

Talk about it

1. A photograph shows a living animal moving; a museum drawing of a shell shows its exact shape. What can each teach that the other cannot?
2. This photograph shows the last of his kind. What responsibility does that give us today?

HANDS-ON: SADDLE OR DOME? A REACH TEST

Build two model tortoise shells and test which shape lets the “neck” reach higher food.

You will need

- Two paper or plastic bowls
- Scissors (with permission)
- Two pencils or craft sticks (necks)
- Tape, a ruler, and a stack of books
- Your Field Notebook

Steps

1. Bowl 1 (dome): cut a small notch at the rim for the neck. Bowl 2 (saddleback): cut a tall arch, about a third of the way up the bowl, at the front.
2. Tape a pencil “neck” inside each bowl at the front so it can tilt upward until it touches the shell.
3. Place each bowl upside down beside a stack of books (a cactus). Tilt each neck up as high as it will go and measure how high the tip reaches.
4. Record your measurements. Then write: On which island, Santa Cruz (wet, with grass) or Española (dry, with tall cactus), would each shape do better? What does the dome shape give a tortoise in exchange for less reach?

Check your work

- I measured the reach of both shapes in centimeters.
- I matched each shape to an island and gave a reason.
- I named one advantage of the dome (better protection of the neck).

FIELD NOTEBOOK

1. Draw a map of the Galápagos. Label Santa Cruz, Isabela, Española, Pinta, Fernandina and Santiago. Mark which kind of shell lives where, and mark Ecuador with an arrow

showing the distance.

2. Make a timeline: 1535 Berlanga; 1831–1868 whaling logbooks; 1835 Darwin; 1959 national park; 1964 research station; 1971 Lonesome George found; 1976 Diego joins; 2012 George dies; 2019 Fernanda found; 2020 Diego goes home.
3. **Narration.** In one written paragraph, tell how the Española tortoise was brought back from 14 animals. Your parent keeps this paragraph.

Did you know? Galápagos tortoises have a partnership with small birds: when a finch hops in front of a tortoise, the tortoise rises up on its legs and stretches out its neck, and the finch picks ticks off its skin. Tortoises also spread seeds; some plants grow best after their seeds pass through a tortoise.

Go deeper. Charles Darwin, *The Voyage of the Beagle*, Chapter XVII, “Galapagos Archipelago” (free at Project Gutenberg, eBook #944), for his own account of the tortoises; Henry Nicholls, *Lonesome George: The Life and Loves of a Conservation Icon* (2006); the Galápagos Conservancy (galapagos.org) and the Charles Darwin Foundation (darwinfoundation.org) tortoise pages; Günther’s 1877 plates in the Biodiversity Heritage Library. Second video topic: Fernanda, the Fernandina tortoise.

Goes deeper in. Geography, unit on South America and the Pacific (coming soon); Life Science, high-school Biology, unit “Reptiles and Amphibians” (coming soon).

For families. The number of species is debated (often 12 or 13 living, plus extinct ones), which the stop says plainly. Whaling figures: C. H. Townsend, *Zoologica* (1925); totals of 100,000–200,000 removed are common estimates. The Española program figures (14 founders; about 2,000 repatriated; ended 2020) come from Galápagos National Park announcements. Diego’s share of offspring is often given as about 40 percent; the stop says “a large share.” Fernanda: Jensen et al., *Communications Biology* (2022). Darwin’s walking-speed figures are paraphrased from his *Journal*; the full text could not be checked against the Gutenberg file for this stop, so no excerpt is printed. Choose a Günther plate of a Galápagos tortoise, not an Indian Ocean one, on BHL or Commons.

PRACTICE

1. **EASY** Where are the Galápagos Islands, and what does their name mean?
2. **EASY** Who was Lonesome George, and when did he die?
3. **MEDIUM** Why did sailors carry off so many tortoises, and why was that so harmful?
4. **MEDIUM** Explain why a saddleback shell suits Española and a domed shell suits Santa Cruz.
5. **CHALLENGE** Darwin timed a tortoise at 60 yards in 10 minutes. (a) What is its speed in yards per hour and in miles per hour (1 mile = 1,760 yards)? (b) Darwin said about four miles a day. How many hours of walking is that at this speed? (c) What does the answer suggest about how a tortoise spends its day?

6. **CHALLENGE** Española had 14 tortoises (12 females, 2 males) plus Diego. About 2,000 young were returned over 55 years. (a) On average, how many were returned per year? (b) Why is starting from so few animals risky even when the numbers grow? (c) Why did removing goats matter as much as breeding tortoises?

Make it a game · Tortoise Relay. Players race in teams, but each runner must move like a giant tortoise: on hands and knees, no faster than one “step” per second called out by a timekeeper, carrying a pillow “shell” on the back. If the shell falls off, return to start. Afterward, compute: at that pace, how long would a four-mile journey take?

Scripture. “So teach us to number our days, that we may apply our hearts unto wisdom.” (Psalm 90:12, KJV)

Some Galápagos tortoises alive today hatched before your great-grandparents were born. Moses’ prayer reminds us that our days are numbered, however long, and that wisdom includes caring well for the creatures who will outlive us.

Practice: answers

1. On the equator in the Pacific, about 1,000 km (600 miles) west of Ecuador. *Galápagos* is an old Spanish word for a tortoise.
2. The last known Pinta Island tortoise, found in 1971; he died on June 24, 2012.
3. A tortoise could live up to a year in a ship’s hold without food or water, so it was a supply of fresh meat. Taking tens of thousands of slow-breeding, long-lived animals, along with introducing goats, pigs and rats, wiped out several island kinds and left others very few.
4. Española is low and dry; the best food is tall tree cactus, and the raised front of a saddleback lets the tortoise stretch its neck up. Santa Cruz’s highlands are wet with grass and low plants, so reaching up matters less and a dome gives better protection.
5. (a) 360 yards per hour; $360 \div 1,760 \approx 0.2$ mph. (b) $4 \times 1,760 = 7,040$ yards; $7,040 \div 360 \approx 19.6$ hours. (c) Walking four miles would fill nearly a whole day, so a tortoise traveling to water must keep plodding almost without stopping (Darwin noted they walked night and day on such journeys); on ordinary days they travel much less.
6. (a) $2,000 \div 55 \approx 36$ per year. (b) All the descendants share the genes of only 15 parents, so the population has little genetic variety and may be more vulnerable to disease or inherited problems. (c) Goats had eaten the cactus and plants the tortoises needed; without restoring the food and shelter, released tortoises could not survive or breed in the wild.

3.7 FROGS: THE DOUBLE LIFE

OBJECTIVES

- Explain what makes a frog an amphibian, and how its skin works for breathing and drinking.
- Describe metamorphosis from tadpole to frog, including the internal changes, and give examples of unusual frog designs and parenting.
- Read Exodus 8 as history and explain what the plague of frogs showed Egypt about the LORD.

Warm-up. Go outside at dusk in spring or early summer near a pond, ditch or wet field, or listen to a recording of frog calls. Close your eyes for two full minutes and count how many different calls you hear. Every frog species has its own call, and females find males of their own kind by ear.

Video slot. Video coming. Tadpole to frog metamorphosis time-lapse; spring peepers and other frogs calling at night; the wood frog that freezes in winter. Search approved channels (Smithsonian’s National Zoo, a state wildlife agency, the U.S. Geological Survey, BBC Earth, National Geographic); preview first.

KEY TERMS

amphibian

From Greek for “double life”: a cold-blooded animal with moist, glandular skin and no scales that typically begins life in water and later lives partly on land. Frogs, salamanders and caecilians are amphibians.

metamorphosis

A dramatic change of body form during growth, as when a tadpole becomes a frog.

cutaneous respiration

Breathing through the skin. Oxygen passes through a frog’s thin, moist skin into tiny blood vessels just beneath it.

thyroid hormone

A hormone from the thyroid gland that triggers metamorphosis; without it, a tadpole stays a tadpole.

vocal sac

A thin pouch of skin on a male frog’s throat or cheeks that fills with air and makes his call louder.

chytrid fungus

A microscopic fungus (*Batrachochytrium dendrobatidis*) that infects frog skin and has caused deaths of many frogs worldwide.

CORE IDEAS

A large and varied family. About 7,800 kinds of frogs are known, nearly nine of every ten living amphibians. They live on every continent but Antarctica, from rainforest treetops to deserts and the Arctic edge. The smallest are tiny frogs of New Guinea and Brazil only about 7 to 8 millimeters long, among the smallest of all animals with backbones; the largest, the goliath frog of Cameroon and Equatorial Guinea, can reach about 32 centimeters in body length and more than 3 kilograms. “Toad” is not a separate scientific group; it is a common name for frogs with drier, warty skin and shorter legs.

Living skin. A frog’s skin is thin, moist and full of glands and blood vessels. Much of its oxygen passes in through the skin, and in cold water some frogs breathe almost entirely that way. A frog does not drink with its mouth; it absorbs water through a patch of thin skin on its belly and thighs. Its skin glands make mucus to keep it moist and, in many species, bitter or toxic chemicals to deter predators. Because water and chemicals pass through so easily, frogs are sensitive to polluted water, which is one reason biologists watch them closely.

Tadpole to frog. Most frogs lay jelly-coated eggs in water. The tadpole that hatches is almost a different creature: it breathes with gills, swims with a tail, scrapes algae with a horny beak, and has a long coiled gut for digesting plants. When thyroid hormone rises, the whole body is rebuilt. Hind legs grow first; front legs develop hidden in the gill chamber and then pop out. The tail is broken down and its material reused. The gut shortens for a diet of insects, lungs take over from gills, the mouth widens, the eyes move and change, and the skeleton hardens. A spring peeper finishes in a couple of months; a bullfrog tadpole may take one to three years. A biologist can trigger metamorphosis early by adding thyroid hormone, or stop it by blocking the gland: a striking picture of a body built according to a plan that is unfolded on schedule.

Winter, eyes and voices. The North American wood frog can freeze in winter. Ice forms in its body cavity and under its skin, its heart stops, and it stops breathing; its liver floods its cells with glucose, which keeps the cells from being torn by ice. In spring it thaws and hops away. A frog’s large eyes help it swallow: it blinks them down into its head to push food toward its throat. And each kind has its own call, made by pushing air back and forth across the vocal cords while the vocal sac swells. Spring peepers sound like sleigh bells; the American bullfrog says a deep “jug-o-rum.”

Strange parents. Most frogs leave their eggs, but many do not. The Surinam toad’s eggs sink into the skin of the mother’s back, and fully formed little toads emerge from her skin months later. Maria Sibylla Merian drew one in the 1700s. Male Darwin’s frogs in Chile carry tadpoles in their vocal sacs. Glass frog fathers guard eggs on leaves over streams. Two Australian gastric-brooding frogs swallowed their eggs and raised the young in their stomachs, which stopped making acid during that time; neither has been seen since the 1980s.

The plague of frogs. In Exodus 8, God told Pharaoh through Moses that if he would not let Israel go, the river would “bring forth frogs abundantly” into houses, bedchambers, ovens

and kneading troughs. Frogs were everywhere along the Nile, and Egyptians associated a frog-headed goddess, Heqet, with birth and life. The plague showed that the LORD, not Egypt's gods, ruled over the river and its creatures. When Pharaoh asked for relief, the frogs died, "and they gathered them together upon heaps: and the land stank." The Bible reports this plainly as history, a real judgment in a real place.

Frogs and stewardship. Since the late 1900s, scientists have recorded steep declines in many frogs, and in some places whole species have vanished. Habitat loss, pollution, introduced predators and especially the chytrid fungus have all played a part; the fungus seems to have spread around the world partly through trade in live amphibians. Ordinary families help by keeping ponds and ditches clean, avoiding pesticides near water, never moving frogs or tadpoles from one pond to another, and taking part in frog-call counts run by state wildlife agencies and zoos.

PICTURE STUDY



Batrachia, Plate 68 of *Kunstformen der Natur* (*Art Forms in Nature*), Ernst Haeckel (with lithographer Adolf Giltch), 1904 (published in parts, 1899–1904) · Color lithograph · From *Kunstformen der Natur*, Leipzig and Vienna

Wikimedia Commons · Public domain

Ernst Haeckel was a German zoologist who drew and published one hundred plates of plants and animals in *Art Forms in Nature*. Plate 68 shows ten frogs from around the world, including a tree frog, a horned frog, a marsupial frog that carries eggs on its back, and a North American leopard frog, set together in one imagined landscape. Haeckel held strong evolutionary views and sometimes let them shape his drawings; this plate is enjoyed for its careful observation of frogs' variety.

Look closely

- Count the frogs. Which seem built for climbing (big toe pads), and which for burrowing or hopping?
- Find the frog with the pouch or eggs on its back. What does that tell you about its parenting?
- Look at how the frogs are arranged. Could all of these frogs meet in one real place?

Talk about it

1. Haeckel arranged animals for beauty as well as accuracy. How can you tell when a picture is decorative and when it is a careful record?
2. Which of these frogs would you most like to see in life, and what would you look for?

Safety first. Wash hands with soap after touching pond water, frogs or tadpoles; some carry salmonella or skin toxins. Handle frogs only with wet, clean hands and only briefly. Never move frogs, tadpoles or pond water from one pond to another. Go to the water at night only with an adult and a flashlight.

HANDS-ON: THREE-NIGHT FROG CALL SURVEY

Real scientists count frogs by ear. You will do the same thing for three evenings and keep a data sheet that could be added to a state frog-call count.

You will need

- A wetland, pond or ditch you can safely reach at dusk (or a recording, if none is near)
- A thermometer
- A watch
- A frog-call guide or recordings for your state (many state wildlife agencies and the U.S. Geological Survey publish them)
- A data sheet in your Field Notebook

Steps

1. Before the first night, listen to recordings of the frogs found in your area and learn at least three calls.
2. Arrive at least 30 minutes after sunset. Stand quietly for 2 minutes, then listen for exactly 5 minutes.
3. Record date, time, air temperature, wind, and each species heard. Rate each with a calling index: 1 = individuals can be counted, 2 = calls overlap but some can be counted, 3 = a full chorus.
4. Repeat on two more evenings, if possible at different temperatures.
5. Write a summary: Which species called? Did temperature make a difference? Compare your count with the “abundance” of frogs in Exodus 8:3.

Check your work

- I surveyed for 5 minutes on three evenings.
- My data sheet records temperature and a calling index for each species.
- My summary connects at least one pattern to temperature or season.

FIELD NOTEBOOK

1. Draw the stages of metamorphosis in a circle: eggs, hatchling tadpole, tadpole with hind legs, tadpole with four legs, froglet with tail stub, adult frog. Under each, write one internal change (gills, gut, lungs, tail).
2. **Narration.** In one written paragraph, retell the plague of frogs from Exodus 8 and explain what it showed Pharaoh about the LORD. Your parent keeps this paragraph.

Did you know? Frogs have teeth only in the upper jaw (and many toads have none). They catch prey with a soft, sticky tongue attached at the front of the mouth that flips out and back in less than a tenth of a second. Frog saliva is unusual too: it becomes runny during the strike and then thickens to glue prey to the tongue.

Primary source. *Exodus 8:2-6, King James Version (1611).*

2 And if thou refuse to let them go, behold, I will smite all thy borders with frogs:
3 And the river shall bring forth frogs abundantly, which shall go up and come into thine house, and into thy bedchamber, and upon thy bed, and into the house of thy servants, and upon thy people, and into thine ovens, and into thy kneadingtroughs:

4 And the frogs shall come up both on thee, and upon thy people, and upon all thy servants.

5 And the LORD spake unto Moses, Say unto Aaron, Stretch forth thine hand with thy rod over the streams, over the rivers, and over the ponds, and cause frogs to come up upon the land of Egypt.

6 And Aaron stretched out his hand over the waters of Egypt; and the frogs came up, and covered the land of Egypt.

Go deeper. Mary C. Dickerson, *The Frog Book: North American Toads and Frogs* (1906; free online at the Internet Archive), with photographs and life histories; Ellin Beltz, *Frogs: Inside Their Remarkable World* (Firefly, 2005); AmphibiaWeb (amphibiaweb.org), a free University of California database with a page for every species; your state wildlife agency's frog-call guide. Second video topic: the wood frog freezing and thawing.

Goes deeper in. Life Science, high-school Biology, unit "Reptiles and Amphibians" (coming soon); History, Ancient World, for Egypt and the Exodus.

For families. Species counts follow AmphibiaWeb. Smallest frogs: *Paedophryne amauensis* (New Guinea, 2012) and *Brachycephalus* species (Brazil); records change as new species are described. The goliath frog figures are commonly cited maxima. Frog saliva: Noel et al., *Journal of the Royal Society Interface* (2017). Hequet is a frog-headed

Egyptian goddess linked with birth; connecting her to the second plague is a common and reasonable interpretation, not stated in the text itself. The line “they gathered them together upon heaps” in the core text is Exodus 8:14 (KJV); read verses 1–15 together. Haeckel held evolutionary views and was criticized for altering embryo drawings; his frog plate is used here for observation only.

PRACTICE

1. **EASY** What does the word “amphibian” mean, and why does it fit a frog?
2. **EASY** How does a frog drink?
3. **MEDIUM** List four changes inside or outside a tadpole’s body during metamorphosis, and name the hormone that triggers them.
4. **MEDIUM** How does a wood frog survive being frozen?
5. **CHALLENGE** Read Exodus 8:2–6 in the primary source. (a) List every place verse 3 says the frogs will go. (b) Why would frogs in ovens and kneading troughs be especially troubling to an Egyptian household? (c) Verse 5 names three kinds of water. What does that tell you about how complete the plague was?
6. **CHALLENGE** On three survey nights you record: Night 1, 9°C, spring peepers index 1; Night 2, 14°C, peepers index 3 and chorus frogs index 2; Night 3, 12°C, peepers index 2. (a) What pattern do you see? (b) Name two other things besides temperature that might explain it. (c) Why do scientists repeat surveys over many years before drawing conclusions about frog numbers?

Make it a game • Find Your Kind. Give each player a slip naming a frog call to imitate (peeper “peep,” bullfrog “jug-o-rum,” chorus frog thumb-run along a comb, green frog “gunk” like a loose banjo string). There must be at least two of each. In a darkened room, everyone calls at once, and players must find their own kind by ear alone. The first matched pair wins.

Scripture. “Their land brought forth frogs in abundance, in the chambers of their kings.” (Psalm 105:30, KJV)

The psalmist remembers the plague as history to be praised. The same God who made the frog and its life in the water directed it to the very rooms of Pharaoh’s palace. He rules over the smallest creature and the greatest king.

Practice: answers

1. “Double life.” A frog usually begins life in water as a gilled tadpole and lives as an adult partly on land.
2. It absorbs water through thin skin on its belly and thighs, not through its mouth.
3. Any four: hind legs then front legs grow; tail is broken down and absorbed; gills are replaced by lungs; the long plant-digesting gut shortens for insects; the beak is lost and the mouth widens; eyes change; skeleton hardens. Thyroid hormone triggers it.

4. Ice forms outside its cells (in the body cavity and under the skin) while its liver floods the cells with glucose, which acts as an antifreeze and keeps the cells from being damaged. Its heart and breathing stop until it thaws in spring.
5. (a) Into Pharaoh's house, his bedchamber, upon his bed, into the houses of his servants, upon his people, into the ovens and into the kneading troughs. (b) Ovens and kneading troughs were where daily bread was made; frogs there fouled food and made ordinary life impossible, and no one, from Pharaoh down, could escape. (c) Streams, rivers and ponds: every water source in Egypt was affected, so the plague reached the whole land.
6. (a) Calling rises with temperature: the warmest night had the loudest chorus and an extra species. (b) Any two: date in the season, rain or humidity, wind, moonlight, time after sunset, noise. (c) Frog calling changes from night to night and year to year with weather, so only long, repeated records can show a real increase or decline rather than chance.

3.8 SALAMANDERS: THE QUIET MULTITUDE UNDER THE LOGS

OBJECTIVES

- Describe how salamanders breathe, defend themselves and regrow lost parts, using real examples and numbers.
- Read Benvenuto Cellini’s account of a “salamander in the fire” and explain how the legend arose and was tested.
- Explain why salamanders matter to forests and streams and how a fungus led to new import rules in 2016.

Warm-up. Before you read, write down in one sentence what you already believe about salamanders. Is it something you saw, something you read, or something you were told? At the end of this stop, come back and check it. That is the habit this stop is about.

Video slot. Video coming. Salamanders of the Great Smoky Mountains; the eastern hellbender in a clean mountain stream; axolotl limb regeneration explained. Search approved channels (National Park Service, Smithsonian’s National Zoo, a state wildlife agency, the U.S. Fish and Wildlife Service); preview first.

KEY TERMS

lungless salamander

A member of the family Plethodontidae, the largest group of salamanders, which has no lungs and breathes entirely through its skin and the lining of its mouth.

regeneration

The regrowing of a lost body part. Many salamanders can regrow tails, whole limbs and parts of the eye, heart and spinal cord.

blastema

A cluster of unspecialized cells that forms at the stump of a lost limb and grows into the new limb.

neoteny

Keeping juvenile features, such as gills, into adulthood. The axolotl is the best-known example.

Bsal

Short for *Batrachochytrium salamandrivorans* (“salamander-eating”), a chytrid fungus discovered in 2013 that kills many salamanders and newts.

CORE IDEAS

Tails, moist skin, and lots of them. Salamanders and newts are the tailed amphibians. About 800 species are known, and more than half are “lungless” salamanders that breathe only through their skin and the lining of their mouths, which is why they must stay damp. The southern Appalachian Mountains have more kinds of salamanders than almost anywhere else on earth: Great Smoky Mountains National Park alone has about 30 species, and it is sometimes called the salamander capital of the world. Most are small, secretive and nocturnal, spending days under logs, rocks and leaf litter.

Hidden in plain sight. Because they hide, salamanders are easy to overlook, yet in some forests they are astonishingly common. In a classic study at the Hubbard Brook Experimental Forest in New Hampshire, published in 1975, Thomas Burton and Gene Likens estimated about 2,950 salamanders per hectare (roughly 1,200 per acre), mostly red-backed salamanders. Their combined weight was more than twice that of the breeding birds in the forest and about equal to that of the small mammals. Later studies have refined the figures, but the lesson stands: salamanders are a large, quiet part of the forest, eating insects, mites and worms and in turn feeding snakes, birds and shrews.

Giants and oddities. The Chinese giant salamander is the largest amphibian alive, recorded up to 1.8 meters long. In the eastern United States, the hellbender reaches about 70 centimeters; it breathes mainly through loose, wrinkled folds of skin and needs cold, clean, fast-flowing water. The olm of the caves of Slovenia and Croatia is pale, nearly blind, keeps its gills all its life, and may live 100 years; one captive olm was recorded not moving from the same spot for seven years. The axolotl of the lakes around Mexico City usually never metamorphoses at all, keeping its feathery gills while it breeds (neoteny). Wild axolotls are now very rare, though millions live in laboratories and aquariums.

Regrowing a limb. In 1768 the Italian priest and scientist Lazzaro Spallanzani reported that salamanders could regrow legs and tails that had been cut off. When a salamander loses a limb, skin quickly covers the wound, and a *blastema* of unspecialized cells forms beneath it. Over weeks those cells multiply and organize into bone, muscle, nerve and skin, in the right order and the right size. Axolotls can regrow limbs many times, as well as parts of their hearts, spinal cords, eyes and brains. Researchers study them closely, hoping to learn why salamanders heal by rebuilding while people heal by scarring. Nobody yet fully understands how the cells “know” what to build.

Defense. Salamander skin often holds toxins. The black-and-yellow European fire salamander releases a nerve poison called samandarin from glands behind its head and along its back. The rough-skinned newt of the Pacific Northwest carries tetrodotoxin, the same poison found in puffer fish, in amounts that can kill a person who swallows one. The Spanish ribbed newt pushes its sharp ribs through its own skin when grabbed, coating them with toxin as it goes. Many salamanders also drop their tails when seized and grow new ones.

Born of fire? For two thousand years people believed salamanders could live in fire. Aristotle and Pliny repeated the idea, medieval books told it, and fireproof asbestos cloth was sold as “salamander’s wool.” The legend probably began at the hearth: salamanders hide in damp, rotting logs, and when such a log was thrown on the fire, a salamander would scramble out of the flames, seeming to be born from them. In about 1505 the young Benvenuto Cellini, later a famous Florentine goldsmith, saw such a creature in a fire, and his father boxed his ears so he would never forget it (see the primary source). Later naturalists tested the claim directly, and salamanders do not survive fire. The legend teaches the duty of Proverbs 14:15: the prudent man “looketh well to his going” and does not believe every word.

Keeping the streams. In 2013 scientists identified a new chytrid fungus, Bsal, that had wiped out most of the fire salamanders at a site in the Netherlands, apparently carried in by the international pet trade from Asia. North America has the most salamander species of any continent and has not yet been invaded by Bsal. In January 2016 the U.S. Fish and Wildlife Service listed 201 salamander species as injurious wildlife, stopping their import and interstate transport to keep the fungus out. Hellbenders also suffer when streams fill with silt or pollution. Clean water, careful pet keeping and leaving logs and rocks as you found them are simple acts of stewardship.

PICTURE STUDY



Emblem XXIX: “As the salamander lives in fire...,” from Atalanta fugiens, Matthäus Merian the Elder (engraver), for Michael Maier, 1617 (reissued 1618) · Engraving (hand-colored in some copies) · Michael Maier, Atalanta fugiens (Oppenheim, 1617/1618); copies at the Science History Institute (Philadelphia) and other libraries

Wikimedia Commons · Public domain

This engraving comes from a 1617 book by Michael Maier, a German physician who wrote about alchemy, the mixture of early chemistry and speculation that came before modern

chemistry. Maier used the old legend of the fire-proof salamander as a picture of an idea. The engraver was Matthäus Merian the Elder, father of Maria Sibylla Merian, whose caiman you studied in Stop C1. The picture is beautifully made, but it shows a belief, not an observation.

Look closely

- Find the salamander. Does it look frightened, or calm in the flames?
- Look at the background. What ordinary scenes did the engraver include around the fire?
- Compare the salamander's spots and shape with a photograph of a real fire salamander. What did the engraver get right?

Talk about it

1. How can an accurate drawing of an animal still teach something false?
2. What would you need to see before believing that an animal could live in fire?

Safety first. When looking for salamanders, wet your hands first and hold one only briefly, or better, just watch; sunscreen, lotion and insect repellent on your hands can harm their skin. Never touch your eyes or mouth after handling a newt or salamander, and wash your hands afterward. Roll logs and rocks toward you, then put them back exactly as you found them. Do not collect salamanders; many are protected by state law.

HANDS-ON: COVER-BOARD SURVEY AND A MYTH TEST

Biologists count salamanders without tearing up the forest by laying out “cover boards,” flat boards that make ready-made hiding places. You will set one up, check it, and then test the old salamander legend by reasoning from evidence.

You will need

- Two untreated wooden boards about 30 × 60 cm (or flat pieces of plywood)
- A shady, damp spot in a yard or woods edge (with permission)
- A notebook, pencil and thermometer
- The Cellini excerpt in the “Primary source” box

Steps

1. Lay the boards flat on bare soil in a shady, damp spot. Press them down so they touch the ground. Wait at least two weeks.
2. Check the boards once a week for four to six weeks, early in the morning or after rain. Lift each board toward you, look, and set it back gently. Record date, temperature, weather, and every animal you see (salamanders, worms, beetles, slugs).
3. If you find a salamander, sketch it without touching it and identify it with a field guide or AmphibiaWeb.
4. Read the Cellini excerpt. In your notebook, make two columns: *What Cellini's father observed* and *What he concluded*. Then write a paragraph: Given what you know about

where salamanders hide, what most likely happened in that fire in about 1505?

Check your work

- I checked the boards at least four times and recorded the conditions each time.
- I put every board back exactly as I found it.
- My myth paragraph separates observation from conclusion and gives a likely explanation.

FIELD NOTEBOOK

1. Draw a salamander and a lizard side by side. Label five differences (moist skin vs. scales, claws vs. no claws, ear opening, toe count, eggs in water vs. eggs with shells).
2. Draw the stages of limb regrowth: stump, wound skin, blastema, small paddle, new limb with toes.
3. **Narration.** In one written paragraph, explain how the legend of the fire salamander probably began, and what it teaches about testing what we are told. Your parent keeps this paragraph.

Did you know? Spotted salamanders in eastern North America have a partner: a green alga that lives inside their eggs, giving them a greenish tint. The alga uses the embryo's waste, and the embryo gets extra oxygen from the alga. Scientists later found the alga inside the embryos' own cells, an unusual partnership for an animal with a backbone.

Primary source. *The Autobiography of Benvenuto Cellini, Book First, chapter IV, translated by John Addington Symonds (1888). Project Gutenberg eBook #4028.*

When I was about five years old my father happened to be in a basement-chamber of our house, where they had been washing, and where a good fire of oak-logs was still burning; he had a viol in his hand, and was playing and singing alone beside the fire. The weather was very cold. Happening to look into the fire, he spied in the middle of those most burning flames a little creature like a lizard, which was sporting in the core of the intensest coals. Becoming instantly aware of what the thing was, he had my sister and me called, and pointing it out to us children, gave me a great box on the ears, which caused me to howl and weep with all my might. Then he pacified me good-humouredly, and spoke as follows: "My dear little boy, I am not striking you for any wrong that you have done, but only to make you remember that that lizard which you see in the fire is a salamander, a creature which has never been seen before by any one of whom we have credible information." So saying, he kissed me and gave me some pieces of money.

Go deeper. James W. Petranka, *Salamanders of the United States and Canada* (Smithsonian Institution Press, 1998), the standard reference; Great Smoky Mountains National Park's salamander pages (nps.gov/grsm); the rest of Cellini's *Autobiography*

(Project Gutenberg #4028), for a lively picture of Renaissance Florence; the Science History Institute's digital copy of *Atalanta fugiens*. Second video topic: hellbender conservation and stream restoration.

Goes deeper in. Life Science, high-school Biology, units "Reptiles and Amphibians" and "Cells and Healing" (coming soon); History, Renaissance and Reformation, for Cellini and Florence.

For families. Species numbers follow AmphibiaWeb. Hubbard Brook: Burton and Likens, *Copeia* (1975); a later re-survey suggested even higher numbers. The olm that stayed put: Balázs et al., *Journal of Zoology* (2020). Spallanzani's 1768 report is a standard date in the history of regeneration. Bsal: Martel et al., *PNAS* (2013); the U.S. rule took effect in January 2016. Cellini was born in 1500, so "about five years old" places the event around 1505. Cellini's autobiography includes adult material elsewhere; the excerpt here is suitable, but preview before assigning more. The Maier emblem comes from an alchemical book; it is used here only as historical evidence of a belief, and the stop says so.

PRACTICE

1. **EASY** How do lungless salamanders breathe?
2. **EASY** Name the largest living amphibian and the largest salamander of the eastern United States.
3. **MEDIUM** What is a blastema, and what does it do?
4. **MEDIUM** Why did the U.S. stop imports of 201 salamander species in 2016?
5. **CHALLENGE** Read the Cellini excerpt. (a) List three things his father actually observed. (b) What conclusion did he draw, and what did he base it on? (c) Give the most likely natural explanation. (d) Did the father reason well? Answer fairly, considering what was believed in his day.
6. **CHALLENGE** Burton and Likens estimated 2,950 salamanders per hectare. Suppose they averaged 0.6 grams each (many were young). (a) What was the salamander mass per hectare in kilograms? (b) A hectare is about 2.47 acres. How many salamanders per acre is that? (c) Why might such a large population go unnoticed by most visitors?

Make it a game · Observed or Told?. The leader reads statements about salamanders: "Salamanders live in fire." "This salamander has four toes on its front feet." "Newts are poisonous." "I saw a salamander crawl out of a log." Players hold up one finger for "I can observe it," two for "I was told it," and three for "It has been tested." Discuss each and how you could test the ones that are only told.

Scripture. "The simple believeth every word: but the prudent man looketh well to his going." (Proverbs 14:15, KJV)

The fire-salamander legend lasted for two thousand years because people repeated it instead of looking well. Christian students honor God's truth by testing claims, keeping what is

proven and gently correcting what is not.

Practice: answers

1. Through their moist skin and the lining of their mouths.
2. The Chinese giant salamander; the hellbender.
3. A cluster of unspecialized cells that forms under the wound skin at a lost limb's stump; it multiplies and organizes into the bone, muscle, nerves and skin of a new limb.
4. To keep out Bsal, a deadly chytrid fungus discovered in 2013 that spread to Europe through the pet trade; North America has more salamander species than any other continent and has not been invaded.
5. (a) A fire of oak logs in a cold basement room; a little lizard-like creature among the hottest coals; it was moving ("sporting"). (b) That it was a salamander, the legendary fire-dwelling creature; he based this on the old tradition that salamanders live in fire. (c) A real salamander (or lizard) had been sheltering in a damp log and was scrambling out of the flames; it would soon have died. (d) He observed honestly and reported what he saw, and in 1505 nearly every learned book taught the legend, so his conclusion was reasonable for his time. But he went beyond his evidence: he did not watch to see whether the creature survived. Proverbs 14:15 calls us to look well before concluding.
6. (a) $2,950 \times 0.6 \text{ g} = 1,770 \text{ g} \approx 1.8 \text{ kg}$ per hectare. (b) $2,950 \div 2.47 \approx 1,190$, about 1,200 per acre. (c) They are small, nocturnal, silent, and spend their days under logs, rocks and leaf litter; most visitors walk through by day and never lift a log.

3.9 POISON DART FROGS: BORROWED POISON, BRIGHT WARNINGS

OBJECTIVES

- Explain where a poison frog’s toxins come from and how batrachotoxin acts on nerves and muscles.
- Describe warning coloration and test it with a simple model-prey experiment.
- Separate fact from legend about “dart” frogs, and weigh the promise and limits of frog toxins as medicines.

Warm-up. Look around your house for warning colors: a yellow-and-black caution sign, a red stop sign, the orange on a hunter’s cap. Why are warnings so often bright yellow, red, orange and black? Hold that question; some of the most poisonous animals on earth wear the same colors.

Video slot. Video coming. Poison dart frogs in the rainforest; a father poison frog carrying tadpoles on its back; strawberry poison frog color forms of Bocas del Toro, Panama. Search approved channels (Smithsonian Tropical Research Institute, Smithsonian’s National Zoo, San Diego Zoo Wildlife Alliance, BBC Earth, National Geographic); preview first.

KEY TERMS

aposematism

Warning coloration: bright, easy-to-remember colors or patterns that tell predators an animal is poisonous or dangerous.

alkaloid

A nitrogen-containing chemical, often bitter or toxic, made by many plants, fungi and small animals. Caffeine and nicotine are alkaloids.

sequestration

Taking in a chemical from food and storing it, unchanged or slightly changed, in the body for one’s own use.

batrachotoxin

An extremely powerful alkaloid in the skin of the golden poison frog and its relatives that holds sodium channels in nerves and muscles open.

sodium channel

A tiny gate in the membrane of a nerve or muscle cell that opens to let sodium in and fire a signal, then closes again.

phytotelma (plural phytotelmata)

A small pool of water held by a plant, such as the cup of a bromeliad or a hollow in a tree, where many poison frog tadpoles grow.

CORE IDEAS

Small jewels of the forest floor. Poison frogs belong to the family Dendrobatidae, about 200 species living in the rainforests of Central and South America, from Nicaragua to Bolivia and Brazil. Most are 1.5 to 5 centimeters long, and many are active in daylight, hopping across the leaf litter in electric blue, gold, scarlet or green. Their brightness is no accident. A bird or snake that tastes one quickly learns that the color means a burning, sickening mouthful, and avoids that pattern afterward. This is aposematism, warning coloration. The strawberry poison frog of Bocas del Toro in Panama comes in dozens of color forms on different islands, from red with blue legs to green, orange or yellow, yet each local form is still a clear warning to local predators.

Poison on the menu. The most surprising fact about poison frogs is that most of them do not make their poison. Frogs raised in captivity on fruit flies and crickets are harmless. In the wild they eat ants, mites, small beetles and other leaf-litter creatures that contain alkaloids, and their bodies move those chemicals into special skin glands. John Daly of the U.S. National Institutes of Health spent decades identifying frog-skin toxins and catalogued more than 800 different alkaloids. Later researchers traced many of them to tiny soil mites and to ants. The frogs eat what would sicken other animals and turn it into armor.

The golden poison frog. In 1978 Charles Myers, John Daly and Borys Malkin described *Phyllobates terribilis*, the golden poison frog of the Pacific rainforest of western Colombia. Its skin holds batrachotoxin. A single wild frog may carry enough to kill about ten people, though the exact figure is an estimate. Batrachotoxin locks sodium channels open, so nerves and muscles cannot stop firing; the result is paralysis and heart failure. How does the frog avoid poisoning itself? Studies have found changes in the frog's own sodium channels, and other research points to proteins that may bind and hold the toxin. The question is still being worked out.

The truth about the darts. The name "poison dart frog" suggests that many of these frogs tipped hunting darts. In fact, only three species, all *Phyllobates* of western Colombia, are known to have been used, by the Emberá and the Wounaan (Noanamá) peoples. Hunters wiped blowgun darts across the back of a living golden poison frog; darts treated this way were said to stay deadly for a year or more. For other species they held the frog near a fire to draw out its secretions. The other 200-odd species have never been used for darts at all, which is why many biologists prefer simply "poison frogs."

Devoted parents. Poison frogs lay their eggs on land, in damp leaf litter, and one parent, often the father, guards and moistens them. When the tadpoles hatch, they wriggle onto the parent's back and are carried, sometimes far up a tree, to small pools in bromeliads or tree holes. A strawberry poison frog mother visits each tadpole in its separate pool every few days and lays an unfertilized egg there for it to eat; the tadpoles of some species even take in alkaloids from these eggs. Such care in a creature the size of a thumbnail is a small picture of the faithful providence that runs through creation.

Medicine: promise and caution. In 1974 Daly collected skin extracts from the Ecuadorian frog *Epipedobates anthonyi*, and by 1992 he and colleagues had identified epibatidine, a compound that in mice blocked pain about 200 times as powerfully as morphine. Drug companies designed safer cousins of it, and one reached human trials in the late 1990s, but side effects stopped it. Epibatidine itself is far too toxic to use. The story is a good example of honest science: a real discovery that taught researchers much about the body's pain pathways, but no miracle drug yet.

Wise warnings and stewardship. Proverbs 22:3 says that “a prudent man foreseeth the evil, and hideth himself.” A predator that heeds a frog's bright warning lives; the one that ignores it suffers. Poison frogs face real threats from forest clearing, mining and pollution in their small ranges, and from the chytrid fungus. Many in the pet trade are now captive-bred and harmless, which spares wild populations. Protecting the forest floor where the frogs, mites and ants live together protects the whole chain.

PICTURE STUDY



Morning in the Tropics, Frederic Edwin Church, 1877 · Oil on canvas · National Gallery of Art, Washington, D.C.

Wikimedia Commons · Public domain

Frederic Edwin Church, the American landscape painter, traveled in Colombia and Ecuador in 1853, returned to Ecuador in 1857, and later visited Jamaica, filling sketchbooks with tropical plants. Years afterward he painted *Morning in the Tropics* in his studio from those sketches and memories. It shows the kind of steamy lowland rainforest where poison frogs live. No frog is visible; that is the point. A two-centimeter frog in that world is easy to miss unless it is bright.

Look closely

- Find the tallest trees and follow their trunks down to the water. Where would leaf litter collect?
- Look for vines, mosses and plants growing on other plants. Which ones might hold small pools of water?
- Notice the light and the mist. What time of day is it, and how would that matter to a frog that dries out easily?

Talk about it

1. If you were a tiny frog in this forest, where would you live, and why would bright colors help you there?
2. Church painted from sketches and memory years later. What might he have changed, and what might he have kept true?

Safety first. Never touch a wild poison frog, and in the tropics avoid handling any bright frog; skin toxins can enter through cuts or the eyes. Captive-bred frogs in a pet shop are generally harmless, but wash hands before and after any contact with frogs. In the clay-model project, place models only on your own property or with the owner's permission, and collect them all at the end.

HANDS-ON: DO WARNING COLORS WORK? A CLAY-FROG EXPERIMENT

Scientists in Costa Rica and Panama have tested warning colors by setting out hundreds of small clay frogs, some brightly colored and some brown, and counting beak marks left by birds. You can run a small version in your yard.

You will need

- Non-toxic modeling clay (plasticine, which does not harden) in brown, red, orange or bright blue and black
- A ruler
- Twenty craft sticks or flags to mark locations
- Your Field Notebook and a calculator

Steps

1. Make twenty frog-shaped models about 2 cm long: ten brown and ten brightly colored (for example red with black spots).
2. Set them out at least 2 meters apart in a yard, garden bed or woods edge, alternating colors, and mark each spot.
3. Check each model every day for three days. Record any beak marks (V-shaped dents), tooth marks (rodent), or missing models.
4. Calculate the percentage of brown and bright models attacked, and make a simple bar graph.
5. Explain your result. Remember: your local birds have never eaten a poison frog, so they have not learned the warning. What would you expect in a rainforest where birds have

learned?

Check your work

- I set out equal numbers of brown and bright models and recorded each one for three days.
- I calculated percentages and drew a graph.
- My explanation discusses learning by predators and why my backyard is different from a rainforest.

FIELD NOTEBOOK

1. Draw a food chain for a golden poison frog: leaf litter, soil mite and ant, frog, skin gland, and a would-be predator. Label where the alkaloid starts and where it is stored.
2. Draw a nerve cell membrane with a sodium channel, first normal (open then closed) and then held open by batrachotoxin.
3. **Narration.** In one written paragraph, explain why a captive-raised poison frog is harmless and a wild one may be deadly. Your parent keeps this paragraph.

Did you know? Batrachotoxin has also been found in a few birds of New Guinea, such as the hooded pitohui, and in beetles they eat. Animals on opposite sides of the world carry the same rare poison, and in both cases the poison seems to come from what they eat.

Go deeper. Stefan Lötters, Karl-Heinz Jungfer, Friedrich Wilhelm Henkel and Wolfgang Schmidt, *Poison Frogs: Biology, Species and Captive Husbandry* (Edition Chimaira, 2007); AmphibiaWeb's pages on *Phyllobates terribilis* and *Oophaga pumilio*; the Smithsonian Tropical Research Institute (stri.si.edu), which studies strawberry poison frogs in Panama; the National Gallery of Art's page on Church's *Morning in the Tropics*. Second video topic: a strawberry poison frog mother feeding her tadpoles.

Goes deeper in. Life Science, high-school Biology, units "Reptiles and Amphibians" and "The Nervous System" (coming soon); Geography, unit on South America (coming soon).

For families. Species count: Dendrobatidae has roughly 200 species (counts vary with classification). Golden poison frog: Myers, Daly and Malkin, *Bulletin of the American Museum of Natural History* (1978). The "ten people" figure is a widely repeated estimate. Daly's alkaloid work: many papers, summarized in Daly et al., *Journal of Natural Products* (2005). Epibatidine: Spande, Daly et al., *Journal of the American Chemical Society* (1992); the trial compound was ABT-594 (tebanicline). Clay-model studies: e.g., Saporito et al., *Copeia* (2007). Church's South American trips (1853, 1857) and Jamaica trip (1865) are standard dates; the exact place that inspired the painting is not certain; the painting is in the National Gallery of Art. No public-domain primary source was found that could be checked word for word, so none is excerpted.

PRACTICE

1. **EASY** What is aposematism? Give one example from this stop.
2. **EASY** Where do most poison frogs get their poison?
3. **MEDIUM** How does batrachotoxin affect the body?
4. **MEDIUM** Correct this statement: “Poison dart frogs got their name because Amazon hunters used all of them to poison darts.”
5. **CHALLENGE** In a clay-model experiment, 9 of 30 brown models and 3 of 30 bright red models show bird beak marks. (a) Give the attack rate for each in percent. (b) How many times more often were brown models attacked? (c) Suggest one reason the bright models were attacked at all, and one way to improve the experiment.
6. **CHALLENGE** Epibatidine blocked pain about 200 times more strongly than morphine in mice, yet it never became a medicine. (a) Why not? (b) What did scientists gain anyway? (c) Write a sentence on why it is wise to protect creatures whose chemistry we do not yet understand.

Make it a game • Learn the Warning. A leader hides colored candies or paper chips in a yard: most are tasty (plain colors) but red-and-black ones “cost” the finder a forfeit (ten jumping jacks). Players forage in rounds. Track how many red-and-black chips are picked up in round one versus round three. Do the “predators” learn?

Scripture. “A prudent man foreseeth the evil, and hideth himself: but the simple pass on, and are punished.” (Proverbs 22:3, KJV)

A bright poison frog is a living warning sign, and a wise predator heeds it. God’s Word, too, gives clear warnings; the prudent listen and turn aside before harm comes.

Practice: answers

1. Warning coloration: bright colors that tell predators an animal is poisonous. Example: the golden poison frog’s yellow, or the strawberry poison frog’s red and blue.
2. From their food: alkaloid-containing mites, ants and small beetles, which they store in skin glands (sequestration).
3. It holds sodium channels in nerve and muscle cells open, so they keep firing and cannot reset; this leads to paralysis and heart failure.
4. Only three species, all *Phyllobates* of western Colombia (not the Amazon), are known to have been used, by the Emberá and Wounaan peoples. The vast majority of poison frogs were never used for darts.
5. (a) Brown $9/30 = 30$ percent; red $3/30 = 10$ percent. (b) Three times as often. (c) Reasons: young birds that have not yet learned the warning; birds that are tolerant of the toxin; curiosity. Improvements: more models, more sites, longer time, models placed in the frogs’ real habitat, counting only clear bird marks, or a third color as an extra comparison.
6. (a) The dose that relieves pain is very close to the dose that is poisonous, and a safer designed cousin (ABT-594) still caused serious side effects in human trials. (b) Knowledge of a type of nerve receptor involved in pain, and new ideas for designing pain medicines. (c) Each species

may hold knowledge useful to medicine and science; once a species is lost, what it could have taught is lost with it, and careful stewardship keeps those riches for the future.

3.10 THE GILA MONSTER: DESERT VENOM AND A MEDICINE

OBJECTIVES

- Describe the Gila monster's range, body and way of life, and explain why it spends most of its life underground.
- Explain how its venom works and correct common myths about it.
- Trace how a peptide from Gila monster venom led to the diabetes drug exenatide, and connect discovery to Proverbs 25:2.

Warm-up. On a sunny afternoon, put one hand flat on bare ground or pavement in full sun and the other on soil in deep shade. Which is hotter? Now imagine a desert where the surface reaches over 60°C (140°F) in summer. Where would you live if you were a slow lizard?

Video slot. Video coming. Gila monsters in the Sonoran Desert; how the Gila monster eats eggs; the story of exenatide and Gila monster venom. Search approved channels (Arizona-Sonora Desert Museum, Smithsonian's National Zoo, San Diego Zoo Wildlife Alliance, a state wildlife agency, PBS); preview first.

KEY TERMS

osteoderm

A small bone embedded in the skin. In the Gila monster, osteoderms lie under the round, bead-like scales.

peptide

A short chain of amino acids. Many hormones and many venom components are peptides.

GLP-1

Glucagon-like peptide-1: a human gut hormone released after meals that tells the pancreas to release insulin when blood sugar is high.

exendin-4

A peptide found in Gila monster venom that acts like human GLP-1 but lasts for hours instead of minutes in the body.

fossorial

Adapted for living underground, in burrows.

CORE IDEAS

The beaded lizard of the Southwest. The Gila monster (*Heloderma suspectum*, say HEE-la) lives in the deserts of the American Southwest and northwestern Mexico: most of southern and western Arizona, southwestern New Mexico, the southwestern corner of Utah, the southern tip of Nevada, a little of southeastern California, and the Mexican states of Sonora and Sinaloa. It is named for the Gila River basin of Arizona. It is the largest native

lizard in the United States, growing to about 50 centimeters (20 inches) and usually under 1 kilogram. Its skin is covered with round, bead-like scales over tiny bones called osteoderms, patterned in black and pink, orange or yellow. Its only close relatives are the beaded lizards of Mexico and Guatemala.

A life mostly underground. Gila monsters may spend 90 percent or more of their lives in burrows and rock shelters, out of the deadly heat and cold. They are most active in spring, when they come out to find food and mates, and again briefly after summer rains. A Gila monster is a nest raider: it finds the eggs of quail, doves and lizards and the newborn young of rabbits and rodents by smell, flicking its forked tongue. Because such meals come only a few times a year, it eats enormous amounts when it can: an adult may eat a third of its body weight at one meal, and a young one even more. It stores fat in its thick tail and can live for months on that reserve.

Venom without fangs. Unlike a rattlesnake, a Gila monster has no hollow fangs. Its venom glands are in its lower jaw, and the venom flows up along grooves in its teeth. When it bites, it holds on and chews so that the venom seeps into the wound. The bite is intensely painful and can cause swelling, weakness and a drop in blood pressure. Human deaths are extremely rare; most old reports are poorly documented, and in modern times the people bitten have nearly always been those who picked the lizard up. Because its usual prey (eggs and helpless nestlings) cannot fight back, most researchers think the venom serves mainly for defense.

Myths and a careful name. Old desert stories said a Gila monster had poisonous breath, could not let go until sunset or thunder, or had no way to get rid of waste and was therefore poisonous. None of this is true. In 1869 the naturalist Edward Drinker Cope gave the species its scientific name *suspectum*, because he *suspected* from its grooved teeth that it was venomous, though he had not proven it. That one word is a small lesson in honest science: Cope named his suspicion without overclaiming, and later study confirmed it.

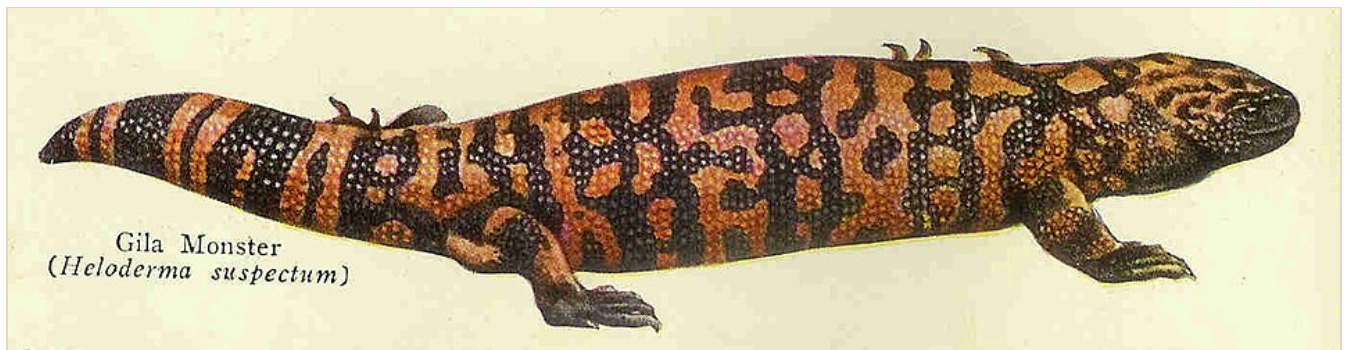
From venom to medicine. In the early 1990s John Eng, an endocrinologist at the Veterans Affairs Medical Center in the Bronx, New York, was searching animal venoms for hormone-like peptides. In 1992 he isolated one from Gila monster venom and called it exendin-4. It closely resembles human GLP-1, a gut hormone that helps release insulin after a meal. But human GLP-1 is broken down in about two minutes, while exendin-4 lasts for hours. A synthetic version, exenatide, was developed by Amylin Pharmaceuticals and approved by the U.S. Food and Drug Administration in April 2005 as Byetta, a treatment for type 2 diabetes. It was the first drug of its kind, and it opened the way for the later GLP-1 medicines widely used today. Those later drugs are designed differently, and all have side effects and must be prescribed by doctors, but the path began with a desert lizard.

“To search out a matter.” Proverbs 25:2 says that “it is the glory of God to conceal a thing; but the honour of kings is to search out a matter.” Exendin-4 lay hidden in the Gila monster’s jaw for as long as there have been Gila monsters. It took patient searching, years of laboratory work and testing before it could help anyone. Eng had to persuade others his idea

was worth funding. The story shows that knowledge of creation is a gift God allows us to discover, and that the smallest or least-loved creature may hold something of great value.

Protecting a slow lizard. In 1952 Arizona gave the Gila monster legal protection, and it is often said to be the first venomous animal protected by law in the United States. Today it is protected in every state where it lives, and collecting one is illegal. Its threats are loss of desert habitat to building and roads, cars, and illegal collecting for the pet trade. Because each Gila monster lays only a few eggs a year and may live 20 years or more, the loss of adults is hard to replace. A family visiting the desert does the right thing simply by watching from a distance, driving carefully, and never picking one up.

PICTURE STUDY



Gila Monster (Heloderma suspectum), color plate from *The New Century Dictionary*, Unknown illustrator, 1920s · Color printed illustration · *The New Century Dictionary of the English Language* (New York: The Century Company)

Wikimedia Commons · Public domain

In the early 1900s, large dictionaries and encyclopedias often included color plates of animals so readers could see creatures they might never meet. This one shows the Gila monster, the beaded lizard Edward Drinker Cope named in 1869, from the side, with its scientific name printed beneath it. Look at it as a naturalist would.

Look closely

- Look at the scales. How are they different from the overlapping scales of a snake or the spiny scales of a fence lizard?
- Look at the tail. What does its thickness tell you about how the Gila monster survives long periods without food?
- Look at the colors and pattern. How might bold black and orange bands warn a predator, and how might they help hide the lizard among desert rocks and shadows?

Talk about it

1. This plate was printed in color in a dictionary. Why would a picture help a reader more than a written description of “black and pink bead-like scales”?
2. Cope named the animal for a suspicion. What could he see in a specimen that would make him suspect venom?

Safety first. Never pick up, poke or corner a Gila monster; it is protected by law and its bite is very painful and medically serious. If anyone is bitten, call 911 and poison control (1-800-222-1222 in the U.S.). In the desert, carry water, wear closed shoes, watch where you put hands and feet, and do the burrow-temperature project only with an adult, away from real animal burrows.

HANDS-ON: WHY LIVE UNDERGROUND? A SOIL TEMPERATURE STUDY

Measure how much cooler (or warmer) it is below the surface, and use your data to explain why a Gila monster spends most of its life in a burrow.

You will need

- Two thermometers (a soil or kitchen probe thermometer works well)
- A garden trowel
- A sunny patch and a shady patch of bare ground in your own yard
- A watch and your Field Notebook

Steps

1. Dig a small hole about 15 cm (6 inches) deep in the sunny patch. Do not dig near any animal burrow.
2. At 9 a.m., noon, 3 p.m. and 6 p.m., record: air temperature in the shade, temperature on the sunny surface, and temperature at the bottom of the hole (let the thermometer settle for two minutes each time).
3. Repeat in the shady patch if you can.
4. Make a line graph with time across the bottom and temperature up the side, one line for each location.
5. Write a paragraph: How much did the surface temperature change during the day compared with 15 cm down? What does this tell you about the Gila monster's burrow? Would a deeper burrow be even steadier?

Check your work

- I recorded at least four times of day at the surface and below ground.
- My graph has a title, labeled axes and a key.
- My paragraph uses my numbers to explain the Gila monster's underground life.

FIELD NOTEBOOK

1. Draw a Gila monster from above. Label the bead-like scales, the forked tongue, the thick fat-storing tail, and the position of the venom glands in the lower jaw. Draw a cross-section of its burrow below.
2. Make a flow chart: Gila monster venom → exendin-4 (1992) → exenatide → FDA approval (2005) → later GLP-1 medicines.

3. **Narration.** In one written paragraph, tell the story of how a lizard's venom led to a diabetes medicine, and explain how Proverbs 25:2 fits it. Your parent keeps this paragraph.

Did you know? A Gila monster's body temperature in its burrow may be 10 to 20 degrees Celsius cooler than the surface on a summer afternoon. Gila monsters also lose water through their skin more slowly than many lizards, and they can store water in their bladders, drawing on it during drought.

Go deeper. Daniel D. Beck, *Biology of Gila Monsters and Beaded Lizards* (University of California Press, 2005), the leading scientific book; David E. Brown and Neil B. Carmony, *Gila Monster: Facts and Folklore of America's Aztec Lizard* (1991); the Arizona-Sonora Desert Museum's Gila monster page (desertmuseum.org); the Golden Goose Award's page on John Eng and exenatide (goldengooseaward.org). Second video topic: how the Sonoran Desert's animals survive summer heat.

Goes deeper in. Life Science, high-school Biology, units "Reptiles and Amphibians" and "Hormones and the Body" (coming soon); Earth Science, unit on deserts and climate zones (coming soon).

For families. Range and size follow the Arizona-Sonora Desert Museum and Beck (2005). Cope named *Heloderma suspectum* in 1869. Eng's discovery: Eng et al., *Journal of Biological Chemistry* (1992); Byetta was approved by the FDA in April 2005. The claim that Arizona's 1952 law was the first protection of a venomous animal in the U.S. is widely repeated; the stop marks it "often said." Reliable figures on human deaths from Gila monster bites are lacking; the stop says only that they are extremely rare. Medicines are mentioned for their history; this is not medical advice. The Cope figure should be checked in the Biodiversity Heritage Library before printing, to be sure it is the whole-animal drawing.

PRACTICE

1. **EASY** Name three U.S. states where Gila monsters live and the river they are named for.
2. **EASY** Where are a Gila monster's venom glands, and how does the venom get into a bite?
3. **MEDIUM** Why does a Gila monster need to eat so much at one meal, and where does it store the extra?
4. **MEDIUM** What does *suspectum* mean in the Gila monster's scientific name, and why is it a good example of careful science?
5. **CHALLENGE** Human GLP-1 lasts about 2 minutes in the blood; exendin-4 lasts several hours. (a) If exendin-4 lasted 2.4 hours, how many times longer is that than GLP-1? (b) Why would a longer-lasting version be more useful as a medicine? (c) Put these in order with dates: FDA approval of exenatide; Cope names the Gila monster; Eng isolates exendin-4.

6. **CHALLENGE** Your soil study gives these afternoon readings: sunny surface 52°C, 15 cm down 31°C, shade air 36°C. (a) How much cooler is 15 cm down than the surface? (b) As a percentage of the surface temperature? (c) Explain, using these data, why a Gila monster spends over 90 percent of its life underground, and why that also saves food energy.

Make it a game • Desert Survival. Mark a “burrow” (a blanket) and a “desert” (the rest of the room). A leader calls out times: “6 a.m. spring!” “Noon in July!” “After a summer rain!” “Midnight in January!” Players decide whether a Gila monster would be out hunting or in its burrow and run to the right place. Anyone wrong must explain the right answer before rejoining.

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 a medicine in the jaw of a desert lizard, and He gave people minds and patience to search it out. Every true discovery in creation is a finding of what He placed there, and the honor of the search belongs to those who go looking.

Practice: answers

1. Any three: Arizona, New Mexico, Utah, Nevada, California. Named for the Gila River (basin) of Arizona.
2. In the lower jaw; the venom flows up grooves in the teeth, and the lizard holds on and chews so it seeps into the wound.
3. Its food (eggs and nestlings) is available only a few times a year, mainly in spring, so it eats up to a third of its weight when it can and stores fat in its thick tail.
4. “Suspected”: Cope suspected from its grooved teeth that it was venomous but had not proven it. He named his suspicion honestly without claiming more than he knew, and later study confirmed it.
5. (a) $2.4 \text{ hours} = 144 \text{ minutes}$; $144 \div 2 = 72$ times longer. (b) A hormone that vanishes in minutes would need constant injection; one that lasts hours can be given once or twice a day and keeps working between doses. (c) Cope names the Gila monster (1869); Eng isolates exendin-4 (1992); FDA approves exenatide (2005).
6. (a) $52 - 31 = 21^\circ\text{C}$ cooler. (b) $21 \div 52 \approx 0.40$, about 40 percent cooler. (c) The surface would overheat and dry out a slow lizard; below ground it stays cooler and steadier. As an ectotherm, a cooler body also burns less energy, so it can survive on only a few large meals a year.

TRAIL 3 BADGE QUIZZES

The badge quizzes are optional and may be taken open-notebook. Answer each question in complete sentences; show work for any calculation. Four right out of five on each quiz earns that badge part. Badges and the certificate are earned by doing the stops and keeping the narrations, not by scores.

Badge quiz 1 (Stops 1–5)

1. Name two things Herodotus got right and one thing he got wrong about the Nile crocodile.
2. Summarize the old and new explanations of how a Komodo dragon's bite kills.
3. Why did King Hezekiah destroy the bronze serpent Moses had made, and how did Jesus later use the story?
4. Name two features of the earth's magnetic field a loggerhead turtle can sense, and two actions that helped the Kemp's ridley recover.
5. How does a chameleon change color, and what are its two main reasons for doing so?

Badge quiz 2 (Stops 6–10)

6. How was the Española tortoise saved from extinction? Include numbers.
7. Name four changes that happen during a frog's metamorphosis and the hormone that triggers them.
8. How did the legend that salamanders live in fire probably begin?
9. Why is a poison frog raised in captivity usually harmless?
10. What is exendin-4, who discovered it, and what medicine came from it?

TRAIL CERTIFICATE: MY REPTILE AND AMPHIBIAN FIELD NOTEBOOK AND TRAIL C CERTIFICATE

Gather your Field Notebook pages from all ten stops into one bound section titled "Reptiles and Amphibians," with your name and the dates you began and finished. Include each project record (the Herodotus fact-check table, frog-call data sheets, cover-board log, clay-frog graph and soil-temperature graph).

Add the ten narration paragraphs, each dated and signed by a parent.

Write a closing essay of 400 to 600 words on one of these questions: (a) What do the stories of the fire salamander and the trochilus bird teach about using old sources? (b) Choose two recoveries from this trail and explain what made stewardship succeed. (c) How do the creatures of this trail display the "manifold" wisdom of Psalm 104:24? Quote at least one primary source exactly.

When the notebook and essay are complete, a parent signs the Trail C certificate.

- **Completeness:** All ten stops have a notebook page, a project record and a dated narration paragraph.

- **Evidence and numbers:** Projects record real observations or measurements with units, and graphs are titled and labeled.
- **Sources:** The essay quotes at least one primary source exactly, names it, and clearly separates observation from interpretation or legend.
- **Writing and reasoning:** Narrations and essay are clear, well organized and correct in grammar, and Scripture is quoted accurately from the KJV and applied thoughtfully.

Answer key

1. Right (any two): it lays goose-sized eggs on land; it grows huge from a small egg; it eats little in the coldest months; it has strong claws and an armored back. Wrong (any one): it has no tongue (it does, fixed to the floor of the mouth); it moves only its upper jaw (it moves its lower jaw).
2. Old: deadly bacteria in its saliva caused infection. New (2009, 2013): deep cutting wounds and blood loss, helped by venom from glands in the lower jaw that prevents clotting and lowers blood pressure; the mouth bacteria are ordinary.
3. The people had made it an idol, burning incense to it and calling it Nehushtan (2 Kings 18:4). Jesus said that as Moses lifted up the serpent, the Son of man must be lifted up, so that those who believe may have life (John 3:14-15).
4. Field strength (intensity) and angle (inclination). Recovery (any two): protecting the Rancho Nuevo nesting beach and its nests; a second nesting colony at Padre Island, Texas; requiring turtle excluder devices in shrimp nets; cooperation between Mexico and the United States.
5. By tightening or relaxing a lattice of guanine nanocrystals in its iridophore cells, which changes the color of reflected light, combined with pigment cells. Mainly to communicate (with rivals and mates) and to control body temperature.
6. Only 14 tortoises (12 females, 2 males) were left; they were brought to Santa Cruz to breed, joined by Diego in 1976; about 2,000 young were returned to Española between 1965 and 2020, and goats were removed so the plants could recover.
7. Any four: legs grow; tail is absorbed; gills replaced by lungs; gut shortens for an insect diet; mouth widens and beak is lost; eyes change; skeleton hardens. Thyroid hormone.
8. Salamanders hide in damp, rotting logs; when such logs were thrown on a fire, salamanders scrambled out of the flames and seemed to come from them. People repeated the story without testing it.
9. Most poison frogs do not make their own toxins; they take in alkaloids from wild mites, ants and beetles. Captive frogs fed fruit flies and crickets have no source of the toxins.
10. A peptide in Gila monster venom that acts like the human hormone GLP-1 but lasts much longer. John Eng discovered it in 1992. A synthetic version, exenatide (Byetta), was approved by the FDA in 2005 for type 2 diabetes.

ANIMALS TRAIL D: OCEAN LIFE

The fourth trail of the Animals track goes to sea: sharks and their electric sense, the octopus, the coral reef, the giant squid, dolphins, jellyfish, the anglerfish and the deep sea, the salmon's journey home, seals and sea lions, and finally Jonah's great fish and the leviathan of Job 41. Each stop joins careful science (real numbers, real experiments and honest open questions) with history, a public-domain picture, a hands-on project and Scripture in the King James Version.

This is the  **Expert** level, written for students 14 and up, and each stop takes about 35 to 50 minutes. The student reads the stop, works the project, writes the narration paragraph that a parent keeps, and does the practice problems, including at least two "challenge" problems with full answers for checking. Most stops include a primary source, copied exactly from Darwin, Melville, Herodotus, Walton, Henry Lee or the Bible, to read closely and test. The trail is creation-friendly: sea creatures are God's handiwork, made "after their kind" (Genesis 1:21), and dates in "millions of years" are treated as interpretations. Conservation is taught as good stewardship (Genesis 2:15).

Five stops earn the **Ocean Expert badge, 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 Field Notebook.

BEFORE YOU BEGIN

- Comfortable with percentages, unit conversions and a scientific calculator; a little right-triangle trigonometry helps for Stop D3 but can be learned on the spot.
- Able to read older English prose (the KJV, Melville, Darwin) slowly and summarize it in your own words.

MASTERY CHECKLIST

- ☐ I can explain how at least five sea animals on this trail are equipped for their lives (for example, the shark's ampullae, the octopus's chromatophores, the dolphin's melon, the seal's myoglobin, the anglerfish's lure) with real numbers.
- ☐ I can tell the story of a scientific discovery from this trail (Darwin's atolls, the giant squid, deep-sea life, salmon homing or GFP) and separate the observations from the interpretations.
- ☐ I can read a primary source from this trail, check its claims against modern evidence and judge it fairly in its own time.
- ☐ I can explain what wise stewardship of the sea looks like, using the fur seal treaty of 1911 or the salmon runs as an example.
- ☐ I can explain from Jonah, Job 41 and Matthew 12 what the Bible teaches through its great sea creatures, and state more than one Christian view of leviathan fairly.

OPTIONAL BOOKS AND RESOURCES

- **NOAA Ocean Exploration** (<https://oceanexplorer.noaa.gov>): Free U.S. government pages, images and dive videos on ocean zones, the deep sea and bioluminescence (Stops D4 and D7).
- **Monterey Bay Aquarium Research Institute (MBARI)** (<https://www.mbari.org>): Free deep-sea videos, including the black seadevil anglerfish (2014) and the long-brooding octopus; good for Stops D2, D6 and D7.
- **OCEARCH Global Shark Tracker** (<https://www.ocearch.org>): Free online map of tagged sharks used in the Stop D1 project; use with a parent.
- **Smithsonian Ocean** (<https://ocean.si.edu>): The Smithsonian's free ocean portal with articles and photos on sharks, the giant squid, corals and marine mammals.
- **Project Gutenberg** (<https://www.gutenberg.org>): Free full texts of the trail's primary sources: Darwin's *Coral Reefs* (#2690), Melville's *Moby-Dick* (#2701), Herodotus (#2707), Henry Lee's *The Octopus* (#72133), Walton's *Compleat Angler* (#683) and the King James Bible (#10).

4.1 SHARKS: SENSES, TEETH AND THE PATHS OF THE SEAS

OBJECTIVES

- Explain how a shark’s body is built (cartilage skeleton, oily liver, toothed skin, endless teeth) and how each part fits its life in the sea.
- Describe the shark’s six senses, including the electric sense of the ampullae of Lorenzini, and weigh popular claims against measured facts.
- Track a real tagged shark on a free online map, calculate its distance and speed, and connect its journey to “the paths of the seas” in Psalm 8.

Warm-up. Write down three things you “know” about sharks before you read (for example: “Sharks can smell one drop of blood a mile away”). Put a small question mark beside each. As you read, mark each one true, false or “more complicated than that.” Experts are people who check what everyone already knows.

Video slot. Video coming. How sharks sense the world: smell, the lateral line and electroreception (ampullae of Lorenzini); shark tagging and tracking at sea. Search approved channels (NOAA Fisheries, Smithsonian Ocean, Monterey Bay Aquarium, OCEARCH); preview first.

KEY TERMS

cartilage

Tough, flexible tissue lighter than bone (the material in your ears and nose). A shark’s whole skeleton is made of it, strengthened in places with mineral.

dermal denticles

“Skin teeth”: tiny, tooth-like scales covering a shark’s skin. They point backward, make the skin feel like sandpaper and reduce drag in the water.

ampullae of Lorenzini

Jelly-filled pores on a shark’s snout that sense very weak electric fields, such as those made by the muscles of a hidden fish. Named for Stefano Lorenzini, who described them in 1678.

lateral line

A row of pressure-sensing cells along each side of a fish or shark that feels vibrations and movements in the water.

ram ventilation

Breathing by swimming forward with the mouth open so that water is forced over the gills. Some sharks must keep moving to breathe; others can pump water while resting.

apex predator

An animal at the top of its food chain, hunted by few or no other animals as an adult.

CORE IDEAS

A different kind of fish. There are more than 500 known species of sharks, from the dwarf lanternshark, small enough to hold in your hand at about 8 inches (20 cm), to the whale shark, the largest fish in the world at up to about 60 feet (18 m), which feeds on tiny plankton. Sharks are fish, but not bony fish. Their skeletons are **cartilage**, lighter and more flexible than bone. They have no air-filled swim bladder to keep them afloat. Instead, a huge oily liver, in some species a quarter or more of the body's weight, gives lift, and the shark's stiff, wing-like front fins work like the wings of an airplane as it swims. A shark that stops swimming slowly sinks.

Skin and teeth. Run your hand from a shark's head to its tail and the skin feels smooth; run it the other way and it feels like sandpaper. The skin is covered with **dermal denticles**, little tooth-like scales with grooves that guide the water and reduce drag. Engineers have studied them for swimsuits and ship coatings. The real teeth sit in rows like a conveyor belt. When a front tooth breaks or falls out, the one behind moves forward. Studies of lemon sharks suggest a front tooth may be replaced in about eight days, and a large shark may use thousands of teeth in its life. That is why shark teeth are among the most common things found on some beaches.

An old puzzle solved. For centuries Europeans dug up triangular stones they called *glossopetrae*, "tongue stones," and many thought they fell from the sky or grew in the rock. In 1666 a great white shark was caught near Livorno, Italy, and its head was sent to the Danish anatomist Nicolas Steno in Florence. Steno saw that the tongue stones were simply shark teeth. His little book of 1667 is a landmark in learning to read the rocks. Steno later became a Catholic bishop, and he is remembered as both a careful scientist and a devout man.

Six senses. Sharks hear low sounds from far away and smell very well; laboratory tests show some can detect certain substances at around one part per million or even less. But careful studies have found that sharks smell about as well as many ordinary fish, and the famous claim that a shark can smell a single drop of blood a mile away is a myth. Closer in, the **lateral line** feels the thrashing of a wounded fish. Their eyes have a mirror layer behind the retina (the *tapetum*) that helps them see in dim water. At the last moment, the **ampullae of Lorenzini** take over. These pores can detect electric fields of only a few billionths of a volt across a centimeter, enough to find a flatfish buried in sand by the electricity of its beating heart and breathing muscles. Hammerheads sweep their wide heads over the bottom like metal detectors.

Many ways to begin life. Some sharks, such as many catsharks, lay eggs in tough cases that wash up on beaches as "mermaid's purses." In others, the eggs hatch inside the mother and the pups are born alive. In still others, such as hammerheads and bull sharks, a placenta feeds the pups much as in a mammal. Sharks grow slowly and have few young. The spiny dogfish carries its pups for about two years, one of the longest pregnancies of any animal with a backbone. The Greenland shark of the cold North Atlantic grows perhaps a centimeter

a year; a 2016 study of the eye lenses of these sharks estimated that the largest had lived at least 272 years, and perhaps much longer.

Danger, both ways. Sharks are **apex predators**, and a few species, chiefly the great white, tiger and bull sharks, can be dangerous to people. Yet bites are rare: the International Shark Attack File usually records fewer than a hundred unprovoked bites a year worldwide, and the number of deaths averages only a handful. Lightning kills far more people. The danger runs much more strongly the other way. Fishing catches tens of millions of sharks each year, many only for their fins. Because sharks grow slowly and have few young, heavy fishing can empty an area quickly. Many nations now ban the cutting of fins at sea and set catch limits. This is not worship of nature; it is the wise use the Bible calls “dominion” (Genesis 1:28) and keeping (Genesis 2:15): taking from the sea in a way that leaves something for our grandchildren.

Following the paths. Today scientists fix satellite tags to sharks’ fins and follow them for years. Great whites tagged off California travel to an open-ocean area halfway to Hawaii that researchers nicknamed the “White Shark Café,” and some in the Atlantic swim thousands of miles from Cape Cod to the Gulf of Mexico and back. Psalm 8 says that God set man over “whatsoever passeth through the paths of the seas.” The tags let us see a few of those paths for the first time.

PICTURE STUDY



The Gulf Stream, Winslow Homer, 1899 · Oil on canvas · The Metropolitan Museum of Art, New York
Wikimedia Commons · Public domain

Winslow Homer (1836–1910) was one of America’s greatest painters of the sea. He made several winter trips to the Bahamas and Florida and crossed the Gulf Stream, the great warm current that runs from the Gulf of Mexico up the Atlantic coast. In this painting a lone sailor, his mast broken, drifts in a dangerous sea. Homer kept people guessing about the

ending. When his dealer passed on questions from worried viewers, Homer wrote back, half joking, that the sailor would be rescued and returned home to live happily ever after.

Look closely

- Count the sharks. Where has Homer placed them, and what do their open mouths and fins add to the mood?
- Find the waterspout and the ship on the horizon. Which one gives hope and which one adds danger?
- Look at the sailor's face and body. Is he panicking, praying, resting or simply waiting?

Talk about it

1. Homer painted sharks as the sailors of his day saw them: a menace in the water. How would a modern shark biologist paint the same sea differently, and what would each painting leave out?
2. The man has done all he can, and his rescue is out of his hands. What does the painting suggest about human strength and dependence, and how does Psalm 107:28-29 speak to a sailor in his place?

HANDS-ON: TRACK A SHARK THROUGH THE PATHS OF THE SEAS

Scientists learn where sharks travel by fixing satellite tags to their fins. Each time the fin breaks the surface, the tag sends a location (a "ping"). Using a free public tracker, follow one real shark, map its path and do the math a marine biologist does.

You will need

- A computer with a parent: the OCEARCH Global Shark Tracker (oceanarch.org, free) or NOAA Fisheries pages on tagged sharks
- A printed outline map of the North Atlantic or North Pacific (free from the National Geographic MapMaker or any atlas)
- Ruler, calculator, colored pencils
- Field Notebook

Steps

1. With a parent, open the tracker and choose one shark that has many pings over at least two months. Record its name, species, sex, length and where and when it was tagged.
2. Write down six to eight pings in order: date, latitude and longitude. Plot each on your map and join them with arrows.
3. Use the map scale (or an online distance calculator for two points) to measure the distance between each pair of pings. Add them for the total distance traveled.
4. For each leg, divide distance by the number of days to get average miles per day. Which leg was fastest? Remember the shark's true path was longer than a straight line between pings.

5. Compare the path with the water temperature or seasons: did your shark move north in summer and south in winter, follow a coast or head into open ocean? Write three sentences explaining what you observe and one sentence on what you cannot know from the pings alone.
6. Copy Psalm 8:8 under your map as its title.

Check your work

- My map shows at least six dated pings joined in order.
- I calculated total distance and average miles per day for each leg.
- I separated what the data show from what I am guessing.

FIELD NOTEBOOK

1. **Shark diagram.** Draw a side view of a shark and label: cartilage skeleton (dotted), oily liver, gill slits, pectoral fins (lift), lateral line, ampullae of Lorenzini on the snout, rows of teeth, and a magnified box of dermal denticles.
2. **Narration (parent keeps).** Without looking at the text, write one well-built paragraph of eight to ten sentences explaining how a shark finds its food from a mile away down to the last few inches. Use at least four senses in the right order and at least two numbers. Date it and give it to a parent for the portfolio.

Did you know? Some sharks, such as nurse sharks, can rest on the bottom and pump water over their gills, but many open-ocean sharks rely on **ram ventilation** and must keep swimming to breathe. When some sharks are gently rolled onto their backs, they go limp and still for several minutes, a state called *tonic immobility* that researchers use to handle them safely. Orcas have been seen using it against great white sharks.

Go deeper. Eugenie Clark, *Lady with a Spear* (1953), the memoir of a pioneering shark scientist (summarize; still in copyright). The Smithsonian Ocean portal (ocean.si.edu) pages on sharks and rays. The Florida Museum's International Shark Attack File (floridamuseum.ufl.edu/shark-attacks) for real yearly numbers. Second video topic: how dermal denticles reduce drag and how engineers copy them.

Goes deeper in. Life Science, "Fish, Sharks and Rays" (coming soon); Geography, "Ocean Currents and the Gulf Stream" (coming soon).

For families. No suitable public-domain primary source on sharks was found for this stop, so the project uses live tracking data instead. Figures are rounded from standard references: more than 500 species; whale shark up to about 18 m; the Greenland shark age estimate is Nielsen et al., *Science* (2016), which gave at least 272 years with a wide range above that; the lemon-shark tooth-replacement figure comes from one study and varies by species. Smell sensitivity follows Meredith and Kajiura (2010), who found sharks comparable to bony fish. Bite numbers change every year; check the International Shark Attack File for the current report. Steno's study of the shark head was published in

1667 as part of his *Elementorum myologiae specimen*. Homer's painting shows a Black sailor adrift; the painting is discussed for its seamanship and suspense, as Homer intended. Online trackers should be used with a parent.

PRACTICE

1. **EASY** Name two ways a shark's body differs from a bony fish such as a trout.
2. **EASY** What do the ampullae of Lorenzini detect, and why is this useful at the end of a hunt?
3. **MEDIUM** If a lemon shark replaces one front tooth in a given position about every 8 days, how many teeth would pass through that one position in a year? If it has 30 such positions working at that rate, about how many teeth would it use in a year?
4. **MEDIUM** Explain what Nicolas Steno showed about "tongue stones" and why it mattered.
5. **CHALLENGE** A website says, "Sharks can smell one drop of blood in an Olympic swimming pool." An Olympic pool holds about 2,500,000 liters, and a drop is about 0.05 milliliters. What concentration is that in parts per billion? Is the claim reasonable in light of what you read?
6. **CHALLENGE** Sharks grow slowly and have few young. Using the spiny dogfish (about a two-year pregnancy) and a fish such as the cod (which can release millions of eggs a year), explain why the same amount of fishing affects the two very differently. Then write two sentences on what Genesis 1:28 and 2:15 together suggest about how people should fish.

Make it a game • Electric Sense. Hide a small magnet under one of eight paper cups. The "shark" may not lift any cup but may pass a compass slowly over the cups, like a hammerhead sweeping the sand. When the needle twitches, the shark points to its cup. Then make it harder: put the cups under a towel. Talk about how a weak field still gives hidden prey away.

Scripture. "Thou madest him to have dominion over the works of thy hands; thou hast put all things under his feet: All sheep and oxen, yea, and the beasts of the field; The fowl of the air, and the fish of the sea, and whatsoever passeth through the paths of the seas." (Psalm 8:6-8, KJV)

David marvels that God set weak man over even the creatures of the deep. A well-loved story says that the oceanographer Matthew Fontaine Maury (1806-1873) took "the paths of the seas" to heart as he charted winds and currents. Dominion is a trust from God, not a license to waste.

Practice: answers

1. Any two: its skeleton is cartilage, not bone; it has no swim bladder and uses an oily liver for lift; its skin is covered with dermal denticles; it has gill slits rather than a single gill cover; its teeth are replaced in rows.

2. Very weak electric fields made by the muscles and heartbeat of other animals. At close range, when the prey may be hidden in sand or too close for the eyes to see, the shark can still find it.
3. $365 \div 8 \approx 45.6$, so about 45 or 46 teeth in one position. $30 \times 45.6 \approx 1,370$ teeth a year (about 1,400).
4. He compared them with the teeth in the head of a great white shark caught in 1666 and showed that they were shark teeth, not stones that grew in rock or fell from the sky. It showed that objects in rock could be the remains of real living things, an important step in learning to read the rocks.
5. $2,500,000 \text{ L} = 2,500,000,000 \text{ mL}$. $0.05 \div 2,500,000,000 = 2 \times 10^{-11}$, or 0.02 parts per billion (20 parts per trillion). That is far below the roughly one-part-per-million (or somewhat lower) levels measured in many tests, so the claim is an exaggeration. Sharks smell well, about as well as many fish, but not that well, and the claim also ignores that the blood must drift to the shark.
6. Sample: A cod population can replace losses quickly because each female produces huge numbers of young every year, but a dogfish population replaces itself slowly, so heavy fishing removes adults faster than they can be replaced and the numbers fall for many years. Genesis 1:28 gives people real dominion and the right to use the sea's creatures for food; Genesis 2:15 adds the duty to keep what God has given, so good fishing takes a harvest that the population can replace.

4.2 THE OCTOPUS: EIGHT ARMS, THREE HEARTS AND A CLEVER ESCAPE

OBJECTIVES

- Describe the octopus's body plan: three hearts, copper-based blue blood, a beak as its only hard part, and a nervous system spread through its arms.
- Explain how an octopus changes color and texture, and state honestly what scientists still do not understand about it.
- Read Henry Lee's 1875 account from the Brighton Aquarium as a primary source and judge how a careful observer separates fact from legend.

Warm-up. Measure the narrowest gap you can push your hand through (a jar mouth, a gap between books). An octopus can pour its whole body through any hole a little larger than its beak, the only hard part it has. A giant Pacific octopus as heavy as a large dog can slip through a hole only a couple of inches across. What would you need to give up to do that?

Video slot. Video coming. Octopus camouflage and problem-solving: color change, the mimic octopus, the coconut-carrying veined octopus, octopus escapes in aquariums. Search approved channels (Monterey Bay Aquarium, MBARI, Smithsonian Ocean, BBC Earth); preview first.

KEY TERMS

cephalopod

"Head-foot": the group of mollusks (with snails and clams) that includes octopuses, squid, cuttlefish and the nautilus, whose arms grow from the head.

chromatophore

A tiny elastic sac of colored pigment in the skin, opened and closed by muscles controlled by nerves. Thousands of them let an octopus change color in a fraction of a second.

hemocyanin

The copper-based substance that carries oxygen in octopus blood and turns it blue; our blood uses iron-based hemoglobin and is red.

siphon

A muscular tube through which an octopus squirts water from its body cavity, used for breathing, jet swimming and aiming ink.

papillae

Small bumps on the skin that an octopus can raise or flatten to copy the texture of rock, coral or seaweed.

brooding

Guarding and caring for eggs until they hatch. A mother octopus broods her eggs without eating and dies soon after they hatch.

CORE IDEAS

A soft-bodied relative of the snail. The octopus is a mollusk, like a snail or a clam, but it has given up the shell. It belongs to the **cephalopods**, “head-foot” animals whose arms grow straight out of the head. There are about 300 known kinds of octopus, from the tiny star-sucker pygmy octopus, smaller than a fingertip, to the giant Pacific octopus of the North Pacific, which commonly weighs around 30 to 50 pounds (15 to 22 kg) with an arm span of about 14 feet (4.3 m); much larger animals have been reported. Its only hard part is a parrot-like beak at the center of the arms, so it can squeeze through any gap a little wider than that beak.

Strange insides. An octopus has three hearts. Two pump blood through the gills and one sends it around the body. Its blood carries oxygen with **hemocyanin**, which uses copper instead of iron and turns blue when it picks up oxygen. When an octopus jets through the water by squeezing water out of its **siphon**, the main heart actually stops, which may be one reason octopuses prefer to crawl. The common octopus has roughly 500 million nerve cells, about as many as a dog, but about two-thirds of them are in the arms rather than the brain. Each arm can taste with its suckers, feel its way into a crack and even keep reaching for food after it is cut off. The brain sets the goal; the arms work out much of the how.

Masters of disguise. Octopus skin holds thousands of **chromatophores**, little bags of yellow, red, brown and black pigment. Muscles pull each one open like an umbrella or let it close to a dot, so the octopus can go from pale to dark brown in under a second, or ripple bands of color across its body. Under these lie reflecting cells that make shimmering blues and greens and white cells that scatter light. At the same time it can raise **papillae** to turn smooth skin into lumpy “rock” or frilly “seaweed.” Here is an honest puzzle: most octopuses seem to have only one kind of light-sensing cell in their eyes, which should make them colorblind. How, then, do they match colors so well? Scientists have proposed that the skin itself may sense light, or that the oddly shaped pupil helps separate colors, but the question is still open.

Clever and resourceful. In 1998 divers off Sulawesi in Indonesia described the mimic octopus, which flattens itself and swims like a flatfish, spreads its arms like a lionfish or hides in a hole with two arms out like a sea snake. In 2009 researchers in Indonesia reported veined octopuses carrying coconut-shell halves along the seafloor and assembling them into a shelter when danger came, one of the first examples of an invertebrate carrying a tool for later use. Octopuses in aquariums unscrew jar lids, learn which keeper feeds them and, famously, escape. In 2016 an octopus named Inky slipped out of his tank at New Zealand’s National Aquarium in Napier, crossed the floor and apparently went down a drainpipe to the sea.

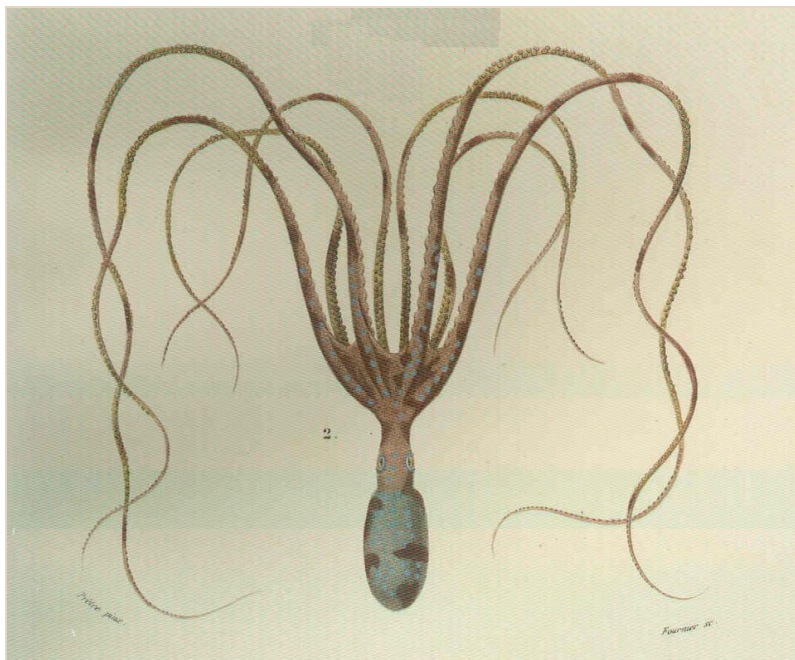
Defense in a cloud. When camouflage fails, an octopus can squirt **ink**, a dark cloud of melanin and mucus, from its siphon. Sometimes the ink hangs in the water in a blob about

the octopus's size, a decoy for the attacker to bite while the real octopus, now pale, jets away. Every octopus has venom in its saliva to quiet the crabs and clams it eats; most are harmless to people, but the small blue-ringed octopuses of the Indian and Pacific Oceans carry tetrodotoxin and have killed people who picked them up.

A short life and a faithful mother. For all their cleverness, most octopuses live only one to two years; the giant Pacific octopus lives three to five. A mother lays thousands of eggs in strings in a den and then stops eating. For weeks or months she guards them, cleaning them with her suckers and blowing fresh water over them, and she dies soon after they hatch. In 2014 scientists at the Monterey Bay Aquarium Research Institute reported a deep-sea octopus that guarded her eggs for about 53 months, the longest brooding known for any animal.

From legend to looking. Aristotle watched octopuses change color more than 2,300 years ago, though he called the animal foolish. In 1866 Victor Hugo's novel *Toilers of the Sea* made the "devil-fish" a monster that drowned men. Henry Lee, a naturalist at the new Brighton Aquarium in England, answered in 1875 with a whole book comparing "fiction" with "fact." He reported what the animals in his tanks actually did, and it was stranger and more delightful than Hugo's horror. Job says, "ask now the beasts, and they shall teach thee." Lee did exactly that.

PICTURE STUDY



Poulpe commun (Common Octopus), plate from the *Dictionnaire universel d'histoire naturelle*, Plate in the encyclopedia edited by Charles d'Orbigny, 1849 · Hand-colored engraving · From the atlas of Charles d'Orbigny's *Dictionnaire universel d'histoire naturelle* (Paris)
Wikimedia Commons · Public domain

In the 1800s, before color photography, natural history encyclopedias hired skilled engravers and colorists to show animals exactly. This plate of *Octopus vulgaris*, the common octopus of

European coasts, comes from a great French encyclopedia of natural history edited by Charles d'Orbigny. Each copy was colored by hand.

Look closely

- Follow one arm from the body to its tip. How do the suckers change in size along the arm?
- Find the eye and the siphon. What do they tell you about which side is the “front”?
- Look at the color. A living octopus changes color constantly; what has the artist had to choose?

Talk about it

1. An engraving shows one moment and one color. What would a scientist lose by relying only on pictures like this, and what would a video or a live animal add?
2. Compare this calm, careful plate with the “devil-fish” of Hugo’s novel. Which helps you love and understand the real animal more, and why?

HANDS-ON: FICTION OR FACT? READING HENRY LEE LIKE A SCIENTIST

Henry Lee wrote *The Octopus; or, The “Devil-fish” of Fiction and of Fact* (1875) to correct the wild stories of his day with careful observation. Read his account (the primary source in this stop), sort its claims, and then test one octopus “fact” you find online in the same way.

You will need

- The primary source in this stop (from Project Gutenberg eBook #72133)
- Two colored pencils or highlighters
- Field Notebook, a page divided into three columns: “Observed,” “Inferred,” “Story-telling”
- A computer with a parent for one search

Steps

1. Read the primary source aloud. Highlight in one color the things Lee or his staff actually saw (where the octopus was found, the height of the partition).
2. Highlight in another color the things Lee inferred but did not see (that the octopus climbed over at night, ate a lump-fish and came back).
3. Underline the words that show Lee enjoying a good story (“marauding rascal,” “demurely,” “contented mind”). Put each phrase in the third column.
4. Answer: Is Lee’s inference reasonable? What evidence would make it certain? (Think: a night watchman, a count of lump-fish before and after, a repeat of the event.)
5. With a parent, find one octopus “fact” on a website (for example, “octopuses have nine brains”). Look for the original study or a museum or university source. Write whether the claim is accurate, exaggerated or false, and why.
6. Write a three-sentence verdict: How is Lee’s octopus different from Hugo’s “devil-fish,” and what made Lee a better guide?

Check your work

- I sorted Lee's account into observed, inferred and story-telling.
- I named evidence that could confirm Lee's inference.
- I traced one modern octopus claim to a reliable source and judged it.

FIELD NOTEBOOK

1. **Octopus diagram.** Draw an octopus and label: mantle, eye, siphon, beak (shown in the center underside), suckers, the three hearts (in a small inset), and a magnified patch of skin with open and closed chromatophores.
2. **Narration (parent keeps).** Without looking at the text, write one well-built paragraph of eight to ten sentences describing a day in the life of a giant Pacific octopus: hunting, hiding, escaping danger. Use at least four true facts from this stop. Date it and give it to a parent for the portfolio.

Did you know? The plural of octopus can be "octopuses" (the usual English form) or, less often, "octopodes" (the Greek form). "Octopi" is common but is built on a mistaken Latin ending, since the word comes from Greek. An octopus's sucker can contain thousands of chemical receptors, so when an arm explores a crack, it is tasting as well as touching.

Primary source. *Henry Lee, The Octopus; or, The "Devil-fish" of Fiction and of Fact (London, 1875), ch. II, "Octopods I Have Known." Text from Project Gutenberg eBook #72133. The "young friends" are young lump-fish in tank No. 27 at the Brighton Aquarium.*

One morning, however, Mr. Lawler, one of the staff, on going to count our young friends, found an interloper amongst them. 'Who put this octopus in No. 27 tank?' he inquired of the keepers. 'Octopus, sir? no one! Well, if he ain't bin and got over out of the next tank!' And this was just the fact. The marauding rascal had occasionally issued from the water in his tank, and clambered up the rocks, and over the wall into the next one; there he had helped himself to a young lump-fish, and, having devoured it, returned demurely to his own quarters by the same route, with well-filled stomach and contented mind. This was not very difficult for him to accomplish, for the partition between the two tanks is only about a foot above the surface of the water.

Go deeper. Henry Lee's whole book is free on Project Gutenberg (eBook #72133); chapter V, "The Octopus Out of Water," tells of two more escapers. Roger Hanlon and John Messenger, *Cephalopod Behaviour* (Cambridge, 2nd ed. 2018), a university-level reference for strong readers. Monterey Bay Aquarium online pages on the giant Pacific octopus. MBARI's news pages on the 53-month brooding octopus (2014). Second video topic: the mimic octopus and the coconut-carrying veined octopus.

Goes deeper in. Life Science, “Mollusks: Snails, Clams and Cephalopods” (coming soon); Literature, for comparing Hugo’s *Toilers of the Sea* with Lee’s reply (coming soon).

For families. The primary source was checked against Project Gutenberg eBook #72133; Lee’s quotation marks are given as single marks, and the keeper’s words are written in dialect as Lee printed them. Sizes and counts are rounded: the 500-million-neuron figure is for the common octopus; giant Pacific octopus sizes vary widely, and some older record weights are not well documented. The mimic octopus was first described by divers in 1998 and formally named in 2005; the coconut-carrying report is Finn, Tregenza and Norman, *Current Biology* (2009); the 53-month brooding octopus (*Graneledone boreopacifica*) is Robison et al., *PLoS ONE* (2014). Inky’s 2016 escape was reported by the National Aquarium of New Zealand; the drainpipe route is the aquarium’s best explanation. The engraver of the d’Orbigny plate is not named on the Commons file. Blue-ringed octopuses are dangerous; tide-poolers should never pick up an octopus.

PRACTICE

1. **EASY** Why can an octopus squeeze through such small holes?
2. **EASY** Why is octopus blood blue, and how many hearts does an octopus have?
3. **MEDIUM** If a common octopus has about 500 million neurons and about two-thirds are in its arms, about how many neurons are in the arms, and how many in each arm if they are shared equally?
4. **MEDIUM** In the primary source, which statement is an observation and which is an inference: (a) the octopus was found in tank No. 27; (b) it had climbed over the wall, eaten a lump-fish and returned?
5. **CHALLENGE** Most octopuses appear to have only one type of light-sensing cell, yet they match the colors around them well. State the puzzle clearly, give two possible explanations scientists have suggested, and describe one experiment that could help decide between them.
6. **CHALLENGE** Compare Hugo’s “devil-fish” and Lee’s octopus. Write a short argument (four sentences) on why accurate observation of God’s creatures is a Christian duty, using Job 12:7–8 and Exodus 20:16 (“Thou shalt not bear false witness”).

Make it a game • Chromatophore Camouflage. Cut a simple octopus shape from white paper for each player. Set a timer for three minutes; each player colors and folds “papillae” on their octopus to match one spot in the room (a rug, a bookshelf, a plant). Then lay the octopuses in place while the “predator” is out. The predator has thirty seconds to find them. The last octopus found wins.

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 answers his friends by pointing to the creatures: they all bear witness that the LORD made them and holds every life in His hand (Job 12:9-10). An octopus teaches by being exactly what it is; we learn by looking patiently and reporting honestly.

Practice: answers

1. It has no bones or shell; its only hard part is its beak, so it can pass through any gap a little larger than the beak.
2. It carries oxygen with hemocyanin, which contains copper and turns blue. It has three hearts: two for the gills and one for the body.
3. About 333 million in the arms ($500 \times 2/3 \approx 333$ million), and about 42 million per arm ($333 \div 8 \approx 41.7$ million).
4. (a) is an observation: Mr. Lawler saw it. (b) is an inference: no one in the passage reports watching it happen; it is the best explanation of the evidence, supported by the low partition.
5. Puzzle: with one photoreceptor type an animal should not tell colors apart, yet octopuses camouflage by color. Possible explanations: (1) light-sensing proteins in the skin may detect light directly; (2) the unusually shaped pupil may let the eye use color blur (different colors focus at different depths) to separate colors. Experiment, for example: cover or numb the eyes' input (or test with skin patches) and see if skin still responds to colored light; or test camouflage under single-color light where pupil-based color separation would fail. Any sound experiment that changes one factor at a time is acceptable.
6. Sample: Hugo's monster was thrilling but false, and it taught readers to fear an animal that rarely harms anyone. Lee watched real octopuses and reported what they did, separating what he saw from what he guessed. Job 12:7-8 says the creatures themselves teach us, but only if we look at them as they are. Since the ninth commandment forbids false witness, Christians should tell the truth about God's works too, enjoying a good story without passing off fiction as fact.

4.3 CORAL REEFS: CITIES BUILT BY TINY ANIMALS

OBJECTIVES

- Explain how coral polyps and the algae living inside them build reefs of limestone, and why reefs grow only in warm, clear, sunlit water.
- Describe fringing reefs, barrier reefs and atolls, and tell how Darwin’s explanation of atolls (1842) was tested by drilling at Enewetak in 1952.
- Read Darwin’s description of Keeling atoll as a primary source, check its numbers against a modern map and calculate the steepness of the reef’s outer slope.

Warm-up. Drop a piece of chalk or a seashell into a small glass of vinegar and watch for bubbles. Both are made of calcium carbonate, the same mineral corals use to build reefs. As you read, keep the glass nearby: the bubbles are carbon dioxide escaping as the acid dissolves the mineral.

Video slot. Video coming. How coral polyps build reefs: zooxanthellae, coral spawning on the Great Barrier Reef, parrotfish making sand, fringing reefs, barrier reefs and atolls. Search approved channels (NOAA Ocean Service, Smithsonian Ocean, Great Barrier Reef Marine Park Authority, Monterey Bay Aquarium); preview first.

KEY TERMS

polyp

A small, soft animal shaped like a tube with a ring of stinging tentacles around its mouth. Coral polyps are cousins of jellyfish and sea anemones.

zooxanthellae

Tiny single-celled algae that live inside the tissues of reef-building corals, make food from sunlight and give corals most of their color (say “zoh-uh-zan-THEL-ee”).

calcium carbonate

The mineral of limestone, chalk and seashells. Coral polyps take it from seawater to build their stony cups.

atoll

A ring-shaped coral reef or chain of low coral islands surrounding a lagoon, with deep ocean outside.

subsidence

The slow sinking of land or of the seafloor. Darwin argued that atolls form as volcanic islands sink while coral keeps growing upward.

coral bleaching

When stressed corals, often by unusually warm water, expel their algae and turn white. Corals can recover if the stress ends soon; if it lasts, they may starve and die.

CORE IDEAS

Animals that build in stone. A coral reef looks like a garden of rocks and plants, but it is built by animals. Each coral **polyp** is a soft tube a few millimeters across, with a mouth ringed by stinging tentacles, a cousin of the jellyfish. A polyp draws calcium and carbonate from seawater and lays down a cup of **calcium carbonate** under itself. It then divides, again and again, into thousands of identical polyps sharing one colony, each on its own cup. When polyps die, their stony cups remain, and new corals grow on top. Over time the skeletons of countless corals, cemented together with coralline algae and filled in with sand, become a reef.

A partnership in the light. Reef-building corals have help. Inside their clear tissues live millions of single-celled algae called **zooxanthellae**. The algae use sunlight to make sugars, and they pass most of that food, in many corals up to about 90 percent of what the coral needs, to their host. In return the coral gives the algae shelter and the carbon dioxide and nutrients they need. The algae also speed up the building of the skeleton. Because the algae need light, reef-building corals grow only in clear, shallow, sunlit seas, mostly warmer than about 68°F (20°C) and within a band roughly 30 degrees north and south of the equator. The algae also give corals their brown, green and gold colors; the brilliant pinks and blues come from the coral's own pigments.

How fast, and how big. Large round “brain” corals may add only a centimeter or so a year, while branching staghorn corals can grow 10 centimeters or more. Reefs grow where building outpaces the breaking down by storms, boring sponges and grazing animals. A large parrotfish bites coral to scrape off algae and grinds the stone to sand in its throat, and over a year a single fish can produce hundreds of pounds of fine white sand, much of the sand on tropical beaches. The Great Barrier Reef off northeastern Australia stretches about 1,400 miles (2,300 km) and is made up of some 2,900 separate reefs. Coral reefs cover well under 1 percent of the ocean floor, yet scientists estimate they shelter about a quarter of all known sea species.

Darwin's puzzle. Reefs come in three main shapes. *Fringing reefs* hug a shoreline. *Barrier reefs* stand offshore with a lagoon between reef and land. **Atolls** are rings of reef and low islands around a lagoon in the open ocean, with no land in the middle at all. How could corals that need shallow water build rings rising from water thousands of feet deep? In 1836 the young Charles Darwin, naturalist on HMS *Beagle*, studied Keeling atoll in the Indian Ocean. In *The Structure and Distribution of Coral Reefs* (1842) he argued that a fringing reef grows around a volcanic island; as the island slowly sinks (**subsidence**), the coral keeps building upward, becoming a barrier reef and at last, when the island has disappeared below, an atoll.

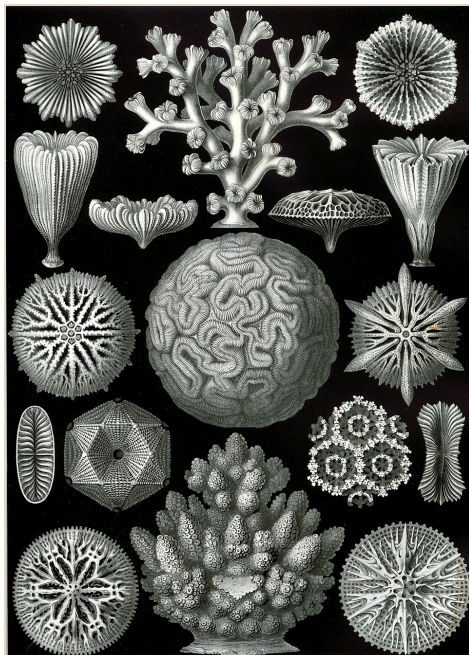
A theory tested. Darwin's idea made a prediction: drill down through an atoll and you should find shallow-water coral rock far deeper than coral can grow, resting on volcanic rock. In 1952 the United States drilled two deep holes at Enewetak atoll in the Marshall Islands. One reached solid basalt, volcanic rock, at about 4,200 feet (1,280 m), under thick layers of reef limestone. The drilling was widely hailed as confirming Darwin's explanation of

atolls. Geologists also give long ages for those layers; those dates are interpretations built on assumptions about growth rates in the past, and Christians who hold to a young earth read them differently. What everyone can observe is the order: coral rock on top, volcanic rock beneath.

Stress and recovery. When water stays unusually warm for weeks, or when corals are stressed by pollution or murky water, they expel their algae and turn white, called **coral bleaching**. A bleached coral is not yet dead; if conditions improve, it can regain its algae and recover, as many reefs have done after past events, though a long or repeated stress can kill large areas. Good stewardship of reefs is practical: mooring buoys so boats do not drop anchors on coral, controlling runoff from farms and towns, sensible fishing limits that keep grazing fish on the reef, and “coral gardening,” in which divers grow fragments in nurseries and plant them back on damaged reefs.

Coral in Scripture. The ancient world prized red precious coral from the Mediterranean as a jewel. Job 28 lists the treasures that people dig and dive for (gold, sapphires, coral, pearls) and says wisdom is worth more than all of them. The reef shows the same lesson: tiny creatures, faithful in small daily work, build something vast.

PICTURE STUDY



Hexacoralla (stony corals), Plate 26 of Kunstformen der Natur (Art Forms in Nature), Ernst Haeckel, 1904 (issued in parts from 1899) · Color lithograph from Haeckel's drawings · From Kunstformen der Natur (Leipzig)

Wikimedia Commons · Public domain

Ernst Haeckel (1834–1919) was a German zoologist and a gifted artist. His book *Art Forms in Nature* arranged sea creatures in symmetrical patterns that later inspired architects and designers. This plate shows the stony skeletons of corals, the little cups (corallites) each polyp builds, seen close up.

Look closely

- Find a single coral cup. Count the ridges (septa) that radiate from the center. Do you see sixes or multiples of six? (“Hexa” means six.)
- Compare the branching skeletons with the round, dome-shaped ones. Which would better survive heavy waves?
- Look at how Haeckel arranged the page. Is it a scientific record, a work of decoration or both?

Talk about it

1. Haeckel shows only the white skeletons, not the living polyps or their colors. Why might he have chosen this, and what does it hide about a living reef?
2. The same patterns of six repeat across many kinds of coral. What does order and pattern in creation suggest to you about its Maker (Psalm 104:24)?

HANDS-ON: DARWIN AT KEELING: CHECK THE NUMBERS

A primary source is evidence, not the last word. Read Darwin’s description of Keeling atoll (in this stop), check his position against a modern map, turn his sounding into a slope and then build a model of how an atoll forms.

You will need

- The primary source in this stop
- An atlas or online map with latitude and longitude
- Graph paper, ruler, protractor, calculator
- For the model: a bowl, a mound of modeling clay (the volcano), water, and small pebbles or aquarium gravel (the coral)

Steps

1. Read the primary source. On the map, find the Cocos (Keeling) Islands. Write the modern latitude and longitude. Do they agree with Darwin’s printed figures? If not, which number is off, and by how much? Suggest two ways such an error could get into a printed book.
2. Darwin says that 2,200 yards from the breakers, a line of 7,200 feet found no bottom. Convert 2,200 yards to feet. On graph paper draw a right triangle with that horizontal distance and that drop, and measure the angle with a protractor. Then check with a calculator: $\text{angle} = \arctan(\text{drop} \div \text{distance})$. Remember that this is the least the slope could be, since there was no bottom.
3. Look up the side slope of a typical volcanic cone (many are about 30°–35°). Is Darwin right that the reef is steeper?
4. Model the atoll: build a clay volcano in the bowl and add water until only the top shows. Ring the shore with pebbles (fringing reef). Push the volcano down a little and

add more pebbles on top of the old ring (barrier reef). Push it down again until the clay is under water and keep the pebble ring at the surface (atoll).

5. Photograph or draw the three stages and label them.

Check your work

- I compared Darwin's position with a modern map and explained any difference.
- I calculated the slope angle (about 47° or more) and compared it with a volcanic cone.
- My model shows fringing reef, barrier reef and atoll in order.

FIELD NOTEBOOK

1. **Reef diagram.** Draw a cutaway of one coral polyp sitting in its stony cup: tentacles, mouth, stomach, zooxanthellae (green dots in the tissue) and the limestone cup beneath. Beside it draw the three reef types in cross-section with arrows showing the island sinking.
2. **Narration (parent keeps).** Without looking at the text, write one well-built paragraph of eight to ten sentences explaining how a reef is built, why it needs sunlight, and how Darwin's explanation of atolls was tested. Include at least three numbers. Date it and give it to a parent for the portfolio.

Did you know? On the Great Barrier Reef many corals spawn together on a few nights after the full moon in late spring (October to December in Australia), releasing bundles of eggs and sperm all at once, so that the sea looks like an upside-down snowstorm. The precious red coral used in jewelry since ancient times is a different, slow-growing coral of the Mediterranean that does not build reefs.

Primary source. *Charles Darwin, The Structure and Distribution of Coral Reefs (first published 1842), ch. I, "Atolls or Lagoon-Islands," on Keeling atoll. Text from Project Gutenberg eBook #2690. The ellipses (...) mark places where sentences have been left out.*

Keeling or Cocos atoll is situated in the Indian Ocean, in 12° 5' S., and longitude 90° 55' E. The greatest width of this atoll is nine miles and a half. Its structure is in most respects characteristic of the class to which it belongs, with the exception of the shallowness of the lagoon. ... Between these plates and in the protected crevices on the reef, a multitude of branching zoophytes and other productions flourish, but the *Porites* and *Millepora* alone seem able to resist the fury of the breakers on its upper and outer edge. ... At a distance of 2,200 yards from the breakers, Captain Fitzroy found no bottom with a line of 7,200 feet in length; hence the submarine slope of this coral formation is steeper than that of any volcanic cone.

Go deeper. Darwin, *The Voyage of the Beagle*, chapter XX, "Keeling Island: Coral Formations" (Project Gutenberg eBook #944), his lively traveler's account of the same

visit. NOAA Ocean Service, “Coral Reef Ecosystems” education pages (oceanservice.noaa.gov). The Great Barrier Reef Marine Park Authority’s pages on coral spawning (gbrmpa.gov.au). Second video topic: parrotfish and how sand is made.

Goes deeper in. Earth Science, “Oceans and the Sea Floor” and “Islands and Reefs” (coming soon); Life Science, “Cnidarians: Corals, Anemones and Jellyfish” (coming soon).

For families. The primary source matches the Project Gutenberg text (eBook #2690). The longitude printed there, 90° 55′ E., does not match the true position of the Cocos (Keeling) Islands (about 96° 50′ E.); whether the slip is Darwin’s, his printer’s or the transcription’s was not checked, and the project uses the difference as a lesson in reading sources. Enewetak figures follow the U.S. Geological Survey report on the 1952 drilling (hole E-1 reached basalt at about 4,158–4,222 feet). Darwin’s subsidence theory concerns the shape of islands, not the origin of species; the stop does not discuss evolution. Geological ages for reef limestone are presented as interpretations. Figures for the Great Barrier Reef (about 2,300 km, about 2,900 reefs) are from the Great Barrier Reef Marine Park Authority; the “quarter of sea species” figure is a common estimate, not a count. Haeckel was a leading promoter of evolution in his day, and some of his embryo drawings were criticized as misleading; his coral plate is used here for its observation and artistry.

PRACTICE

1. **EASY** What two living things work together in a reef-building coral, and what does each give the other?
2. **EASY** Name the three main kinds of coral reefs in the order Darwin believed they form.
3. **MEDIUM** Why are there no reef-building corals in deep, dark water or in cold seas far from the equator?
4. **MEDIUM** In the primary source, which corals does Darwin say can survive on the reef’s upper and outer edge, and why is that edge so hard to live on?
5. **CHALLENGE** From the primary source: 2,200 yards from the breakers, a line of 7,200 feet found no bottom. Find the least possible average slope of the reef’s outer side in degrees, and explain why the answer is “at least.”
6. **CHALLENGE** Darwin’s atoll theory predicted what drillers would find at Enewetak. Write out the prediction, what was found in 1952, and one thing the drilling did not by itself settle. Explain the difference between testing an explanation of present structures and assigning ages to past events.

Make it a game · Build the Reef. Players stand in a ring as “polyps.” Each round, every polyp places one block or cup on the shared “reef” in the middle (growth), then a caller rolls a die: on a 1 or 2 a “storm” removes three blocks, on a 6 a “parrotfish” removes one. After ten rounds, is the reef taller or shorter than when you started? Change the rules (more polyps, fewer storms) and see when a reef can grow.

Scripture. “No mention shall be made of coral, or of pearls: for the price of wisdom is

above rubies.” (Job 28:18, KJV)

Coral was a treasure in Job’s world, like pearls and rubies. Job 28 says people search mountains and seas for such riches, but true wisdom is found only in the fear of the Lord (Job 28:28). The best use of the reef’s beauty is to lead us to its Maker.

Practice: answers

1. The coral polyp and its zooxanthellae (algae). The algae give the coral food made from sunlight (and color, and help in building the skeleton); the coral gives the algae shelter, carbon dioxide and nutrients.
2. Fringing reef, barrier reef, atoll.
3. Their algae need sunlight to make food, so the corals need clear, shallow water; and reef-building corals need warm water (mostly above about 20°C), which is found mainly within about 30 degrees of the equator.
4. Only Porites and Millepora. The outer edge takes the full “fury of the breakers,” the waves of the open ocean.
5. 2,200 yards = 6,600 feet. Slope angle = $\arctan(7,200 \div 6,600) = \arctan(1.09) \approx 47.5^\circ$. It is “at least” this steep because the line did not touch bottom, so the true depth there was more than 7,200 feet, which makes the slope steeper still. (Typical volcanic cones are about 30°–35°, so Darwin’s comparison holds.)
6. Prediction: beneath an atoll lie great thicknesses of shallow-water coral rock resting on a sunken volcano. Found: about 4,200 feet of reef limestone on top of basalt in hole E-1. Not settled by the drilling alone: how long the building took, since ages depend on assumptions about past growth rates and conditions. Testing the theory compares a prediction with what can be observed now (the layers and their order); assigning ages adds interpretation about unobserved past rates, which is why Christians who agree on the observations may disagree about the dates.

4.4 THE GIANT SQUID: FROM KRAKEN TO CAMERA

OBJECTIVES

- Describe the giant squid's real size, body plan and senses, and separate measured facts from exaggerated sailors' tales.
- Trace how knowledge of the giant squid grew from the Norwegian kraken (1750s) to Newfoundland (1873), to the first photographs (2004) and video (2012).
- Read Melville's description in *Moby-Dick* (1851) as a primary source and judge what it gets right from what sailors could actually see.

Warm-up. Find something about the size of a dinner plate and hold it up to your face. The eye of a giant squid is about that wide, roughly 10 inches (25–27 cm) across, the largest eye of any animal. Why would an animal living in near-darkness need such an enormous eye? Write your guess and check it as you read.

Video slot. Video coming. The giant squid filmed in its habitat (2012 and 2019, with Edith Widder's Medusa camera); Moses Harvey and the Newfoundland squid of 1873. Search approved channels (Smithsonian Ocean, NOAA Ocean Exploration, Ocean Research & Conservation Association (ORCA), Discovery/NHK documentary clips); preview first.

KEY TERMS

Architeuthis

The scientific name (genus) of the giant squid, from Greek for "chief squid," given by the Danish zoologist Japetus Steenstrup in 1857.

tentacles

The two long feeding limbs of a squid, much longer than its eight arms, with suckers only at the club-shaped tips.

mantle

The muscular, tube-shaped main body of a squid that holds the organs and squeezes water out through the siphon for jet propulsion.

kraken

A sea monster of Norwegian sailors' tales, said to be as big as an island; probably inspired in part by sightings of giant squid.

bioluminescence

Light made by living things through a chemical reaction. In the deep sea it is the main source of light.

specimen

A real animal (or part of one) collected and kept for study, the evidence on which a description rests.

CORE IDEAS

A real giant. The giant squid, **Architeuthis**, is a cephalopod like the octopus but built for open water: a long, torpedo-shaped **mantle**, two fins, eight thick arms and two much longer feeding **tentacles** with toothed suckers on their tips. The largest reliably measured specimens are about 40 to 43 feet (12 to 13 m) long, most of that length in the two tentacles; the mantle itself reaches about 7 feet (2.25 m). Females are bigger than males and can weigh about 600 pounds (275 kg). Older reports of 60-foot squid are almost certainly animals measured after their stretchy tentacles had been pulled out on a beach. The giant is real, but not quite as giant as the legends.

Built for the dark. Giant squid live in the twilight and midnight waters, mostly somewhere between about 1,000 and 3,000 feet (300 to 1,000 m) deep, where sunlight fades to nothing. Their eyes, up to about 10 inches across, are the largest of any animal, shared only with the colossal squid. Researchers have suggested a reason: such huge eyes can pick out, from hundreds of feet away, the faint glow of **bioluminescence** stirred up by a large animal moving through the water, especially the giant squid's main enemy, the sperm whale. Its tissues are filled with ammonium chloride, which is lighter than seawater, so the squid floats without effort, though it also tastes of ammonia and is no good for calamari.

The whale's prey. Sperm whales dive thousands of feet to hunt squid. Whalers found pieces of giant squid in whales' stomachs and round sucker scars on their heads. Indigestible squid beaks collect in the whale's gut by the thousands; they are often found embedded in ambergris, a waxy substance from sperm whales once prized for perfume. For centuries this was most of what people knew: a few beaks, chunks of arms, rotting carcasses washed ashore, and stories.

From kraken to specimen. In the 1750s Erik Pontoppidan, the Lutheran bishop of Bergen, collected Norwegian fishermen's accounts of the **kraken**, a beast so large it could be mistaken for islands, in his *Natural History of Norway*. He was careful to say what he had only heard. In 1857 the Danish zoologist Japetus Steenstrup studied a beak and other remains and gave the giant squid its scientific name. Then, in 1873, in Conception Bay, Newfoundland, three fishermen in a small boat met a giant squid at the surface. As the story was told, the boy among them, Tom Piccot, cut off a tentacle with a hatchet, and the animal let go and sank away. The Rev. Moses Harvey, a Presbyterian minister and keen naturalist in St. John's, bought the 19-foot piece. Weeks later fishermen netted a whole squid at Logy Bay, and Harvey photographed it draped over his bathtub, the first photographs of a giant squid. He sent descriptions to scientists around the world.

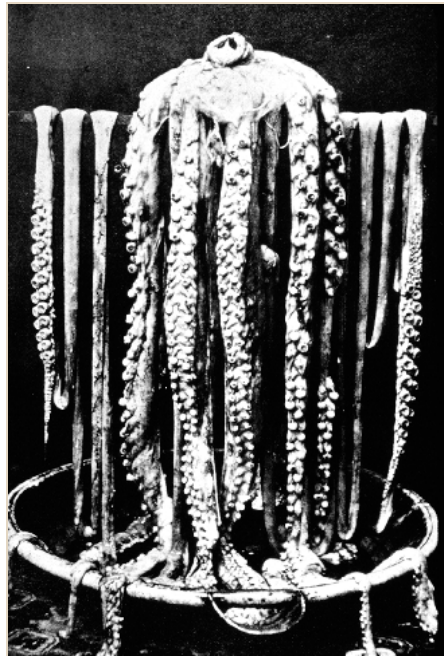
At last, alive. For more than a century no one saw a living giant squid in its home. Japanese researchers Tsunemi Kubodera and Kyoichi Mori finally photographed one in 2004, about 3,000 feet down near the Ogasawara Islands south of Tokyo, using a camera on a long line with bait; the squid left a piece of tentacle behind. In 2012 Kubodera, the American deep-sea biologist Edith Widder and the New Zealand scientist Steve O'Shea filmed one in its habitat for the first time. Widder's trick was an "electronic jellyfish," a ring of blue lights imitating the alarm glow of a jellyfish being attacked, a signal that might draw a larger hunter. In 2019

Widder and Sönke Johnsen used the same method to film a young giant squid in the Gulf of Mexico.

Its heavier cousin. The colossal squid of the cold Southern Ocean is shorter but heavier: a specimen caught near Antarctica in 2007 weighed about 1,091 pounds (495 kg). It has swiveling hooks on its arms as well as suckers. In 2025 researchers working near the South Sandwich Islands reported the first video of a living colossal squid in its habitat, a see-through youngster about a foot long.

What the story teaches. The giant squid shows how knowledge grows. Legends contained a grain of truth, careful observers like Harvey turned stories into **specimens**, and patient scientists with new tools finally saw the animal at home. Melville, writing in 1851 before any photograph existed, called it “an unearthly, formless, chance-like apparition of life.” Psalm 107 says those who go down to the sea in ships “see the works of the LORD, and his wonders in the deep.” The deep still hides wonders we have barely glimpsed.

PICTURE STUDY



*The Logy Bay giant squid draped over Moses Harvey's bathtub, St. John's, Newfoundland, Photograph made for the Rev. Moses Harvey (photographer not recorded), 1873-1874 · Photograph · St. John's, Newfoundland; reproduced in many histories of the giant squid
Wikimedia Commons · Public domain*

Moses Harvey had no laboratory and no museum, only a house in St. John's and a determination to get the facts. To photograph the whole squid, he hung it over the rim of his own bathtub so that the arms and tentacles could be spread out. This plain domestic photograph helped prove to scientists everywhere that the giant squid was real.

Look closely

- Find the mantle, the eight arms and the two long tentacles. How much longer are the tentacles than the arms?
- Look for the clubs at the tentacle tips. What would they be used for?
- Look at the setting. What everyday objects tell you this is a home, not a museum?

Talk about it

1. Why was a photograph so important in 1873, when many people still thought the giant squid was a sailors' tale?
2. Harvey was a pastor as well as a naturalist. What does his example suggest about how faith and careful science can go together?

HANDS-ON: LIFE-SIZE GIANT SQUID ON THE LAWN

Numbers like “40 feet” are hard to picture. Lay out a life-size giant squid outdoors with string, then compare it with Melville’s description (the primary source) and with other ocean giants.

You will need

- About 100 feet (30 m) of string or rope, a measuring tape, sidewalk chalk or stakes
- A dinner plate (the eye)
- The primary source in this stop
- Field Notebook and a calculator

Steps

1. Choose a large female: mantle 7 feet (2.1 m), head and arms 10 feet (3 m), tentacles reaching 33 feet (10 m) from the head. Mark the tip of the mantle with a stake. Lay string 7 feet for the mantle, then mark the head with the dinner plate as one eye.
2. Lay eight shorter strings, 10 feet each, for the arms, and two strings, 33 feet each, for the tentacles. Measure the total length from mantle tip to tentacle tip.
3. Beside it, chalk or string out a school bus (about 40 feet), a great white shark (about 20 feet) and yourself. Photograph or sketch the comparison from above.
4. Read the primary source. Melville describes the squid as “furlongs in length and breadth.” A furlong is 220 yards. Calculate how long Melville’s squid would be and compare it with your string squid. What does the difference tell you about how giant squid were seen from a whaleboat?
5. Write a short paragraph: Which details in Melville’s description match the real animal (cream color, many arms, no clear face), and which are exaggerated?

Check your work

- My life-size layout uses the measurements given and shows arms and tentacles.
- I compared it with at least two other large things.
- I calculated a furlong and judged Melville’s description fairly.

FIELD NOTEBOOK

1. **Timeline.** Draw a timeline from 1750 to today with these points: Pontoppidan's kraken (1750s), Melville's *Moby-Dick* (1851), Steenstrup names *Architeuthis* (1857), Newfoundland squid and Harvey's photograph (1873), first photographs of a live squid (2004), first video in its habitat (2012), Gulf of Mexico video (2019). Add a small sketch at three points.
2. **Narration (parent keeps).** Without looking at the text, write one well-built paragraph of eight to ten sentences telling how people moved from the kraken legend to filming a living giant squid. Name at least three people and two dates. Date it and give it to a parent for the portfolio.

Did you know? A giant squid's brain is shaped like a doughnut, and its esophagus (food tube) passes right through the hole. That is one reason squid tear their food into small bites with their beaks and a rasping tongue (radula): a large swallow could press on the brain. Giant squid blood, like octopus blood, is blue.

Primary source. *Herman Melville, Moby-Dick; or, The Whale (1851), chapter 59, "Squid." The Pequod's boats have lowered for what they think is the white whale. Checked against the 1851 American edition text (also Project Gutenberg eBook #2701). Starbuck, the first mate, speaks the last line.*

A vast pulpy mass, furlongs in length and breadth, of a glancing cream-colour, lay floating on the water, innumerable long arms radiating from its centre, and curling and twisting like a nest of anacondas, as if blindly to clutch at any hapless object within reach. No perceptible face or front did it have; no conceivable token of either sensation or instinct; but undulated there on the billows, an unearthly, formless, chance-like apparition of life.

"The great live squid, which, they say, few whale-ships ever beheld, and returned to their ports to tell of it."

Go deeper. Moses Harvey's articles and letters are described in Richard Ellis, *The Search for the Giant Squid* (1998), the best general history (summarize; in copyright). Edith Widder's talks and her book *Below the Edge of Darkness* (2021) on deep-sea light and the 2012 filming. The Smithsonian National Museum of Natural History's "Giant Squid" pages (ocean.si.edu). Second video topic: sperm whales hunting in the deep.

Goes deeper in. Life Science, "Mollusks: Snails, Clams and Cephalopods" (coming soon); Literature, *Moby-Dick* in the high-school American literature course (coming soon).

For families. The Melville excerpt was checked word for word against the 1851 American edition text on Wikisource; the same text is in Project Gutenberg eBook #2701. Melville spelled "centre" in the British way. Sizes follow Smithsonian and published scientific summaries; 12–13 m is the usual maximum for well-measured specimens. The

1873 Newfoundland story (the Piccot boat at Portugal Cove, Conception Bay, and the Logy Bay specimen) is told as Harvey and later historians reported it; details such as exact lengths vary between accounts. The 2004 photographs were published by Kubodera and Mori in *Proceedings of the Royal Society B* (2005). The colossal squid video was announced by the Schmidt Ocean Institute in April 2025. The photographer of Harvey's bathtub picture is not recorded on the Commons file.

PRACTICE

1. **EASY** What is the difference between a squid's arms and its tentacles?
2. **EASY** Who photographed the first whole giant squid specimen, where did he hang it, and in what year?
3. **MEDIUM** Give one reason scientists think the giant squid needs such huge eyes.
4. **MEDIUM** Why do scientists doubt old reports of 60-foot giant squid?
5. **CHALLENGE** Melville's squid is "furlongs in length and breadth." If it were just two furlongs long, how many times longer would it be than a 43-foot giant squid? Give two reasons, from the passage and from what you know, why sailors might have overestimated the size.
6. **CHALLENGE** Melville calls the squid a "formless, chance-like apparition of life." Write a short response (four sentences) explaining how the facts in this stop answer the words "formless" and "chance-like," using Psalm 107:24.

Make it a game • Electronic Jellyfish. Play in a dark room. One player is the "camera" and holds a flashlight with a blue cloth or blue cellophane over it; others are "squid" hiding in the room. The camera may flash the light in short bursts only (the e-jelly's alarm). A squid caught in the flash must freeze and is "filmed." The last unfilmed squid becomes the next camera. Talk about why Widder's lure worked better than a bright white light.

Scripture. "They that go down to the sea in ships, that do business in great waters; These see the works of the LORD, and his wonders in the deep." (Psalm 107:23-24, KJV)

Psalm 107 is a song of thanks from sailors God rescued from storms. Fishermen and whalers saw the giant squid long before scientists did. The psalm calls such sights "works of the LORD," things to give thanks for, not only to fear.

Practice: answers

1. A squid has eight arms with suckers all along them and two much longer tentacles with suckers only on the club-shaped tips, used to seize prey.
2. The Rev. Moses Harvey of St. John's, Newfoundland; over his bathtub; in 1873 (into 1874).
3. In the dark deep sea, huge eyes can detect faint bioluminescence from far away, such as the glow stirred up by a diving sperm whale, giving the squid warning of its main predator.
4. Squid tentacles are very elastic; stranded or dead animals were often measured after the tentacles had stretched, and no reliably measured specimen exceeds about 12-13 m (about

40–43 feet).

5. Two furlongs = 440 yards = 1,320 feet. $1,320 \div 43 \approx 31$ times longer. Reasons: sailors saw it at the surface from a low boat and at a distance, with arms spread and moving; it was a rare, frightening sight (“unearthly”); there was nothing nearby for scale; and Melville is writing as a novelist, using grand language for effect.
6. Sample: Close study shows the giant squid is anything but formless: it has a precise body plan of mantle, fins, eight arms, two tentacles, beak, a doughnut brain and the largest eyes on earth. Its ammonium-filled tissues make it float without effort, and its eyes seem made for seeing a predator’s glow in the dark. What looked like chance to frightened sailors on the surface was design they could not yet see. Psalm 107:24 says those who go to sea see “the works of the LORD, and his wonders in the deep,” and the giant squid is one of those works.

4.5 DOLPHINS: SOUND, SLEEP AND SIGNATURE WHISTLES

OBJECTIVES

- Show why dolphins are mammals and not fish, using at least five lines of evidence, and explain how people classified them in the past.
- Explain how a dolphin echolocates, sleeps with half its brain and recognizes others by signature whistles.
- Read Herodotus' story of Arion as a primary source, separating what Herodotus reports as fact, what he reports as hearsay and what it reveals about ancient sailors and dolphins.

Warm-up. Hum with your lips closed and gently press your fingers on your jawbone, then on the top of your head. Can you feel the vibration? Sound travels through bone and fat as well as through air. A dolphin “hears” its echoes mostly through its lower jaw. As you read, find out how.

Video slot. Video coming. Bottlenose dolphin echolocation, signature whistles and dolphin sleep; the U.S. Navy Marine Mammal Program. Search approved channels (NOAA Fisheries, Smithsonian Ocean, U.S. Navy Marine Mammal Program, Sarasota Dolphin Research Program, Monterey Bay Aquarium); preview first.

KEY TERMS

cetacean

A member of the whale group of mammals (Cetacea), including the great whales, dolphins and porpoises.

echolocation

Finding objects by sending out sounds and listening to the echoes, used by dolphins, toothed whales and bats.

melon

The rounded, fatty forehead of a dolphin that focuses its clicks into a beam, like a lens.

signature whistle

A whistle unique to one dolphin, learned when it is young, that works much like a name.

unihemispheric sleep

Sleep in which one half of the brain rests while the other half stays awake, letting a dolphin keep breathing and watching for danger.

flukes

The two horizontal lobes of a whale's or dolphin's tail, beaten up and down to swim.

CORE IDEAS

Mammals of the sea. A dolphin looks like a fish, but it is a **cetacean**, a mammal like a whale. It breathes air through a blowhole on top of its head and must surface to breathe. It is warm-blooded and keeps warm with a layer of blubber. It has a few bristles on its snout at birth, a remnant of hair. Its calves are born alive, usually tail first so that they do not drown during birth, and the mother at once nudges the calf to the surface for its first breath. Bottlenose calves nurse on their mother's milk for a year and a half or more and often stay with her for three to six years. Even the tail tells the story: a fish's tail is upright and sweeps side to side, but a dolphin's **flukes** are flat and beat up and down, as a mammal's backbone bends.

Fish or not? For most of history, anything that lived in the sea and swam was called a fish. The Hebrew of Genesis 1:21 groups sea creatures by how they live, not by modern classification, and old English writers called whales "fish" too. The Swedish naturalist Carl Linnaeus placed whales and dolphins with the mammals in 1758, and that is now universal. Herman Melville, in *Moby-Dick* (1851), playfully insisted a whale was still a fish. The words changed; the dolphin did not. Science sorts creatures by their bodies and lives, and Scripture is not contradicted when a later age draws finer lines.

Seeing with sound. A dolphin makes rapid clicks with "phonic lips" in its nasal passages, just below the blowhole. The fatty **melon** in its forehead focuses the clicks into a beam. When the clicks hit a fish, the echoes return, and the dolphin receives them through a channel of fat in its lower jaw that carries the sound to the inner ear. By timing the echoes and judging their strength, it learns the distance, size, shape and even what something is made of; bottlenose dolphins in tests have told apart objects of the same shape made of different metals, and they can find a fish buried in sand. This **echolocation** is so good that the U.S. Navy has trained bottlenose dolphins since the 1960s to find sea mines and lost equipment that machines have trouble detecting.

Names and whistles. Besides clicks, dolphins whistle. In the 1960s researchers Melba and David Caldwell noticed that each captive bottlenose dolphin had its own whistle. A dolphin develops its **signature whistle** in its first months and keeps it for life. Studies in the 2000s showed that wild dolphins respond when they hear their own whistle played back, and that they sometimes copy another dolphin's whistle, as if calling it by name. Mothers and calves whistle back and forth constantly when separated.

Half asleep. A dolphin must choose to breathe; it cannot breathe without thinking about it, as we do. So how does it sleep? Dolphins rest one half of the brain at a time while the other half stays awake. During **unihemispheric sleep** a dolphin may swim slowly or float at the surface with one eye open (the eye connected to the waking half). Experiments found that dolphins can keep watch this way for days. Their bodies are also designed for diving: when a dolphin dives, its heart slows and blood is sent mainly to the heart and brain.

Speed and a puzzle. Bottlenose dolphins usually cruise at about 3 to 7 miles per hour, but they can sprint at over 20 mph for short bursts and leap high out of the water. In 1936 the

British zoologist James Gray calculated that a dolphin's muscles seemed far too weak to swim as fast as dolphins were seen to swim. "Gray's paradox" puzzled scientists for decades. Later measurements showed that dolphin muscles are in fact much more powerful than Gray assumed and that their smooth skin and shape reduce drag. The puzzle was not a miracle to be explained away but a call to measure better.

Dolphins and sailors. Sailors have always loved dolphins racing at a ship's bow. From 1888 to 1912 a Risso's dolphin nicknamed Pelorus Jack met steamers at the entrance to French Pass in New Zealand and swam beside them; in 1904 the government protected him by law. Long before, the Greek historian Herodotus wrote down a story that a dolphin had carried the musician Arion to shore. Herodotus was honest enough to say "they say." We can enjoy the tale, and the painting it inspired, while keeping clear what is history and what is legend.

PICTURE STUDY



Arion, Albrecht Dürer, c. 1514 · Pen and watercolor on paper · Kunsthistorisches Museum, Vienna
Wikimedia Commons · Public domain

Albrecht Dürer (1471–1528) of Nuremberg was the greatest German artist of his age and a keen student of animals. Here he illustrates the old Greek story of Arion, the musician saved by a dolphin. Dürer had almost certainly never seen a living dolphin, so he drew it from older pictures and descriptions. Above the drawing he wrote a Latin line that means, roughly, "Carried on the curved fish, Arion sang."

Look closely

- Study the dolphin. Find the tusks, the scales and the shape of the tail. Which features are right for a real dolphin, and which are wrong?
- Is the tail drawn upright like a fish's or flat like a dolphin's flukes?
- Look at Arion. What is he doing, and what is the mood of the scene?

Talk about it

1. Dürer drew his famous *Rhinoceros* (1515) from a written description without ever seeing one. What happens to an artist's (or a scientist's) picture when it rests on

secondhand reports? How is that like the history of the giant squid?

2. Why do you think the story of a dolphin rescuing a man has lasted for more than two thousand years?

HANDS-ON: ECHO RANGING: MEASURE DISTANCE WITH SOUND

A dolphin judges distance by timing echoes. You can do the same with a wall, a stopwatch and a clap, then use the speed of sound in water to do a dolphin's math.

You will need

- A large flat wall or building with open space in front (at least 50 meters away is best)
- Two wooden blocks to clap (or hands)
- A stopwatch (a phone is fine) and a long measuring tape or a measuring wheel
- Field Notebook and calculator

Steps

1. Stand about 50 meters (or more) from the wall and measure the distance exactly. Clap once and listen for the echo. Then clap in a steady rhythm so that each clap falls exactly on the echo of the last one.
2. When you have the rhythm, have a partner time 20 claps. Each interval between claps is the time for sound to go to the wall and back.
3. Find the time for one interval (total time $\div$ 20). The sound traveled twice the distance in that time. Calculate the speed of sound: $(2 \times \text{distance}) \div \text{time}$. Compare with the textbook value in air (about 343 meters per second).
4. Now do the dolphin's math. Sound travels about 1,500 meters per second in seawater. If a dolphin hears an echo 0.04 seconds after its click, how far away is the fish? (Divide the round trip in half.)
5. Write three sentences: Why does a dolphin click faster and faster as it closes in on a fish? (Hint: the echoes come back sooner.)

Check your work

- I measured my distance and timed at least 20 echo intervals.
- I calculated the speed of sound in air and compared it with 343 m/s.
- I solved the dolphin problem (30 meters) and explained the faster clicks.

FIELD NOTEBOOK

1. **Echolocation diagram.** Draw a dolphin's head in cross-section: blowhole, phonic lips, melon, lower jaw fat channel and inner ear. Draw arrows for the outgoing click beam and the returning echo from a fish.
2. **Narration (parent keeps).** Without looking at the text, write one well-built paragraph of eight to ten sentences proving to a skeptical reader that a dolphin is a mammal and

explaining how it finds food in murky water. Use at least five pieces of evidence and one number. Date it and give it to a parent for the portfolio.

Did you know? The orca, or killer whale, is the largest member of the dolphin family, reaching about 30 feet (9 m). There are about 40 species of ocean dolphins, plus a handful of river dolphins in Asia and South America. Porpoises are close relatives but have spade-shaped teeth and short, blunt snouts, while most dolphins have cone-shaped teeth and a longer beak.

Primary source. *Herodotus, The History, Book I, section 24 (written about 430 B.C.), translated by G. C. Macaulay (1890), from Project Gutenberg eBook #2707. Arion, a famous musician, was sailing home to Corinth when the crew plotted to kill him for his money. He asked leave to sing one last song in his full minstrel's dress. Periander was the ruler of Corinth; Tainaron is a cape at the southern tip of Greece.*

Then as the measure ended, he threw himself into the sea just as he was, in his full minstrel's garb; and they went on sailing away to Corinth, but him, they say, a dolphin supported on its back and brought him to shore at Tainaron: and when he had come to land he proceeded to Corinth with his minstrel's garb. Thither having arrived he related all that had been done; and Periander doubting of his story kept Arion in guard and would let him go nowhere, while he kept careful watch for those who had conveyed him. When these came, he called them and inquired of them if they had any report to make of Arion; and when they said that he was safe in Italy and that they had left him at Taras faring well, Arion suddenly appeared before them in the same guise as when he made his leap from the ship; and they being struck with amazement were no longer able to deny when they were questioned.

Go deeper. NOAA Fisheries species pages on the common bottlenose dolphin (fisheries.noaa.gov). The Sarasota Dolphin Research Program (sarasotadolphin.org), the longest-running study of a wild dolphin community, begun in 1970. The U.S. Navy Marine Mammal Program's public pages (niwc.navy.mil). Herodotus, Book I, 23–24, in full (Project Gutenberg eBook #2707). Second video topic: dolphin sleep and the dive reflex.

Goes deeper in. Life Science, "Mammals of the Sea" (coming soon); History, "Ancient Greece: Herodotus and the Histories" (coming soon); Art, Albrecht Dürer (coming soon).

For families. The Herodotus excerpt was checked against Macaulay's translation in Project Gutenberg eBook #2707; it is an ancient Greek story that Herodotus himself presents as what the Corinthians and Lesbians say, and it is taught here as legend. Arion was a real poet of about 600 B.C. Dürer's *Arion* is in the Kunsthistorisches Museum, Vienna, according to standard references; dating is given as about 1514. The Caldwells first described signature whistles in 1965; playback studies include Janik, Sayigh and Wells (2006) and King and Janik (2013). Gray's paradox: Gray (1936); later work by Frank Fish and others. Pelorus Jack was protected by an Order in Council of 1904. Speeds vary

by species and study; figures here are rounded. Linnaeus placed cetaceans among the mammals in the 10th edition of *Systema Naturae* (1758). The stop does not discuss evolutionary claims about dolphin ancestry.

PRACTICE

1. **EASY** Give four pieces of evidence that a dolphin is a mammal.
2. **EASY** What is a signature whistle?
3. **MEDIUM** Sound travels about 1,500 meters per second in seawater. A dolphin's click returns as an echo after 0.1 second. How far away is the object? If it returns after 0.01 second, how far?
4. **MEDIUM** Why must a dolphin sleep differently from us?
5. **CHALLENGE** In the primary source, list (a) one detail Herodotus presents as hearsay, (b) one detail that would be easy to check in his day, and (c) one clue from the story about how Greek sailors thought of dolphins. Then argue in three sentences whether a dolphin really carried Arion.
6. **CHALLENGE** James Gray (1936) calculated that dolphins were too weak for their observed speeds. Explain what a "paradox" is in science, how this one was resolved, and what it teaches about trusting either observations or calculations.

Make it a game · Dolphin and Fish. A version of Marco Polo for a pool or a big yard. The blindfolded "dolphin" clicks ("click!"), and every "fish" must answer at once by clapping. The dolphin uses only the echoes of claps to tag a fish. Tagged fish become dolphins. Afterward, talk about how direction and distance were judged by sound alone. Play only with an adult watching if in water.

Scripture. "O LORD, how manifold are thy works! in wisdom hast thou made them all: the earth is full of thy riches. So is this great and wide sea, wherein are things creeping innumerable, both small and great beasts. There go the ships: there is that leviathan, whom thou hast made to play therein." (Psalm 104:24-26, KJV)

The psalm says God made the great sea creatures "to play" in the sea. Anyone who has watched dolphins leap and ride a ship's bow wave has seen something of that delight. Play, too, is part of God's good design.

Practice: answers

1. Any four: breathes air with lungs (through a blowhole); warm-blooded; gives birth to live young; nurses young with milk; has hair (bristles) at birth; has horizontal flukes that move up and down.
2. A whistle unique to one dolphin, learned young and kept for life, used much like a name.
3. Round trip = $1,500 \times 0.1 = 150$ m, so the object is 75 m away. For 0.01 s: 15 m round trip, so 7.5 m away.
4. Its breathing is voluntary; it must decide to surface and breathe, and it must watch for predators. Resting half of the brain at a time lets it keep breathing and stay alert.

5. (a) “him, they say, a dolphin supported on its back”; (b) for example, that Arion appeared at Corinth and the sailors were questioned by Periander, or that Tainaron is a cape on the route; (c) the story assumes dolphins are friendly to people and rescue the drowning. Sample argument: Herodotus marks the rescue itself as hearsay, and no one but Arion could have witnessed it. Real dolphins sometimes push objects and swim with people, so the story may grow from true behavior, but carrying a man for many miles is very unlikely. It is best read as a legend about a real poet, which is how Herodotus himself frames it.
6. A paradox is a result that seems to contradict something we know: here, careful math said dolphins could not do what people plainly saw them doing. It was resolved by better measurements, which showed dolphin muscles produce far more power than Gray assumed (and their shape and skin help reduce drag). The lesson: a calculation is only as good as its assumptions; when it clashes with careful observation, the right response is to check the assumptions and measure again, not to dismiss the observation.

4.6 JELLYFISH: NO BRAIN, NO BONES, AND THE FASTEST STING

OBJECTIVES

- Describe the body and two-stage life cycle of a jellyfish (polyp and medusa), and tell true jellyfish from look-alikes such as the Portuguese man o' war and comb jellies.
- Explain how a nematocyst fires, using real numbers for its speed, and give correct first aid for common stings.
- Tell how a protein from a glowing jellyfish, discovered by Osamu Shimomura in 1962, became one of the most useful tools in modern medicine and biology.

Warm-up. Weigh an empty plastic bag, then fill it with water and weigh it again. A jellyfish is about 95 percent water, held in shape by a thin jelly called mesoglea. If you took the water out of a 1-pound jellyfish, about how much would be left? Write your answer, then read on.

Video slot. Video coming. Jellyfish life cycle (polyp, ephyra, medusa), nematocysts firing in slow motion, the crystal jelly and green fluorescent protein. Search approved channels (Monterey Bay Aquarium, MBARI, Smithsonian Ocean, NOAA Ocean Exploration, the Nobel Prize channel); preview first.

KEY TERMS

medusa

The free-swimming, bell-shaped stage of a jellyfish, with tentacles hanging below (named for the snake-haired figure of Greek legend).

polyp

The small, attached, stalk-like stage of a jellyfish's life, fixed to a rock or shell, which buds off tiny young jellyfish.

nematocyst

A stinging capsule inside a cnidocyte (stinging cell) holding a coiled, often barbed thread that fires out and injects venom.

nerve net

A web of nerve cells spread through the body instead of a brain; it coordinates swimming and stinging.

siphonophore

A colony of many small specialized animals working as one, such as the Portuguese man o' war; it looks like a jellyfish but is not a single animal.

green fluorescent protein (GFP)

A protein from the crystal jelly that glows green under blue or ultraviolet light; scientists attach it to other proteins to watch them work inside living cells.

CORE IDEAS

A simple, elegant body. A jellyfish has no brain, no heart, no bones and no blood. Its body is two thin layers of cells with a thick jelly (mesoglea) between them, about 95 percent water. It has one opening that serves as both mouth and outlet, a stomach cavity, a ring of tentacles and a **nerve net** instead of a brain. Clusters of sense organs around the rim of the bell detect light, gravity and touch and keep it right side up. Yet this simple body works superbly. A jellyfish swims by squeezing its bell and letting it spring back; studies of the moon jelly found it among the most energy-efficient swimmers known, because each stroke makes a ring of swirling water that it pushes against on the next.

Two lives in one. Most true jellyfish live two very different lives. A fertilized egg becomes a tiny swimming larva, which settles on a rock and becomes a **polyp**, a little stalk with tentacles, like a miniature sea anemone. The polyp can clone itself and live for months or years. Then, often when the water warms in spring, it stacks itself into a pile of discs like plates and releases them one by one as tiny eight-armed baby jellyfish called ephyrae. Each grows into a **medusa**, the drifting bell we call a jellyfish. One small hydrozoan, *Turritopsis dohrnii*, can do something stranger: when injured or starving, the adult medusa can turn back into a polyp and start over, which is why it is nicknamed the “immortal jellyfish,” though in the wild it is still eaten or dies of disease.

The fastest weapon in nature. Each tentacle is armed with thousands of stinging cells, each holding a **nematocyst**, a tiny capsule with a coiled, hollow thread under great pressure, by some measurements about 150 times the pressure of the air around us, far more than in a car tire. A touch, together with the right chemical signal, makes it fire. In 2006 researchers using ultra-high-speed cameras found that a nematocyst in a small hydra discharged in about 700 billionths of a second, with an acceleration of over 5 million times the force of gravity, among the fastest movements known in nature. The thread punches through the prey’s skin and injects venom, and the tentacles draw the stunned fish or shrimp to the mouth.

Look-alikes and real dangers. Not everything called a jellyfish is one. The Portuguese man o’ war, with its blue gas-filled float and long purple tentacles, is a **siphonophore**, a colony of many tiny animals working as one. Comb jellies, which shimmer with rainbow rows of beating hairs, have no stinging cells at all. Box jellyfish, shaped like a cube with tentacles from each corner, have true eyes, 24 of them in four clusters, some with lenses, and the Australian box jellyfish *Chironex fleckeri* carries one of the most dangerous venoms in the sea. For box jellyfish stings, vinegar is used to stop unfired nematocysts from firing; for many other stings, rinsing with seawater and soaking in hot water is now recommended. Rubbing the sting or rinsing with fresh water can make more nematocysts fire.

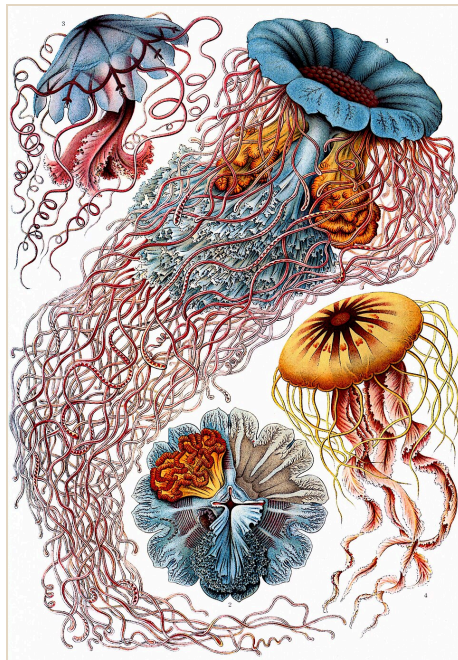
Giants and swarms. The lion’s mane jellyfish of cold northern seas is the largest known: a specimen stranded in Massachusetts Bay in 1870 was reported with a bell about 7½ feet (2.3 m) across and tentacles about 120 feet (37 m) long, longer than a blue whale. Jellyfish sometimes appear in huge “blooms” when food is plentiful, clogging fishing nets and the water intakes of power plants. They are not useless: leatherback sea turtles eat great

quantities of them, many fish shelter under their bells, and dried cannonball jellyfish from the coast of Georgia are shipped to Asia as food.

A jellyfish that lit up medicine. In 1961 a young Japanese chemist named Osamu Shimomura went to Friday Harbor, Washington, to find out why the crystal jelly, *Aequorea victoria*, glows. He and his helpers collected jellyfish by the thousands each summer, cutting off the glowing rims by hand. In 1962 he and his colleagues isolated a light-making protein, and with it a second protein that glowed green under ultraviolet light: **green fluorescent protein**. Decades later, Martin Chalfie showed that the gene for GFP could make other living things glow, and Roger Tsien made versions in many colors. Today scientists attach GFP to proteins to watch nerve cells grow, cancer cells spread and viruses move inside living cells. In 2008 the three men shared the Nobel Prize in Chemistry.

Abundant waters. On the fifth day of creation God said, “Let the waters bring forth abundantly the moving creature that hath life.” The jellyfish, mostly water, drifting in uncounted numbers, is a picture of that abundance, and a reminder that even the simplest-looking creature can hold gifts no one expected.

PICTURE STUDY



Discomedusae, Plate 8 of *Kunstformen der Natur* (Art Forms in Nature), Ernst Haeckel, 1904 (issued in parts from 1899) · Color lithograph from Haeckel's drawings · From *Kunstformen der Natur* (Leipzig) Wikimedia Commons · Public domain

Ernst Haeckel (1834–1919) spent years studying jellyfish and other small sea creatures and drew them with great care and imagination. This plate shows a jellyfish he named *Desmonema annasethe*, after his first wife, Anna Sethe, who had died young. Many think it is the most beautiful plate in his book.

Look closely

- Find the bell, the frilled oral arms around the mouth and the long, thin tentacles. Which would carry the most stinging cells?
- Look for symmetry. Is the jellyfish drawn as perfectly symmetrical, or does Haeckel let the tentacles flow freely?
- Look at the colors. Which parts look solid and which look see-through?

Talk about it

1. Haeckel named this creature for his late wife. How does knowing that change the way you see the picture?
2. Is this a scientific drawing, a work of art or both? What might a scientist want that this plate does not give?

Safety first. Beach safety: never touch a jellyfish or man o' war with bare hands, even one washed up and seemingly dead, because the stinging cells can still fire. Swim at guarded beaches and obey warning flags. Seek medical help at once for box jellyfish stings or any sting with trouble breathing, chest pain or a large area of skin affected.

HANDS-ON: NEMATOCYST MODEL AND STING FACTS CARD

Build a working model of a stinging cell and make a pocket first-aid card for beach trips, with facts checked against a reliable source.

You will need

- A latex balloon (the capsule) and a long, thin "magic" balloon, or a rubber glove finger and a straw
- Thin string, tape, a paper cup
- An index card, a pen, and a computer with a parent to check a first-aid source (for example, a national lifeguard association or a hospital page)
- Field Notebook

Steps

1. Push the tip of the long, thin balloon inside the round balloon so that it is coiled inside (the folded thread). Tape a short loop of string to the opening as the "trigger" (cnidocil).
2. Blow gently into the round balloon. As pressure builds, the thin balloon turns inside out and shoots outward, just as a nematocyst's thread everts (turns inside out) as it fires. Repeat and time it. Compare your time with 700 billionths of a second.
3. Calculate: if a nematocyst fires in 0.0000007 second and your model takes 0.5 second, how many times faster is the real thing?
4. With a parent, look up current first-aid advice for (a) box jellyfish, (b) Portuguese man o' war and (c) common jellyfish stings in your region. Note where advice differs, and why vinegar helps for some but not all.

5. Make an index card: “Jellyfish Sting Card,” with three short, correct steps and the rule “If stung by a box jellyfish, or if breathing is hard, call for emergency help.”

Check your work

- My model turned inside out when “fired.”
- I calculated how much faster a real nematocyst is (over 700,000 times).
- My first-aid card is checked against a reliable source and dated.

FIELD NOTEBOOK

1. **Life-cycle wheel.** Draw a circle with five stages: egg, swimming larva, polyp on a rock, stacked polyp releasing ephyrae, adult medusa. Add arrows and one sentence for each stage. Beside it, draw a nematocyst before and after firing.
2. **Narration (parent keeps).** Without looking at the text, write one well-built paragraph of eight to ten sentences telling the story of Osamu Shimomura and green fluorescent protein, from the docks of Friday Harbor to the Nobel Prize, and explain why it matters. Date it and give it to a parent for the portfolio.

Did you know? Box jellyfish do not just drift: they swim actively, steer around objects and, in some species, use their eyes to stay near the shady edges of mangrove roots, looking up through the water’s surface to find the trees. A jellyfish’s mouth also serves as its way out for waste, since it has only one opening.

Go deeper. Osamu Shimomura’s Nobel lecture and autobiography on the Nobel Prize website (nobelprize.org, 2008 Chemistry). The Monterey Bay Aquarium’s jellies pages and live “Jelly Cam.” The Smithsonian Ocean portal’s jellyfish and comb jelly pages. Second video topic: how scientists use GFP to watch living cells.

Goes deeper in. Life Science, “Cnidarians: Corals, Anemones and Jellyfish” and “Cells and the Microscope” (coming soon).

For families. No suitable public-domain primary source was found for this stop; the GFP story is told from the Nobel Prize records instead. The nematocyst timing is from Nüchter et al., *Current Biology* (2006), measured in a freshwater hydra, a close cousin of jellyfish. The 1870 lion’s mane specimen is widely reported (originally by Alexander Agassiz); its measurements were not made by modern methods. First-aid advice for stings has changed over the years and differs by species and region; families should check a current local source. The water figure (about 95 percent) varies a little by species. Shimomura’s first glowing protein was aequorin; GFP was noticed alongside it in the 1962 paper. Haeckel promoted evolution and some of his embryo drawings were criticized as misleading; his plate is used here for its observation and artistry.

PRACTICE

1. **EASY** Name three things a jellyfish does not have that you do.

2. **EASY** Is the Portuguese man o' war a true jellyfish? Explain.
3. **MEDIUM** Put these in order in a jellyfish's life: medusa, egg, polyp, ephyra, larva.
4. **MEDIUM** A 2-pound jellyfish is 95 percent water. How many ounces of it are not water? (1 pound = 16 ounces.)
5. **CHALLENGE** A nematocyst fires in about 700 nanoseconds (700×10^{-9} s). How many could fire one after another in a single second? If the thread travels about 10 micrometers (10×10^{-6} m) in that time, what is its average speed in meters per second and in miles per hour ($1 \text{ m/s} \approx 2.24 \text{ mph}$)?
6. **CHALLENGE** Shimomura spent years collecting jellyfish simply to learn why they glowed, with no medical use in view. Write a short argument (four sentences) about the value of studying creatures "just to understand them," using his story and Proverbs 25:2 ("It is the glory of God to conceal a thing: but the honour of kings is to search out a matter").

Make it a game · Sting Tag. One player is the "jellyfish" and may only drift slowly (walking heel-to-toe) with arms out as "tentacles." Others are fish darting past. Anyone tagged by a tentacle is "stung" and must freeze for ten seconds. After two minutes, switch to a "box jellyfish" who may walk normally. Talk about why a drifting hunter needs long tentacles and so many stinging cells.

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)

On the fifth day God filled the sea "abundantly." Jellyfish drift in numbers no one can count, and even these simple creatures, with no brain or heart, carry gifts like GFP that people found only after long searching.

Practice: answers

1. Any three: a brain, a heart, bones, blood, a separate mouth and outlet (it has one opening).
2. No. It is a siphonophore, a colony of many small specialized animals working together as one.
3. Egg, larva, polyp, ephyra, medusa.
4. 2 pounds = 32 ounces. 5 percent of 32 = 1.6 ounces.
5. $1 \div (700 \times 10^{-9}) \approx 1,430,000$ (about 1.4 million). Average speed = $10 \times 10^{-6} \text{ m} \div 700 \times 10^{-9} \text{ s} \approx 14.3 \text{ m/s}$, about 32 mph. (The tip reaches much higher peak speeds; the averaging hides the huge acceleration.)
6. Sample: Shimomura wanted only to understand the crystal jelly's light, and no one could have predicted that it would become a tool for studying nerve cells and cancer. Many great useful discoveries began as patient curiosity about God's works. Proverbs 25:2 says God hides things for us to search out, and that searching is honorable work. Studying a creature to know it better honors its Maker, and the usefulness often follows later.

4.7 ANGLERFISH AND THE DEEP SEA: LIGHT IN THE DARKNESS

OBJECTIVES

- Name the zones of the ocean by depth and calculate the water pressure at different depths.
- Explain how the deep-sea anglerfish and other deep animals are equipped for darkness, cold, scarce food and crushing pressure, including bioluminescence.
- Trace how people learned that the deep sea is full of life, from the “azoic” idea of the 1840s to HMS Challenger, the bathysphere, the Trieste and Alvin, and read Job 38:16–18 as God’s question to Job about the deep.

Warm-up. Hold your hand flat. The air above it presses down with about 15 pounds on every square inch. Every 33 feet (10 m) of seawater adds that much again. At the bottom of the Mariana Trench, almost 7 miles down, how many times the pressure on your hand would that be? Make a guess, and check it in practice problem 3.

Video slot. Video coming. The black seadevil anglerfish filmed alive (MBARI, 2014); bioluminescence in the deep sea; the HMS Challenger expedition; Beebe’s bathysphere and the Trieste. Search approved channels (MBARI, NOAA Ocean Exploration, Schmidt Ocean Institute, Smithsonian Ocean, Woods Hole Oceanographic Institution); preview first.

KEY TERMS

bioluminescence

Light made by a living thing through a chemical reaction (usually a substance called luciferin reacting with oxygen, helped by an enzyme). In the deep sea it is almost the only light.

esca

The glowing “bait” at the tip of an anglerfish’s fishing rod (the illicium), a modified fin spine. In many species bacteria living inside it make the light.

midnight zone

The bathypelagic zone, from about 1,000 to 4,000 meters (3,300 to 13,100 feet), where no sunlight reaches at all.

marine snow

A slow, steady fall of bits of dead plants and animals, waste and mucus from the sunlit water above, a main food source for the deep.

azoic hypothesis

The idea, proposed by Edward Forbes in the 1840s, that no animals could live below about 300 fathoms (550 m); later disproved.

chemosynthesis

Making food from chemicals rather than sunlight. Bacteria at deep-sea hot springs do this, feeding whole communities of animals.

CORE IDEAS

Layers of the sea. Sunlight fades fast in water. The *sunlight zone*, the top 200 meters (about 660 feet), holds nearly all the ocean's plants and algae. Below it, the *twilight zone* (200–1,000 m) has only a faint blue glow by day. Below 1,000 meters begins the **midnight zone**, black and about 39°F (4°C), and deeper still the abyss (4,000–6,000 m) and the trenches. The deepest known point, the Challenger Deep in the Mariana Trench, is about 10,935 meters (nearly 36,000 feet) down. Since every 10 meters of seawater adds about one atmosphere of pressure, the pressure there is over 1,000 times what we feel at the surface, about 8 tons on every square inch. Most of the water in the ocean is deeper than 200 meters, so most of the living space on earth lies in darkness.

“No life down there.” In the 1840s the respected British naturalist Edward Forbes, dredging in the Aegean Sea, found fewer and fewer animals the deeper he went. He suggested that below about 300 fathoms (550 m) there would be no animals at all, the **azoic hypothesis**. It was a reasonable guess from his data, but it was wrong. In 1860 a telegraph cable hauled up from more than a mile deep in the Mediterranean came up with corals and other creatures growing on it. Then the British ship HMS *Challenger*, from 1872 to 1876, sailed nearly 69,000 nautical miles, sounding and dredging the oceans of the world. Its scientists described about 4,700 new species, many from great depths. The deep was full of life.

Going down. In 1934 William Beebe and Otis Barton were lowered off Bermuda in the bathysphere, a steel ball less than five feet wide, to 3,028 feet (923 m). Beebe described by telephone the glowing fish passing his window. In 1960 Jacques Piccard and Lt. Don Walsh of the U.S. Navy took the bathyscaphe *Trieste* to the bottom of the Challenger Deep. In 1977 scientists in the submersible *Alvin* found hot springs on the seafloor near the Galápagos Islands surrounded by giant tubeworms, clams and crabs, whole communities fed not by sunlight but by bacteria using **chemosynthesis**. No one had imagined them.

The angler's equipment. The deep-sea anglerfishes include about 160 known species, most of them small, a few inches long. A female's first dorsal fin spine has become a fishing rod with a glowing lure, the **esca**. In many species the light is made by colonies of bacteria living inside the lure, which the fish can apparently brighten or dim. Small fish and shrimp drawn to the light find themselves facing a huge mouth full of long, inward-pointing, see-through teeth. Food is scarce in the dark, so an angler cannot be choosy: its jaw and stomach can stretch to swallow prey as large as itself or larger. Its body is soft and watery, with weak muscles and bones, which saves energy; it simply waits.

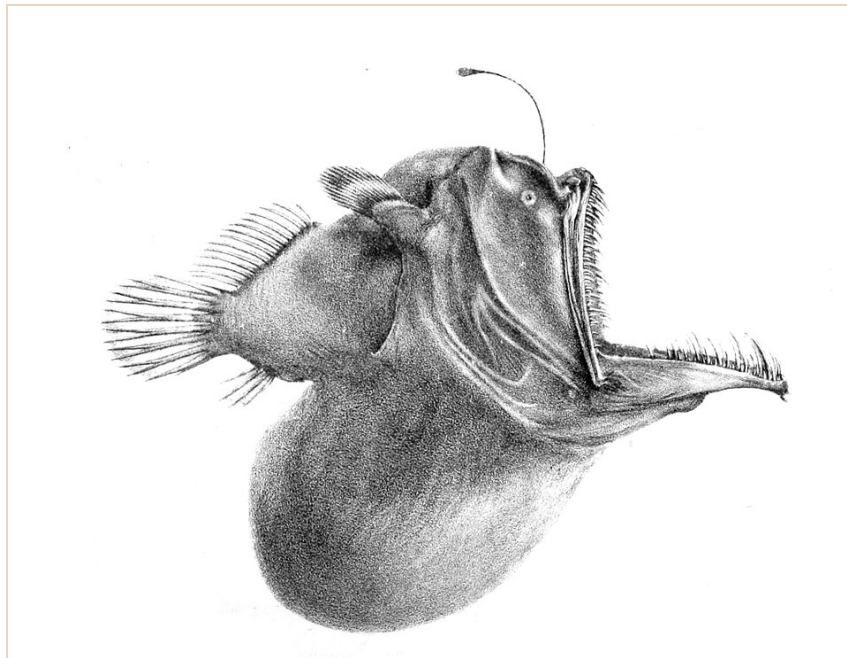
An unusual family life. Male anglers of many species are tiny, a small fraction of the female's size, with large nostrils and eyes for finding a female in the dark. In some families the male bites onto the female and stays attached for life; over time his tissues fuse with

hers and he shares her blood supply. The British ichthyologist Charles Tate Regan first explained this in 1925 after studying specimens from Iceland. Nothing like it is known in other backboned animals. In 2018 a pair was filmed alive in the Atlantic near the Azores for the first time.

Lights everywhere. A study in Monterey Bay found that about three-quarters of the animals seen by underwater robots, from the surface down to about 13,000 feet, could make light. Animals use **bioluminescence** to lure prey, to find mates, to startle attackers and to hide: many twilight-zone animals glow faintly on their bellies to erase their shadows against the dim light above. A few dragonfish even make red light, which most deep animals cannot see, giving them a private searchlight. The black seadevil, *Melanocetus johnsonii*, was described from a dead specimen in 1864; it was not filmed alive until 2014, when an underwater robot of the Monterey Bay Aquarium Research Institute found one about 1,900 feet down.

Questions from the whirlwind. When God answered Job, He asked: “Hast thou entered into the springs of the sea? or hast thou walked in the search of the depth?” For almost all of history the honest answer was no. Even now only a small fraction of the deep seafloor has been seen. Job’s questions were meant to humble him, and they still humble us. But they also invite us, as God’s image-bearers, to search out His works, and to remember that the darkness is not dark to Him.

PICTURE STUDY



Melanocetus johnsonii (the humpback anglerfish or black seadevil), G. H. Ford, 1864 · Lithographed scientific illustration · From Albert Günther’s description of the species in the *Proceedings of the Zoological Society of London* (1864); via the Biodiversity Heritage Library
Wikimedia Commons · Public domain

In 1864 the zoologist Albert Günther of the British Museum described a strange black fish found floating off the island of Madeira. G. H. Ford, a leading scientific artist, drew it for the

published description. No one would see this fish alive for another 150 years, so this drawing, made from a dead specimen, was for a long time the best picture anyone had.

Look closely

- Find the fishing rod (illicium) and the lure (esca). Where does the rod grow from?
- Look at the teeth. Which way do they point, and what would that do to a fish trying to escape?
- Compare the size of the mouth with the size of the body. What does that tell you about how it eats?

Talk about it

1. Ford drew from a dead fish brought up from the deep. What might be different about the living animal (color, shape, posture, the glowing lure)?
2. Compare this drawing with a photograph or video of a living black seadevil (search MBARI 2014). What did the artist get right, and what could no artist of 1864 have known?

HANDS-ON: THE DEEP-SEA PRESSURE COLUMN

Build a scale model of the ocean's depth zones from floor to ceiling, place real animals and explorers on it, and calculate the pressure at each level.

You will need

- A roll of adding-machine paper or paper strips taped together, about 11 feet (3.4 m) long
- Meter stick or tape measure, markers in five shades from light blue to black
- Index cards for animals and explorers
- Calculator and Field Notebook

Steps

1. Use the scale 1 foot = 1,000 meters (so the Challenger Deep, 10,935 m, is just under 11 feet). Mark and color the zones: sunlight (0–200 m), twilight (200–1,000), midnight (1,000–4,000), abyss (4,000–6,000) and trenches (6,000–10,935).
2. Make cards and tape them at the right depths: Beebe's bathysphere (923 m), black seadevil filmed (about 580 m), giant squid filmed (about 600–1,000 m), sperm whale dives (often 1,000 m or more), Alvin's vent discovery (about 2,500 m), the Titanic wreck (about 3,800 m), Trieste (10,900 m+).
3. For each card, calculate the pressure: atmospheres = $1 + \text{depth} \div 10$. Then pounds per square inch = atmospheres $\times 14.7$. Write both on the card.
4. Hang the column on a wall or stairwell. Stand at the top and look down: what fraction of the column is in total darkness (below 1,000 m)?
5. Write three sentences: What has the deep sea taught people about the limits of a confident scientific guess (the azoic hypothesis)?

Check your work

- My column is to scale with five colored zones.
- At least seven cards are placed correctly with pressures calculated.
- I calculated the dark fraction (about 90 percent of the column).

FIELD NOTEBOOK

1. **Anglerfish diagram.** Draw a female deep-sea anglerfish and label: illicium (rod), esca (lure with glowing bacteria), inward-pointing teeth, stretchy jaw and stomach, small eyes, soft body. Add a tiny attached male near her belly, labeled.
2. **Narration (parent keeps).** Without looking at the text, write one well-built paragraph of eight to ten sentences explaining how people discovered that the deep sea is full of life, from Forbes's guess to Alvin's hot springs. Include at least four dates and two numbers. Date it and give it to a parent for the portfolio.

Did you know? Deep-sea fish have no air-filled swim bladders, which would be crushed, and their cells carry a natural chemical (TMAO) that helps keep their proteins working under great pressure. Because pressure does not crush animals that have no air spaces, a deep-sea fish is not "squashed"; the danger for it comes in being brought up, not in living down there.

Primary source. *Job 38:16–18, King James Version (1611). The LORD answers Job "out of the whirlwind" (Job 38:1) with a series of questions about the earth, the sea, the weather and the animals.*

Hast thou entered into the springs of the sea? or hast thou walked in the search of the depth? Have the gates of death been opened unto thee? or hast thou seen the doors of the shadow of death? Hast thou perceived the breadth of the earth? declare if thou knowest it all.

Go deeper. William Beebe, *Half Mile Down* (1934), his account of the bathysphere dives (summarize; check copyright status before copying). NOAA Ocean Exploration (oceanexplorer.noaa.gov), especially its pages on ocean zones and bioluminescence. MBARI's online videos of the black seadevil (2014). The Natural History Museum, London, pages on the HMS Challenger expedition. Second video topic: hydrothermal vents and chemosynthesis.

Goes deeper in. Earth Science, "Oceans and the Sea Floor" (coming soon); Life Science, "Fish" and "Light and Living Things" (coming soon).

For families. The primary source is Job 38:16–18 (KJV), checked word for word. Depths and pressures are rounded: Challenger Deep about 10,935 m (measurements vary by a few dozen meters); pressure over 1,000 atmospheres. The "three-quarters" figure is Martini and Haddock, *Scientific Reports* (2017), from Monterey Bay. Regan's 1925 paper

described attached males in *Ceratias holboelli*; the 2018 footage was filmed by Kirsten and Joachim Jakobsen of a *Caulophryne* pair. The MBARI black seadevil video (2014) was filmed at about 600 m. The attached-male biology is stated plainly as a fact of the animal's life. Ford's illustration accompanies Günther's 1864 description; the Commons file credits Ford and the Biodiversity Heritage Library. Species counts for deep-sea anglerfishes are approximate.

PRACTICE

1. **EASY** What is an esca, and what makes it glow in many anglerfish?
2. **EASY** What was the azoic hypothesis, and what disproved it?
3. **MEDIUM** Using $\text{atmospheres} = 1 + \text{depth} \div 10$, find the pressure at the Challenger Deep (10,935 m) in atmospheres and in pounds per square inch ($\times 14.7$).
4. **MEDIUM** Give three ways deep-sea animals use bioluminescence.
5. **CHALLENGE** Edward Forbes's azoic hypothesis fit his data but was wrong. Explain what was wrong with his reasoning from the data, and write a rule for good scientific reasoning that his mistake teaches. Then connect it to God's question in the primary source: "declare if thou knowest it all."
6. **CHALLENGE** Food in the midnight zone is scarce. Using the anglerfish, explain three ways its body saves energy or makes the most of rare meals, and calculate: if an angler eats one meal every 3 weeks, how many meals is that a year? Compare with your own (three a day).

Make it a game • Anglerfish in the Dark. In a dark room, the "anglerfish" sits still holding a small flashlight or glow stick on a stick or ruler. Other players are small fish who must walk across the room. Any fish who comes within arm's reach of the light is "caught." The angler may slowly move the lure but may not get up. Talk about why a lure works better than chasing when food is rare.

Scripture. "If I say, Surely the darkness shall cover me; even the night shall be light about me. Yea, the darkness hideth not from thee; but the night shineth as the day: the darkness and the light are both alike to thee." (Psalm 139:11-12, KJV)

David knew that no darkness hides anything from God. The midnight zone is the largest dark place on earth, yet it is full of creatures that make their own light, and every one of them is seen and known by its Maker.

Practice: answers

1. The lure at the tip of the anglerfish's fishing-rod spine; in many species, bacteria living inside it make the light.
2. Edward Forbes's idea (1840s) that no animals live below about 300 fathoms (550 m). It was disproved by animals found on a deep telegraph cable (1860) and by the HMS Challenger expedition (1872-1876), which found life at great depths.

3. $1 + 1,093.5 = 1,094.5$ atmospheres (about 1,095). $1,094.5 \times 14.7 \approx 16,090$ psi (about 16,000 pounds per square inch, or 8 tons).
4. Any three: to lure prey (anglerfish); to find or signal mates; to startle or distract predators; to hide by glowing on the belly (counter-illumination); to see with red light (dragonfish).
5. Sample: Forbes saw fewer animals at greater depths in one sea (the Aegean, which is poor in life) with simple dredges and extended the trend far beyond where he had sampled, to the whole ocean. Rule: do not extend a pattern far beyond the range of your evidence; test it where it predicts something new. God's question to Job reminds us that our knowledge is always partial; humility about what we have not seen is both good science and good theology.
6. Saves energy: soft, watery body with weak muscles; sits still and lures prey instead of chasing; can swallow very large prey with stretchy jaw and stomach; inward-pointing teeth keep anything it catches. $52 \div 3 \approx 17$ meals a year. You eat about $3 \times 365 = 1,095$ meals a year, about 64 times as many.

4.8 SALMON: THE LONG WAY HOME

OBJECTIVES

- Describe the salmon's life cycle from egg to spawner, using the correct names for each stage, and explain how its body changes to move between fresh and salt water.
- Explain the evidence that salmon find their home streams by smell (Hasler's experiments) and by the earth's magnetic field, and give real migration distances.
- Read Izaak Walton's 1653 account of the salmon as a primary source and judge which of his claims modern study confirms and which it corrects.

Warm-up. Close your eyes and have someone hold three different things under your nose, one at a time (an orange peel, coffee, cinnamon). Can you name each one? A salmon, years after leaving its home stream and thousands of miles away, finds its way back to the very stream where it hatched, and in the last stretch it does it mostly by smell. Write one question you have about how that could work.

Video slot. Video coming. Pacific salmon life cycle and spawning run; salmon leaping falls; fish ladders and the Elwha River dam removal; Arthur Hasler's homing experiments. Search approved channels (NOAA Fisheries, U.S. Fish and Wildlife Service, National Park Service (Olympic National Park, Katmai bear cam), Smithsonian); preview first.

KEY TERMS

anadromous

Born in fresh water, grows up in the sea and returns to fresh water to spawn (from Greek "running upward"). Salmon, shad and sturgeon are anadromous.

redd

The nest a female salmon digs in the gravel of a stream with her tail, where she lays her eggs.

smolt

A young salmon that has turned silver and changed its body chemistry so it can live in salt water, ready to go to sea.

imprinting

Learning that happens at a particular stage of young life and lasts. Young salmon imprint on the smell of their home stream.

kype

The hooked lower jaw that grows on male salmon (and some females) as they come up the river to spawn.

fish ladder

A series of stepped pools or a channel built beside a dam so that migrating fish can swim and leap past it.

CORE IDEAS

A life in two worlds. Salmon are **anadromous**: they hatch in fresh water, grow up in the sea and come back to fresh water to spawn. There are two main groups. Atlantic salmon live on both sides of the North Atlantic. Pacific salmon include five species in North America: chinook (king), coho (silver), sockeye (red), pink and chum, along with their cousin the steelhead trout. Pacific salmon are a great harvest: commercial, tribal and sport fishermen land hundreds of millions of pounds a year, and bears, eagles, orcas and seals depend on them too.

From egg to spawner. In autumn the female digs a **redd** in clean gravel by turning on her side and beating her tail, lays her eggs, and the male fertilizes them; she then covers them with gravel. Depending on species and size, a female lays a few thousand eggs, and large chinook may lay more than ten thousand. The eggs hatch in winter into *alevins*, which hide in the gravel living on a yolk sac. In spring they wriggle out as *fry*, then grow into *parr* with dark bars on their sides. After months or a few years, depending on species, the parr turn silver and become **smolts**: their gills and kidneys change so they can get rid of salt instead of holding onto it, and they head downstream to the sea. There they grow fast on shrimp, squid and small fish. After one to five years they return. Of every few thousand eggs, perhaps only a handful of adults come home; that is why each female lays so many.

The run upriver. Returning salmon stop eating once they enter fresh water and live on stored fat. Some travel astonishing distances: Yukon River chinook swim nearly 2,000 miles upstream to spawn in Canada's Yukon Territory, and sockeye bound for Redfish Lake in Idaho climb about 6,500 feet over 900 miles. They leap waterfalls; Atlantic salmon have been seen to clear falls over 10 feet high. On the way their bodies change. Sockeye turn bright red with green heads, males grow humps and a hooked jaw called a **kype**, and their teeth grow large for fighting rivals. Pacific salmon spawn once and then die, their work complete. Atlantic salmon and steelhead may survive, return to the sea and spawn again.

How do they find home? In the 1950s Arthur Hasler of the University of Wisconsin tested the idea that salmon smell their way home. His team caught returning coho salmon at two branches of Issaquah Creek in Washington, plugged the noses of half of them with cotton, and released them downstream. The fish with open noses mostly returned to the branch where they had been caught; the fish with plugged noses chose almost at random. Later experiments showed that young salmon **imprint** on the chemical "scent" of their stream as smolts and remember it for years. Smell works only near the river, though. At sea, studies of sockeye returning to the Fraser River in British Columbia found that their choice of route around Vancouver Island shifted with tiny yearly changes in the earth's magnetic field, strong evidence that salmon carry a kind of magnetic map.

Feeding the forest. A dying salmon feeds the stream that fed it. Bears catch salmon and carry them into the woods, eating only the best parts; eagles, gulls, insects and fungi finish

the rest. Scientists can trace nitrogen from the ocean, which has a slightly different chemical signature from land nitrogen, into streamside trees, and some studies have found that trees along salmon streams grow faster than trees beside streams without salmon. The sea, by way of the salmon, fertilizes the forest.

Keeping the run. Dams, mill weirs and pollution have blocked or harmed many salmon rivers. Even in 1653 Izaak Walton noticed that salmon “stopt by Flood-gates or Weres” suffered. Good stewardship has taken many forms: **fish ladders** at dams such as Bonneville on the Columbia River (1938), hatcheries, protecting spawning gravel, and sometimes removing old dams. On the Elwha River in Washington, two dams were taken down between 2011 and 2014, the largest dam removal in American history, and salmon were soon spawning in reaches they had not reached for a century. Genesis 2:15 calls people to “dress” and “keep” the earth: to use it and to guard it.

“Thither they return again.” Ecclesiastes observes that the rivers run into the sea and return to the place from which they came. The salmon follows the same circle, home to sea and back to home, guided by senses God built into it. Walton, a devout Anglican, saw in it the Creator’s care for creatures too small to notice.

PICTURE STUDY



Salmon (Sake), Takahashi Yuichi, c. 1877 · Oil painting · Several versions exist; the best known is in the University Art Museum, Tokyo University of the Arts, and is an Important Cultural Property of Japan. The Commons image is credited to the Yamagata Art Museum.

Wikimedia Commons · Public domain

Takahashi Yuichi (1828–1894) was one of the first Japanese painters to master Western oil painting. In his day, salted salmon hung in Japanese kitchens through the winter, and he painted this ordinary food with startling realism, down to the rough rope and the dried, scaly skin. It became one of the most famous paintings in Japan.

Look closely

- Find the rope, the head, the fins and the place where slices have been cut away. What part of the fish is missing?
- Look at the textures: skin, flesh, rope, wood. Which looks most real to you?
- Why do you think Takahashi chose such a tall, narrow canvas?

Talk about it

1. Why might a painter choose a common kitchen food as the subject of a serious painting? Compare with still-life paintings of food from Europe.
2. This salmon was caught on its way home to spawn. How does knowing its long journey change the way you see the painting?

HANDS-ON: WALTON FACT-CHECK AND SALMON JOURNEY MAP

Izaak Walton wrote *The Compleat Angler* in 1653, and anglers still love it. Fact-check his account of the salmon (the primary source in this stop) against what you have learned, then map one real salmon run.

You will need

- The primary source in this stop
- A three-column page in the Field Notebook: “Walton says,” “Modern study says,” “Verdict”
- A map of the Pacific Northwest and Alaska or of the North Atlantic (atlas or printed outline)
- Colored pencils, ruler, calculator

Steps

1. Read the primary source slowly, aloud. Old spellings: “dye” = die; “Weres” = weirs (fish dams); “Melter” = male; “Samlets” = young salmon; “kipper” here = a spawning male with a hooked jaw.
2. List at least five claims Walton makes (for example: salmon spawn in August; they dig a hole in the gravel; they hide the eggs; they go to sea before winter; males that cannot reach the sea grow a hooked jaw and waste away). For each, write what modern study says and give a verdict: correct, partly correct or mistaken.
3. Choose one run: Yukon River chinook (Bering Sea to the Yukon headwaters), Fraser River sockeye or Redfish Lake sockeye (Pacific to central Idaho by the Columbia and Snake rivers). Draw the route from the ocean to the spawning ground and measure its length with the map scale.
4. If the fish swim about 30 miles a day upstream, how many days does the run take? Mark any dams on the route and whether they have fish ladders.
5. Write four sentences: Where was Walton a careful observer, and where did he rely on “some say”? What can a modern student learn from both?

Check your work

- My fact-check table has at least five of Walton's claims with verdicts.
- My map shows one real run with distance and days calculated.
- My closing sentences are fair to Walton.

FIELD NOTEBOOK

1. **Life-cycle circle.** Draw a circle from a mountain stream to the sea and back. Label and sketch each stage: egg in the redd, alevin, fry, parr, smolt, ocean adult, spawner with kype, and the carcass feeding the forest. Mark where the fish imprints on smell.
2. **Narration (parent keeps).** Without looking at the text, write one well-built paragraph of eight to ten sentences telling the life of one sockeye salmon from egg to spawning, including how it finds its way home. Use at least three numbers and Hasler's experiment. Date it and give it to a parent for the portfolio.

Did you know? The largest chinook salmon on record, caught in a fish trap near Petersburg, Alaska, in 1949, is reported to have weighed 126 pounds. Sockeye salmon get their deep red color from the tiny shrimp-like animals (krill and copepods) they eat at sea, which contain red pigments. Farm-raised salmon are given similar pigments in their feed.

Primary source. *Izaak Walton, The Compleat Angler (first published 1653; text of the fifth edition, 1676, as printed in Project Gutenberg eBook #683), chapter VII, Piscator (the fisherman) speaking.*

The Salmon is accounted the King of freshwater fish; and is ever bred in rivers relating to the sea, yet so high, or far from it, as admits of no tincture of salt, or brackishness. He is said to breed or cast his spawn, in most rivers, in the month of August: some say, that then they dig a hole or grave in a safe place in the gravel, and there place their eggs or spawn, after the melter has done his natural office, and then hide it most cunningly, and cover it over with gravel and stones; and then leave it to their Creator's protection, who, by a gentle heat which he infuses into that cold element, makes it brood, and beget life in the spawn, and to become Samlets early in the spring next following.

The Salmons having spent their appointed time, and done this natural duty in the fresh waters, they then haste to the sea before winter, both the melter and spawner; but if they be stopped by flood-gates or weirs, or lost in the fresh waters, then those so left behind by degrees grow sick and lean, and unseasonable, and kipper, that is to say, have bony gristles grow out of their lower chaps, not unlike a hawk's beak, which hinders their feeding; and, in time, such fish so left behind pine away and die.

Go deeper. Izaak Walton, *The Compleat Angler*, a modernized edition free on Project Gutenberg (eBook #683). NOAA Fisheries species pages for each Pacific salmon and the

Atlantic salmon (fisheries.noaa.gov). The National Park Service's Elwha River Restoration pages (nps.gov/olym). Katmai National Park's "bear cam" at Brooks Falls (explore.org) in July. Second video topic: how fish ladders work.

Goes deeper in. Life Science, "Fish" and "Ecosystems and Food Webs" (coming soon); Geography, "Rivers of North America" (coming soon); Literature, *The Compleat Angler* (coming soon).

For families. Walton's text differs between his editions (1653-1676) and modern reprints, and this excerpt follows the old-spelling transcription at Project Canterbury, which does not name its edition; the Project Gutenberg version (eBook #683) is a modernized text that could not be checked line by line here. The omitted clause concerns the male fertilizing the eggs. Walton's mistakes (an August spawning time, the idea that a hooked jaw is a sickness) are left for students to find. Hasler's nose-plugging study was published by Wisby and Hasler (1954); the magnetic-field study is Putman et al., *Current Biology* (2013). Distances are rounded from NOAA and state agency figures. The 126-pound chinook is widely reported but was a commercial catch, not an official angling record. Elwha River figures follow the National Park Service. Stewardship is presented as good care of a harvest, not as a political position.

PRACTICE

1. **EASY** What does anadromous mean?
2. **EASY** Put these salmon stages in order: smolt, egg, parr, alevin, fry, adult.
3. **MEDIUM** Describe Hasler's nose-plugging experiment: what was changed, what was compared, and what did the result show?
4. **MEDIUM** A sockeye run to Redfish Lake is about 900 miles and climbs about 6,500 feet. What is the average climb per mile? If the fish swim 25 miles a day, how many days does the run take?
5. **CHALLENGE** From the primary source, identify two claims Walton presents as hearsay ("is said," "some say") and one he presents as plain fact. For each, give the modern verdict. What does his use of "some say" tell you about him as a writer?
6. **CHALLENGE** If a female sockeye lays 3,000 eggs and, on average, only 2 return as spawning adults, what percentage survive? Explain why the population can stay steady with such low survival, and why a dam without passage can wipe out a run in only a few years.

Make it a game • Find Your Stream. Put drops of five different scents (vanilla, peppermint, lemon, cinnamon, vinegar) on cotton balls in five cups around the room. Each player secretly sniffs one scent (their "home stream") at the start. Then everyone leaves the room, the cups are shuffled to new places and players come back blindfolded with a helper to guide their steps. Each must sniff cups to find home. Talk about how a salmon smells a stream through miles of river.

Scripture. “All the rivers run into the sea; yet the sea is not full; unto the place from whence the rivers come, thither they return again.” (Ecclesiastes 1:7, KJV)

The Preacher saw a great circle in creation: water running to the sea and returning to its source. The salmon makes the same journey in its own body, guided home by the senses God gave it.

Practice: answers

1. Born in fresh water, grows up in the sea and returns to fresh water to spawn.
2. Egg, alevin, fry, parr, smolt, adult.
3. Returning coho caught at two branches of a creek were released downstream; half had their noses plugged. Fish with open noses mostly returned to the branch where they were caught, while plugged fish chose about at random. It showed salmon use smell to find their home stream.
4. $6,500 \div 900 \approx 7.2$ feet of climb per mile. $900 \div 25 = 36$ days.
5. Hearsay: that salmon spawn in August (“is said”), mostly mistaken, since in Britain they spawn chiefly in late autumn and winter; that they dig a hole in the gravel and cover the eggs (“some say”), correct, this is the redd. Plain fact: that salmon left in fresh water grow a hooked jaw (“kipper”) and pine away; partly correct, the hook (kype) is a normal breeding change in males, not a sickness from being trapped, though spawned-out fish do weaken and many die. “Some say” shows Walton honestly marking what he had only heard, a good habit for any writer.
6. $2 \div 3,000 = 0.067$ percent (about 1 in 1,500). It stays steady because 2 returning adults (one male, one female) replace the two parents. If a dam blocks all spawners from reaching the gravel, no new eggs are laid upstream; since most salmon return after 2 to 5 years, a whole run can disappear once those few year-classes come back and cannot spawn.

4.9 SEALS AND SEA LIONS: DEEP DIVERS AND A RESCUED HERD

OBJECTIVES

- Tell true seals, eared seals (sea lions and fur seals) and walruses apart by at least four features.
- Explain how elephant seals and Weddell seals dive so deep and so long on one breath, using real numbers for depth, time, heart rate and blood.
- Tell the history of the Pribilof fur seals, from near-destruction to the North Pacific Fur Seal Convention of 1911, and read Melville's lines on seals as a primary source about sailors' beliefs.

Warm-up. Take a breath and hold it while someone times you (stop as soon as you feel uncomfortable; do not do this in water). Most people manage 30 to 90 seconds. A southern elephant seal can stay under for about two hours on one breath. As you read, list every trick its body uses that yours does not.

Video slot. Video coming. Elephant seal and Weddell seal diving; harbor seal whiskers tracking fish; sea lions vs. true seals; Pribilof Islands northern fur seals. Search approved channels (NOAA Fisheries, Smithsonian Ocean, National Park Service (Año Nuevo, Point Reyes), Monterey Bay Aquarium); preview first.

KEY TERMS

pinniped

"Fin-footed": the group of sea mammals with flippers that includes seals, sea lions, fur seals and walruses.

true seal

A seal of the family Phocidae (such as harbor, gray and elephant seals) with no outer ear flaps, which swims with its hind flippers and wriggles on land.

eared seal

A sea lion or fur seal (family Otariidae), with small outer ear flaps, long front flippers for swimming, and hind flippers that turn forward so it can walk on land.

myoglobin

A protein in muscle that stores oxygen; seal muscles are packed with it, which makes them almost black.

bradycardia

Slowing of the heartbeat. Diving seals slow the heart sharply to save oxygen.

pelagic sealing

Hunting seals in open water at sea, which killed many females and left their pups to starve on shore; banned by the 1911 treaty.

CORE IDEAS

Three kinds of pinnipeds. Seals, sea lions and walruses are **pinnipeds**, “fin-footed” mammals, about 33 species in all. **True seals**, such as harbor seals and elephant seals, have only a small hole for an ear, swim by sweeping their hind flippers side to side, and on land wriggle along on their bellies like caterpillars. **Eared seals**, the sea lions and fur seals, have little ear flaps, “fly” through the water with their long front flippers, and can turn their hind flippers forward to walk and even gallop on land; the trained “seals” of circuses and aquariums are almost always California sea lions. The walrus, in a family by itself, has tusks and can walk on all fours like a sea lion but swims like a true seal. Sea lions bark; true seals mostly grunt, growl and sing underwater.

Champion divers. Northern and southern elephant seals spend most of the year at sea, diving almost without rest, day and night, usually 1,000 to 2,000 feet (300–600 m) deep for about 20 to 30 minutes, then surfacing for only two or three minutes before going down again. The deepest recorded dive by a southern elephant seal reached about 7,800 feet (2,388 m), and the longest lasted about two hours. Weddell seals hunt under Antarctic ice, diving to about 2,000 feet and staying down more than an hour, and must find their breathing holes again in the dark.

How they do it. A seal does not dive with a lungful of air; true seals breathe out before they dive, and their lungs collapse as they go deeper, which keeps nitrogen out of the blood and prevents “the bends.” Instead they carry oxygen in the body. A seal has about two to three times as much blood for its size as a person, and its blood is thicker with red cells; a large spleen stores extra red cells and squeezes them into the blood during a dive. Its muscles are loaded with **myoglobin**, so much that seal meat is nearly black. During a dive the heart slows dramatically (**bradycardia**), in elephant seals from about 100 beats a minute at the surface to fewer than 10 at times, and blood is sent chiefly to the brain and heart while the muscles use their own stored oxygen. Every part of the body works together for one purpose.

Warmth and whiskers. True seals and sea lions keep warm mostly with thick **blubber**. Fur seals rely more on fur: a dense underfur, tens of thousands of hairs to the square centimeter, traps a layer of air next to the skin. That fur nearly destroyed them. Seals also have remarkable whiskers. In experiments, blindfolded harbor seals followed the invisible wake left by a small submarine model, and later the trails of real fish, purely by feeling the swirling water with their whiskers, even trails half a minute old.

The fur seal millions. In 1786 the Russian navigator Gavriil Pribylov found the remote Pribilof Islands in the Bering Sea, where millions of northern fur seals came ashore each summer to breed. When the United States bought Alaska in 1867, the herd was probably around three million. The government leased the islands to companies that harvested young males on land under rules, but after about 1880 ships from several nations began **pelagic sealing**, shooting and spearing seals at sea. Most seals killed at sea were females, many with pups waiting on shore that then starved. By 1911 the herd had fallen to perhaps 200,000 or fewer.

A treaty to save a herd. Henry Wood Elliott, an artist and naturalist who first painted the Pribilof rookeries in 1872, spent decades warning Congress and the public. On July 7, 1911, the United States, Great Britain (for Canada), Russia and Japan signed the North Pacific Fur Seal Convention, which banned pelagic sealing and shared the managed land harvest among the four nations. It was the first international treaty to protect a wild animal. Congress also stopped the land harvest for several years. The herd recovered strongly, to well over a million by the 1950s. It was a clear example of good stewardship: not ending all use, but restoring a harvest to what the herd could bear.

A lesson from the shore. Proverbs says, “A righteous man regardeth the life of his beast.” The fur seal story shows both sides of human dominion: greed that took every animal it could reach, and wise rule that restored the herd. A darker example lies nearby: Steller’s sea cow, a huge, gentle sea mammal found in the Commander Islands in 1741, was hunted out within about 27 years. Stewardship came too late for it.

PICTURE STUDY



The Fur Seal Millions, Henry Wood Elliott, 1872 · Watercolor on paper · Anchorage Museum, Anchorage, Alaska

Wikimedia Commons · Public domain

Henry Wood Elliott (1846–1930) went to the Pribilof Islands in 1872 for the U.S. government and painted what he saw: beaches and slopes so covered with fur seals that the ground could hardly be seen. Years later, when the herd was collapsing, he used his paintings and counts as evidence to persuade lawmakers to protect it.

Look closely

- Try to estimate how many seals are in one small square of the painting, then how many squares make up the crowded area. What total do you get?

- Find the shoreline, the hillside and the sea. Where are the seals thickest?
- Look at the colors and the weather. What does the mist add?

Talk about it

1. Elliott's painting was later used as evidence. What makes a painting good evidence, and what are its limits compared with a careful count?
2. How do you think Elliott felt when he returned decades later and found the beaches nearly empty? What would you have done in his place?

Safety first. Seal-watching safety: stay at least 50 yards (about half a football field) from seals and sea lions on beaches, and never touch or feed a pup that seems alone; its mother is usually feeding nearby. Seals and sea lions can bite hard and carry diseases, and in the United States it is against federal law to disturb them. Keep dogs leashed.

HANDS-ON: THE PRIBILOF HERD: GRAPH A RESCUE

Turn the history of the northern fur seal into a line graph, mark the events that caused the fall and the rise, and write a short case for wise stewardship.

You will need

- Graph paper, ruler, pencil and two colors
- The rounded population figures in step 1
- The primary source in this stop
- Field Notebook

Steps

1. Plot these rounded estimates of the Pribilof fur seal herd (in millions) against the year: 1867, about 3.0; 1911, about 0.2; 1952, about 1.5. Join the points with straight lines, but remember that the real path between them was not straight: label the lines "estimated trend." Label the axes and give the graph a title.
2. Mark these events with arrows: Alaska purchased (1867); pelagic sealing grows (1880s); treaty signed (1911); land harvest paused (1912-1917).
3. Calculate the percentage drop from 1867 to 1911, and how many times larger the herd was in 1952 than in 1911.
4. Write a paragraph of five sentences explaining what caused the fall and what caused the recovery, using the words "pelagic sealing," "treaty" and "stewardship."
5. Read the primary source. Sailors once feared seals as omens. Write two sentences: How did the men who emptied the Pribilof beaches think about seals, and how is that different from Melville's superstitious sailors and from Proverbs 12:10?

Check your work

- My graph is labeled and the three points and four events are plotted correctly.

- I calculated the drop (about 93 percent) and the recovery (about 7½ times).
- My paragraph explains causes, not just numbers.

FIELD NOTEBOOK

1. **Compare chart.** Draw a harbor seal and a California sea lion side by side and label the differences: ear hole or ear flap, front flippers short or long, hind flippers back or turned forward, how each moves on land and in water.
2. **Narration (parent keeps).** Without looking at the text, write one well-built paragraph of eight to ten sentences telling the story of the Pribilof fur seals from 1786 to the 1950s. Include at least four dates, two population numbers and the name of the man who painted the rookeries. Date it and give it to a parent for the portfolio.

Did you know? The Steller sea lion, the largest sea lion, is named for Georg Wilhelm Steller, the German naturalist on Vitus Bering's 1741 voyage, who described it along with the sea cow, a jay and an eider that also bear his name. The U.S. Navy has trained California sea lions to find and mark objects on the seafloor, since they see well in dim water and can dive repeatedly.

Primary source. *Herman Melville, Moby-Dick; or, The Whale (1851), chapter 126, "The Life-Buoy." At night the Pequod's crew hears wild, mournful cries near some rocky islets, and some of the men are frightened. Checked against the 1851 American edition text (also Project Gutenberg eBook #2701).*

Most mariners cherish a very superstitious feeling about seals, arising not only from their peculiar tones when in distress, but also from the human look of their round heads and semi-intelligent faces, seen peeringly uprising from the water alongside. In the sea, under certain circumstances, seals have more than once been mistaken for men.

Go deeper. NOAA Fisheries pages on the northern fur seal and the Pribilof Islands, including the history of the 1911 convention (fisheries.noaa.gov). The Smithsonian Institution Archives on Henry Wood Elliott. Año Nuevo State Park (California) and Point Reyes National Seashore pages on elephant seals and their winter breeding season. Rudyard Kipling, "The White Seal," in *The Jungle Book* (1894; Project Gutenberg eBook #236), a story set on the Pribilofs. Second video topic: how elephant seals dive.

Goes deeper in. Life Science, "Mammals of the Sea" (coming soon); History, "Alaska and the North Pacific" (coming soon); Gardening & Animals, for stewardship.

For families. The Melville excerpt was checked word for word against the 1851 American edition text on Wikisource; it is in Project Gutenberg eBook #2701. Population figures for the Pribilof herd are rough historical estimates and differ between sources (the 1911 low is given variously as about 125,000 to 216,000); the graph uses rounded values for practice. NOAA reports about 1.5 million in 1952 and an estimated 2.2 million

in the 1950s; the herd has declined again since then for reasons still studied. The treaty was signed July 7, 1911, by the United States, Great Britain, Russia and Japan. Dive records follow published tracking studies (southern elephant seal maximum depth about 2,388 m). The whisker studies are Dehnhardt et al., *Science* (2001) and later papers. The 50-yard guideline is NOAA's for seals and sea lions on land; local rules may differ. Hunting history is told plainly without graphic detail.

PRACTICE

1. **EASY** Give three ways to tell a sea lion from a true seal.
2. **EASY** What did the 1911 North Pacific Fur Seal Convention ban, and which four nations signed it?
3. **MEDIUM** Name four ways a seal's body is equipped to dive long and deep.
4. **MEDIUM** An elephant seal dives for 25 minutes and rests at the surface for 2.5 minutes, around the clock. What fraction of a day is it underwater? About how many dives does it make in 24 hours?
5. **CHALLENGE** From the primary source, Melville gives two reasons sailors felt superstitious about seals. Name them, explain the real biology behind each, and say why Melville calls the faces "semi-intelligent." Is that fair?
6. **CHALLENGE** Pelagic sealing killed mostly females, while the land harvest took mostly young males. Explain why killing females at sea was far more damaging to the herd than taking the same number of young males on land. Then connect your answer to Proverbs 12:10.

Make it a game · Seal or Sea Lion?. The leader calls out a feature: "ear flaps," "wriggles on its belly," "walks on four flippers," "swims with back flippers," "barks," "tusks." Players answer by acting it out: clap like a sea lion's front flippers for sea lion, wriggle on the floor for true seal, hold two fingers down from the mouth like tusks for walrus. Wrong answers sit out a round.

Scripture. "A righteous man regardeth the life of his beast: but the tender mercies of the wicked are cruel." (Proverbs 12:10, KJV)

To "regard" the life of an animal is to pay attention to how it lives and what it needs. The rescue of the fur seals came when people regarded the herd's life, harvesting with care instead of taking every animal. That is the "keeping" God asked of Adam in Genesis 2:15.

Practice: answers

1. Any three: sea lions have ear flaps, true seals only ear holes; sea lions swim with long front flippers, true seals with hind flippers; sea lions turn hind flippers forward and walk on land, true seals wriggle on their bellies; sea lions bark loudly.
2. Pelagic sealing (hunting seals at sea). The United States, Great Britain (for Canada), Russia and Japan.

3. Any four: large blood volume with many red cells; a big spleen storing red cells; muscles rich in myoglobin; heart rate slows sharply (bradycardia); blood is directed to the brain and heart; breathes out and lets lungs collapse (avoiding the bends); low-energy gliding.
4. Each cycle is 27.5 minutes, of which 25 are underwater: $25 \div 27.5 \approx 91$ percent of the day.
 $1,440 \div 27.5 \approx 52$ dives.
5. Reasons: (1) their “peculiar tones when in distress” (cries that sound human, especially at night); (2) “the human look of their round heads” and faces rising from the water. Biology: seals and sea lions make loud, varied calls, and pups and mothers call to each other in voices that can sound like crying; their round heads, large forward-facing eyes and lack of ear flaps (in true seals) look strikingly human at a distance. “Semi-intelligent” is Melville’s way of saying they look as if they are thinking; it is fair in that seals are alert, curious and quick learners, though of course not human. Answers should separate the feeling from the fact.
6. Fur seal males mate with many females, so a herd can lose many young males with little effect on the number of pups born. Each female produces one pup a year, so every female killed means fewer pups for years to come; a nursing mother killed at sea also left her pup on shore to starve, so one death was really two. Pelagic sealing therefore cut the herd’s ability to replace itself. Proverbs 12:10 says the righteous regard the life of their beasts: a wise harvest considers how the animals live and breed, and takes only what the herd can replace, while greed takes whatever it can reach.

4.10 JONAH AND LEVIATHAN: THE GREAT FISH AND THE KING OF THE PROUD

OBJECTIVES

- Place Jonah in history (2 Kings 14:25) and geography (Joppa, Tarshish, Nineveh), and explain why the words “great fish” (Jonah) and “whale” (Matthew 12:40) do not contradict each other.
- Read Job 41 closely as a primary source and weigh fairly the main ways Christians have identified leviathan.
- Explain what Jesus taught by “the sign of the prophet Jonas,” and why the book of Jonah is finally about God’s mercy more than about a fish.

Warm-up. Write down the first thing you think of when you hear “Jonah.” Most people say “the whale.” But the fish appears in only three verses of the book’s forty-eight. As you read, keep a tally of what else the book is about.

Video slot. Video coming. The book of Jonah in its historical setting: Joppa, Tarshish, Nineveh and the Assyrian empire; Nineveh excavations; sperm whales and what large sea creatures can swallow. Search approved channels (The British Museum (Assyrian galleries), Answers in Genesis, Associates for Biblical Research, The Bible Project (preview for theology)); preview first.

KEY TERMS

Nineveh

A great city of the Assyrian empire on the Tigris River, across from modern Mosul in Iraq; later the empire’s capital, destroyed in 612 B.C.

Tarshish

A far-off seaport in the west, probably in Spain (perhaps the region the Greeks called Tartessos); Jonah sailed toward it to flee from God.

ketos

The Greek word used in Matthew 12:40 for Jonah’s sea creature, meaning a huge sea animal or sea monster; the KJV translates it “whale.”

leviathan

A great creature of the sea described in Job 41 and named in Job 3:8, Psalms 74:14 and 104:26, and Isaiah 27:1; from a Hebrew root meaning twisted or coiled.

type

A real person or event in the Old Testament that God used to point ahead to Christ. Jesus Himself made Jonah a type of His death and resurrection.

repentance

Turning away from sin to God, in mind, heart and action. The Ninevites repented, and so, in the end, must Jonah.

CORE IDEAS

A real prophet. The book of Jonah is not a fable about a talking whale but the account of a known prophet. 2 Kings 14:25 names Jonah the son of Amittai, a prophet from Gath-hepher, a town in Galilee, who prophesied in the reign of Jeroboam II of Israel (about 793–753 B.C.). In his day Assyria was a fierce and feared empire. God sent Jonah to cry against Nineveh, one of its great cities, about 500 miles northeast of Israel on the Tigris River. Instead, Jonah went down to the port of Joppa (modern Jaffa) and bought passage on a ship to Tarshish, probably in Spain, roughly 2,000 miles in the opposite direction, as far west as ships of that time commonly went.

The great fish. When a terrible storm came and the sailors learned that Jonah was fleeing from God, he told them to throw him into the sea, and the sea grew calm. “Now the LORD had prepared a great fish to swallow up Jonah” (Jonah 1:17). The Hebrew words are simply *dag gadol*, “great fish.” When Jesus spoke of it in Matthew 12:40, the Greek text used *ketos*, a general word for any huge sea creature, which the KJV translators rendered “whale.” Neither text names a species. Ancient people sorted sea creatures by size and habitat, not by modern classification, so “fish” and “whale” are both fair words for the same great creature.

Could it happen? People have long asked whether any animal could swallow a man whole. A sperm whale’s throat is wide enough: sperm whales swallow giant squid and large sharks whole. In 2021 a lobster diver off Cape Cod was briefly caught in the mouth of a feeding humpback whale and then spat out, bruised but alive, though a humpback’s throat is far too small to swallow a person. Stories sometimes told of a sailor named James Bartley swallowed by a whale in 1891 have been investigated and cannot be confirmed, so they should not be used as evidence. The honest answer is that the text does not ask us to find a natural explanation. The key word is “prepared”: the same Hebrew verb is used when God prepares a gourd, a worm and an east wind later in the book (Jonah 4:6–8). God appointed the creature, and Jonah’s survival for three days and nights was a miracle, as Jesus treated it.

The sign of Jonas. When some scribes and Pharisees asked Jesus for a sign, He answered that no sign would be given “but the sign of the prophet Jonas” (Matthew 12:39). As Jonah was three days and three nights in the creature’s belly, “so shall the Son of man be three days and three nights in the heart of the earth.” Jesus treated Jonah as history, and added that “the men of Nineveh” would rise in judgment, because they repented at Jonah’s preaching (Matthew 12:41). Jonah, swallowed by death and given back to life to preach to the nations, is a **type** of Christ’s death and resurrection.

What the book is really about. The fish brings Jonah back to his calling. He preaches in Nineveh, and from the king down, the Ninevites believe God, fast and turn from violence, and God spares the city. Jonah is furious: he had fled because he knew God was “gracious” and “merciful” and did not want his enemies forgiven (Jonah 4:2). The book ends with God’s

question to Jonah about His pity for the great city, its people and “also much cattle.” The book is about God’s mercy to the nations, and to an angry prophet, more than about a fish.

Leviathan. Job 41 is the longest description of any animal in the Bible. God asks Job whether he can catch leviathan with a hook, make a covenant with it or keep it as a pet for his girls, and then describes its armor-like scales, terrible teeth, fearsome breath and churning wake. Christians have identified it in several ways. Many commentators see the *crocodile*, the most dreadful animal of the ancient Near East, with its scaly hide and teeth (and the crocodile was a symbol of Egypt’s power). Others, following older English usage, think of a *whale*, and in modern Hebrew *livyatan* means whale. Some young-earth creationists suggest a great sea reptile now gone, perhaps like the marine reptiles found as fossils. Still others stress that Isaiah 27:1 calls leviathan “that crooked serpent” and uses it as a picture of evil powers God will destroy. The text does not settle the species; we should hold our identifications humbly.

The point of the poem. Whatever leviathan is, God’s purpose in describing it is plain. If Job cannot stand before a creature, how can he stand before its Creator? Job 41:10 asks exactly that: “who then is able to stand before me?” Leviathan is “a king over all the children of pride”; only God is King over leviathan. Job’s answer in chapter 42 is humility and repentance. The sea’s greatest creatures, from the great fish to leviathan, are in God’s hand and do His bidding, and the right response to them is awe and worship.

PICTURE STUDY



The Destruction of Leviathan, Gustave Doré, 1865 · Wood engraving · From *La Grande Bible de Tours* (the Doré Bible), illustrating Isaiah 27:1
Wikimedia Commons · Public domain

Gustave Doré (1832–1883) was the most famous book illustrator of the 1800s. His Bible of 1865, with more than 240 engravings, was printed in many languages and hung in countless

homes. This plate illustrates Isaiah 27:1, where the LORD “shall punish leviathan the piercing serpent, even leviathan that crooked serpent.” Doré drew leviathan as a vast sea dragon, which is his artistic choice, not a statement of what species it was.

Look closely

- Follow the coils of leviathan. How does Doré show its size and strength?
- Find the figure in the sky. Where does the light come from, and what is the effect?
- Look at the waves and clouds. How does Doré use black and white to create drama?

Talk about it

1. Doré pictured leviathan from Isaiah 27, a prophecy that uses it as an image of evil God will defeat. How is that different from Job 41, where God describes it as a creature He made? Can both be true at once?
2. Compare Doré’s leviathan with your own reading of Job 41 (the primary source). Which details did Doré use, and which did he add?

HANDS-ON: CLOSE READING: WHO CAN STAND BEFORE LEVIATHAN?

Read Job 41 as a primary source the way a careful scholar does: question by question, detail by detail, then weigh the identifications fairly and write a short essay.

You will need

- A KJV Bible (all of Job 38–42) and the primary source in this stop
- Three colored pencils or highlighters
- Field Notebook, with a page divided into four columns: “Crocodile,” “Whale,” “Great sea reptile,” “Symbol of evil”

Steps

1. Read Job 41:1–34 aloud. In the primary source excerpt, highlight in one color every question God asks. How many are there? What answer does each expect?
2. In a second color, highlight in the whole chapter every physical detail: scales (41:15–17), teeth (41:14), eyes (41:18), breath and smoke (41:19–21), neck (41:22), wake (41:32).
3. Put each physical detail in the column of each identification it fits. A detail may fit more than one column, or none.
4. In the third color, mark the verses that state God’s point (41:10–11, 34). Read Job’s reply in Job 42:1–6.
5. Write a five-paragraph essay: (1) the setting in Job; (2) the strongest case for the identification you think best; (3) the strongest case for another view, stated fairly; (4) what all views agree on; (5) what God teaches Job, and you, through leviathan.

Check your work

- I counted and listed God's questions in Job 41:1-7.
- My chart places at least eight details from the chapter.
- My essay states another view fairly and ends with God's purpose, not just the species.

FIELD NOTEBOOK

1. **Jonah's map.** Draw the eastern Mediterranean and Mesopotamia. Mark Gath-hepher, Joppa, the route toward Tarshish (arrow west), the Tigris River and Nineveh. Write the distance to Nineveh (about 500 miles) and toward Tarshish (about 2,000 miles).
2. **Narration (parent keeps).** Without looking at the text, write one well-built paragraph of eight to ten sentences retelling the book of Jonah from God's call to God's final question, and explain how Jesus used the story in Matthew 12. Date it and give it to a parent for the portfolio.

Did you know? Excavations at Nineveh since the 1840s by Austen Henry Layard and others uncovered the palace of Sennacherib, huge stone reliefs and the library of King Ashurbanipal, with tens of thousands of clay tablets, now largely in the British Museum. Nineveh's walls under Sennacherib ran about 7½ miles around. The site lies across the Tigris from modern Mosul; a mound there is still called Nebi Yunus, "the prophet Jonah."

Primary source. *Job 41:1-7 and 41:31-34, King James Version (1611). The LORD speaks to Job out of the whirlwind.*

Canst thou draw out leviathan with an hook? or his tongue with a cord which thou lettest down? Canst thou put an hook into his nose? or bore his jaw through with a thorn? Will he make many supplications unto thee? will he speak soft words unto thee? Will he make a covenant with thee? wilt thou take him for a servant for ever? Wilt thou play with him as with a bird? or wilt thou bind him for thy maidens? Shall the companions make a banquet of him? shall they part him among the merchants? Canst thou fill his skin with barbed irons? or his head with fish spears?

He maketh the deep to boil like a pot: he maketh the sea like a pot of ointment. He maketh a path to shine after him; one would think the deep to be hoary. Upon earth there is not his like, who is made without fear. He beholdeth all high things: he is a king over all the children of pride.

Go deeper. The British Museum's Assyrian galleries and online collection pages on Nineveh and the Ashurbanipal library. Answers in Genesis and the Institute for Creation Research articles on leviathan and on Jonah's great fish (to compare with a commentary that favors the crocodile, such as the notes in a good study Bible). Herman Melville, *Moby-Dick*, chapter 9, "The Sermon," Father Mapple's sermon on Jonah (Project Gutenberg eBook #2701). Second video topic: the excavation of Nineveh.

Goes deeper in. History, “The Assyrian Empire and the Prophets” (coming soon); Literature, “Reading the Bible as Literature” and Melville’s *Moby-Dick* (coming soon).

For families. The primary source is Job 41:1–7 and 31–34 (KJV), checked word for word; the Scripture is Matthew 12:40 (KJV). Jeroboam II’s dates are given as commonly reckoned (about 793–753 B.C.); scholars differ by a few years. Tarshish is probably in Spain, but other locations have been proposed. Distances are straight-line estimates. The Hebrew verb in Jonah 1:17 and 4:6–8 is *manah*, “appoint, prepare.” The 2021 Cape Cod humpback incident was widely reported (the diver was Michael Packard). The James Bartley story was examined by historian Edward B. Davis (1991), who found it unsupported. On leviathan, the stop presents four views without requiring one; families may teach their own conclusion. Doré’s engraving illustrates Isaiah 27:1; the Commons file is titled “Destruction of Leviathan.”

PRACTICE

1. **EASY** Where was God sending Jonah, and where did Jonah try to go instead?
2. **EASY** What verse outside the book of Jonah shows that Jonah was a real prophet, and what does it tell us?
3. **MEDIUM** Jonah says “great fish” and Matthew 12:40 (KJV) says “whale.” Explain why these do not contradict each other.
4. **MEDIUM** In the primary source (Job 41:1–7), how many questions does God ask? What answer does every one of them expect, and why?
5. **CHALLENGE** From the primary source, list four details of leviathan. For each, say whether it fits a crocodile, a whale, both, or neither. Which identification do the details favor overall? State one detail that is hard for each view.
6. **CHALLENGE** Jonah 4 ends with a question, not an answer. Write a short argument (four or five sentences) explaining what God’s final question is meant to teach Jonah, and how Jesus’ words about “the sign of the prophet Jonas” and the men of Nineveh (Matthew 12:39–41) apply that lesson to His own hearers.

Make it a game · Who Can Stand?. One player reads a question from Job 38–41 (for example, “Canst thou draw out leviathan with an hook?”). The others must answer honestly, “No, Lord,” and take one step back. Then a player reads a promise of God’s power or mercy (Job 42:2; Jonah 4:2; Matthew 12:40) and all take one step forward. End by reading Job 42:2 together. Talk about why God’s questions humble us and His promises draw us near.

Scripture. “For as Jonas was three days and three nights in the whale’s belly; so shall the Son of man be three days and three nights in the heart of the earth.” (Matthew 12:40, KJV)

“Jonas” is the Greek form of Jonah. Jesus took the most famous sea creature in the Bible and made it a sign of His own death and rising. The great fish was prepared by God to bring a

runaway prophet back; the cross and the empty tomb were prepared to bring the whole world back to God.

Practice: answers

1. To Nineveh, a great Assyrian city on the Tigris; he tried to sail from Joppa to Tarshish, far to the west.
2. 2 Kings 14:25. It names Jonah son of Amittai, from Gath-hepher, a prophet in the reign of Jeroboam II of Israel.
3. The Hebrew dag gadol means “great fish,” and the Greek ketos means any huge sea creature; neither names a species. Ancient languages grouped sea animals by size and habitat, not modern classification, so both words fairly describe the same great creature God prepared.
4. Fourteen questions, two in each verse. Every one expects the answer “No”: Job cannot catch, tame, bargain with, play with or sell leviathan. God is showing Job the limits of human power.
5. Sample: hook in nose and jaw (41:1-2): fits both; skin pierced with barbed irons and fish spears (41:7): fits both (harpoons for whales; spears for crocodiles); makes the deep boil like a pot (41:31): fits a large animal in water, perhaps better a whale; a path that shines after him, the deep looking hoary (41:32): a white, foaming wake, fits a whale well; “king over all the children of pride” (41:34): fits neither as biology, it is a statement about its place. Hard details: for the crocodile, the deep sea (“the deep ... the sea”) and its great wake; for the whale, the scales (41:15) and teeth (41:14, a crocodile’s are more fearsome); for a sea reptile, that we have no living example to compare; for a symbol only, that Job 41 describes it as a creature God made, alongside real animals in chapters 38-39. Any reasoned conclusion is acceptable.
6. Sample: Jonah pitied a plant that grew up overnight but was angry that God spared a city of people who had repented; God’s question shows that His mercy reaches even Israel’s enemies, and it asks Jonah, and every reader, to share that mercy. The book leaves the question open so that we must answer it ourselves. Jesus told those demanding a sign that Jonah’s three days and nights in the great fish pointed to His own death and resurrection. He added that the Ninevites, who repented at Jonah’s preaching, would condemn a generation that would not repent at the preaching of One greater than Jonah. The lesson is the same in both: God is merciful to all who turn to Him, and those who have heard most have the most reason to repent.

TRAIL 4 BADGE QUIZZES

The badge quizzes are optional. Students answer in writing, in complete sentences, with numbers where asked; a parent checks against the answers given. Four right out of five earns each badge. Badges and the certificate are earned by doing the stops and keeping the Field Notebook, not by scores.

Badge quiz 1 (Stops 1-5)

1. Name the shark sense that detects weak electric fields, explain when in a hunt it matters most, and say who first described the organs and when.
2. How does an octopus change color, and what is the honest open question about it?
3. State Darwin's explanation of atolls and the 1952 evidence that tested it.
4. Name three steps by which people came to know the giant squid, with dates.
5. Sound travels about 1,500 m/s in seawater. A dolphin's click echo returns in 0.02 second. How far away is the fish? Give two other facts showing a dolphin is a mammal.

Badge quiz 2 (Stops 6-10)

6. What is green fluorescent protein, where did it come from, and why does it matter?
7. What was the azoic hypothesis, and name two expeditions or dives that showed the deep sea is full of life.
8. Describe Hasler's experiment and what it showed about how salmon find home.
9. Why did pelagic sealing damage the Pribilof fur seal herd so badly, and what did the 1911 treaty do?
10. What did Jesus mean by "the sign of the prophet Jonas," and what is the main point of God's description of leviathan in Job 41?

TRAIL CERTIFICATE: MY OCEAN FIELD NOTEBOOK AND TRAIL D CERTIFICATE

Gather the Field Notebook pages from this trail into one booklet with a cover: "My Ocean Field Notebook," your name and the dates you started and finished. Put the ten narration paragraphs, each dated and kept by a parent, in order at the front.

Include at least three finished projects: for example, the shark-tracking map (D1), the Darwin slope calculation (D3), the deep-sea pressure column photograph (D7), the Walton fact-check (D8), the fur seal graph (D9) or the leviathan essay (D10).

Add a one-page "Primary Sources" summary listing each source you read on this trail, its author and date, one thing it got right and one thing modern study corrected or added.

When the booklet is complete, a parent signs the Trail D certificate.

- **Ten narrations:** A dated paragraph of eight to ten sentences for each stop, written without looking at the text, accurate and in the student's own words.
- **Projects and numbers:** At least three completed projects with calculations shown and units correct.

- **Reading sources:** The primary sources page fairly separates what each author observed, what was hearsay or interpretation, and what later study confirmed or corrected.
- **Stewardship and Scripture:** The student can explain, in writing or aloud, one example of wise stewardship of the sea and the meaning of Matthew 12:40 or Job 41.

Answer key

1. The ampullae of Lorenzini, jelly-filled pores on the snout. They matter at the very end of the hunt, at close range, when prey may be hidden in sand or too close to see. Stefano Lorenzini described them in 1678.
2. Muscles stretch open or close thousands of pigment sacs (chromatophores) in its skin, with reflecting cells beneath. Most octopuses seem to have only one type of light-sensing cell, which should make them colorblind, so scientists still do not know for sure how they match colors (possibly light-sensing skin or the shape of the pupil).
3. A fringing reef grows around a volcanic island; as the island slowly sinks, the coral keeps growing upward, becoming a barrier reef and finally an atoll when the island is gone. In 1952 drilling at Eniwetok passed through about 4,200 feet of reef limestone and reached volcanic basalt beneath, as the theory predicted.
4. Any three: Pontoppidan's kraken accounts (1750s); Steenstrup names *Architeuthis* (1857); the Newfoundland specimens and Moses Harvey's photographs (1873); first photographs of a live giant squid by Kubodera and Mori (2004); first video in its habitat (2012); Gulf of Mexico video (2019).
5. $1,500 \times 0.02 = 30$ m round trip, so the fish is 15 m away. Any two: breathes air through a blowhole; warm-blooded; bears live young; nurses with milk; has hair at birth; flukes move up and down.
6. A protein that glows green under blue or ultraviolet light, discovered by Osamu Shimomura and colleagues in the crystal jelly (*Aequorea victoria*) at Friday Harbor, Washington, reported in 1962. Scientists attach it to other proteins to watch them inside living cells (nerves, cancer, viruses). Shimomura, Chalfie and Tsien shared the 2008 Nobel Prize in Chemistry.
7. Edward Forbes's idea (1840s) that no animals lived below about 300 fathoms. Any two: animals on a deep Mediterranean cable (1860); HMS Challenger (1872–1876); Beebe and Barton's bathysphere (1934); the Trieste (1960); Alvin's discovery of hydrothermal vent communities (1977); MBARI's filming of the black seadevil (2014).
8. Returning coho salmon caught at two branches of a creek were released downstream, half with their noses plugged. Fish with open noses mostly returned to their own branch; plugged fish chose at random. Salmon use smell, imprinted when young, to find their home stream (and other studies show they use the magnetic field at sea).
9. Seals killed at sea were mostly females, often nursing mothers, so each death also killed a pup and cut future births; the herd fell from about 3 million to perhaps 200,000. The North Pacific Fur Seal Convention of July 7, 1911 (United States, Great Britain, Russia, Japan) banned pelagic sealing and shared a managed land harvest, and the herd recovered.
10. As Jonah was three days and three nights in the great fish, Jesus would be three days and three nights in the heart of the earth and rise again (Matthew 12:40); Jonah is a type of Christ's death and resurrection. In Job 41, God shows that Job cannot master even a creature, so he cannot stand before its Creator; the lesson is humility and worship.

ANIMALS TRAIL E: INSECTS AND SMALL CREATURES

The fifth trail of the Animals track gets down on hands and knees with the small creatures: the ant of Proverbs 6:6, the honeybee and its dance, the monarch butterfly's migration to Mexico, spiders and their silk, the beetles in their hundreds of thousands of kinds, fireflies and their cold light, dragonflies, the locusts of Exodus 10, Jean-Henri Fabre the patient insect watcher, and a bee hotel to build and keep. Each stop has a reading with real numbers and honest questions, a picture study, a hands-on project or field experiment, a narration, practice problems, a game and a passage of Scripture.

This is the  **Expert** level, written for students about 14 and up, at a high-school level. Each stop takes 35 to 50 minutes and is done mostly on the student's own. Read the core ideas, study the picture, carry out the project (several are true experiments with a hypothesis, data and a graph), write the narration paragraph for a parent to keep, and work the practice problems, including at least two challenge problems. Most stops include a primary source copied exactly from the King James Bible or a public-domain book: Langstroth on the hive (1853), Darwin on beetle collecting, and Fabre on the glow-worm and his harmas. The trail is creation-friendly: insects are God's handiwork, made "after his kind," and their design is studied with wonder and care. Where scientists disagree or do not yet know, the stop says so.

Five stops earn the **Small Creatures Expert badge, part 1**, and ten stops earn part 2 and the **Trail E certificate**. The two badge quizzes are at the end of the trail and are optional; the certificate is earned by doing the stops and keeping the Field Notebook.

BEFORE YOU BEGIN

- Read a page of nonfiction with care and write a paragraph summarizing it in your own words.
- Work with percentages, ratios, area and simple squares and cubes; record data in a table and draw a line graph with labeled axes.

MASTERY CHECKLIST

- ☐ I can tell an insect from a spider and explain complete and incomplete metamorphosis with examples from this trail.
- ☐ I can explain, with numbers, how ants, honeybees and locusts act together without a ruler (pheromone trails, the waggle dance, crowding and serotonin).
- ☐ I can explain how a firefly makes cold light, how a monarch steers by the sun, and how a dragonfly intercepts its prey.
- ☐ I can read a primary source on insects closely, quote it accurately and connect it to what scientists know today.
- ☐ I can design a fair experiment or field survey with small creatures, record and graph the results, and treat the animals with care.

OPTIONAL BOOKS AND RESOURCES

- **BugGuide (Iowa State University)** (<https://bugguide.net>): Free identification guide with photographs of insects and spiders of the United States and Canada; useful for the beetle survey, the web project and the bee hotel record.
- **Monarch Watch (University of Kansas)** (<https://monarchwatch.org>): Migration maps, tagging programs and milkweed guidance for Stop E3.
- **Xerces Society** (<https://xerces.org>): Free guides to native bees, nesting sites and pollinator gardens for Stops E2 and E10.
- **Project Gutenberg** (<https://www.gutenberg.org>): Free full texts of Fabre's insect books, Langstroth's 1853 bee manual and Bates's *The Naturalist on the River Amazons*.
- **Biodiversity Heritage Library** (<https://www.biodiversitylibrary.org>): Old natural history books and plates, including Maria Sibylla Merian's 1705 Surinam insects and Moggridge's *Harvesting Ants and Trap-Door Spiders*.

5.1 ANTS: “GO TO THE ANT, THOU SLUGGARD” (PROVERBS 6:6)

OBJECTIVES

- Explain how an ant colony divides its work and coordinates thousands of workers with no commander, using pheromone trails as the main example.
- Use the square-cube law to explain why ants can lift many times their own weight and why a giant ant could not.
- Read Proverbs 6:6-8 and 30:25 closely, and tell how harvester ants answered the naturalists who once said Solomon was wrong.

Warm-up. Put one drop of honey or sugar water on an index card and set it near an ant trail outside (or on a kitchen windowsill where ants visit). Note the time. How many minutes until the first ant finds it? How many ants are there ten minutes later? Keep your numbers for the project.

Video slot. Video coming. Ant colonies: leafcutter ants farming fungus, harvester ants storing seed, ants following pheromone trails. Search approved channels (Smithsonian, National Geographic, BBC Earth, Deep Look from KQED, a university entomology department); preview first.

KEY TERMS

colony

A family of social insects living together, usually one or a few egg-laying queens with their worker daughters and, at certain seasons, males.

caste

A group within a colony with a particular body form or job: queen, worker, soldier or male.

pheromone

A chemical signal one animal releases that changes the behavior of others of its kind, such as a trail scent that says “food this way.”

harvester ant

An ant that gathers and stores seeds in underground granaries, such as the Messor ants of Israel and the Mediterranean.

square-cube law

When an object grows larger, its surface and cross-sections grow with the square of its length, but its volume and weight grow with the cube.

sluggard

The KJV’s word for a lazy person who will not work or plan ahead.

CORE IDEAS

“Having no guide.” Solomon sends the lazy man to school with a teacher only a quarter of an inch long: “Go to the ant, thou sluggard; consider her ways, and be wise: Which having no guide, overseer, or ruler, Provideth her meat in the summer” (Proverbs 6:6–8). For centuries people assumed the large ant in the nest must be a king or queen who gave orders. Careful study has shown that Solomon’s phrase is exact. The queen is the colony’s mother, not its commander. She lays eggs, sometimes for many years; one black garden ant queen kept in a laboratory lived almost thirty. No ant gives orders to the others, yet the nest is built, the young are fed and the food is gathered.

How the work is divided. Nearly all the ants you see are workers, and every worker is a female that does not lay eggs in a normal colony. Males appear only for a short season to fly out and mate. In many species a worker’s job changes with her age: young workers stay deep inside to nurse eggs and larvae, middle-aged workers dig and clean, and the oldest go outside to forage, the most dangerous work. Some species have soldiers with huge heads and jaws. No one assigns these jobs; each ant responds to what she meets, such as hungry larvae, a blocked tunnel or a returning sister carrying food.

Talking with chemicals. Ants “speak” mostly by smell. A forager who finds food drags her abdomen on the way home and leaves a trail pheromone. Other workers follow it, and if they also find food, they lay more scent. A rich source soon has a strong trail and a crowd; a poor one fades because the scent evaporates. In a famous 1990 experiment, Belgian scientists gave Argentine ants two bridges of different lengths to the same food. At first the ants used both, but ants on the short bridge returned sooner, the scent there built up faster, and soon nearly the whole colony used the short path. Simple rules, followed by thousands, give a wise result. Engineers now copy this idea, called *ant colony optimization*, to plan delivery routes and phone networks.

The numbers. About 14,000 to 15,000 ant species have been named, and more are found every year. In 2022 a team of researchers estimated that about 20 quadrillion (20,000,000,000,000,000) ants are alive at once, roughly 2.5 million for every person on earth. Their total dry weight is estimated at about one-fifth of the weight of all human beings. Estimates like this are built from thousands of local counts and have wide error bars, but every method agrees that ants are among the most common animals on land. They turn and air the soil more than earthworms do in many dry places, spread the seeds of many plants and clean up dead insects.

Was Solomon wrong about the harvest? Proverbs 6:8 says the ant “gathereth her food in the harvest,” and Proverbs 30:25 says ants “prepare their meat in the summer.” Several naturalists of the 1700s and early 1800s, who studied only the ants of northern Europe, concluded that ants do not store grain and that Solomon and Aesop had repeated a fable. Then in 1871 and 1872 the English naturalist J. Traherne Moggridge, wintering at Menton on the French Riviera, dug into the nests of harvester ants and found chambers packed with seeds. He watched columns of workers carrying seeds home and dumping the husks outside. His book *Harvesting Ants and Trap-Door Spiders* (1873) settled the matter. The harvester

ants of Israel do exactly what Proverbs says, gathering grain at harvest time and storing it underground in dry chambers where most of it does not sprout. The lesson: test every claim, including claims against Scripture, by careful observation.

Strength and size. Many ants can lift ten to fifty times their own weight, and some have been measured holding far more with their jaws. This is real, but it is not because ants are “super-strong.” A muscle’s force depends on its cross-section, which grows with the square of an animal’s length, while weight grows with the cube. Shrink an animal and its weight falls faster than its strength, so small creatures are strong for their size. A movie ant the size of a horse would collapse under its own weight and could not breathe through its tiny air tubes. God fitted the ant’s design to the ant’s size.

The lesson of the ant. Solomon was not teaching biology for its own sake. The ant works without a foreman watching, prepares in summer for winter, and stays at the task. The sluggard does none of these. Proverbs 30:25 adds that ants “are a people not strong,” yet wise: they win by diligence and foresight, not by size. A student who keeps a schedule with no one checking is doing what the ant does.

PICTURE STUDY



The Ants & the Grasshopper, from *The Aesop for Children*, Milo Winter, 1919 · Color book illustration · From *The Aesop for Children* (Chicago: Rand McNally, 1919); digitized by the Library of Congress and Project Gutenberg
Wikimedia Commons · Public domain

Aesop’s fable of the ants and the grasshopper is more than 2,000 years old: the grasshopper sings all summer, and in winter the ants, who worked and stored food, will not feed him. Milo Winter illustrated it for one of the best-loved American Aesop books. His picture shows the harvest, before winter comes: the grasshopper fiddles while the ants work. The fable and Proverbs teach the same lesson, but the fable is a story and the proverb is a command.

Look closely

- Find the grasshopper. How does Winter show that he is carefree rather than working?
- Look at the ants. What are they carrying, and how does the artist make them look busy and orderly?
- What season does the picture show? Find two clues, and say what will happen to the grasshopper when the season changes.

Talk about it

1. Real grasshoppers do not wear scarves or play fiddles, and real harvester ants gather seeds by instinct, not by planning. What does the artist gain, and what does he lose, by making the insects act like people?
2. The fable's ants refuse to share. Proverbs praises the ant's diligence but elsewhere also praises generosity (Proverbs 11:25). How would you add both lessons to the story?

HANDS-ON: ANT TRAIL EXPERIMENT: RECRUITMENT AND THE SCENT TRAIL

Measure how fast ants recruit their sisters to food, compare foods, and test the scent trail. This is a real experiment: write a hypothesis first and keep careful numbers.

You will need

- Three index cards and a timer or watch
- Three baits: a drop of honey or sugar water, a pea-sized dab of peanut butter (skip if anyone has a nut allergy) and a crumb of cooked egg or tuna
- A damp cloth or paper towel
- Graph paper, a pencil and a magnifying glass

Steps

1. Find an active ant trail on a sidewalk, patio or windowsill. Write a hypothesis: which bait will gather the most ants in 20 minutes, and why?
2. Set the three baited cards in a row about 12 inches (30 cm) from the trail and the same distance from each other. Start the timer.
3. Every 2 minutes for 20 minutes, count the ants on each card. Record the numbers in a table with columns for time and each bait.
4. When a strong line of ants forms to one card, gently wipe a band across the trail with the damp cloth, about 4 inches wide. Watch the ants that reach the wiped band. Write what they do for two minutes.
5. Graph your counts: time on the bottom axis, number of ants up the side, one line per bait. Describe the shape of each line (slow start? steep rise? leveling off?).
6. Read the primary source again. Write two sentences connecting what you saw to the words "having no guide, overseer, or ruler."

Check your work

- I wrote a hypothesis before I began.
- My table has eleven rows of counts (0 to 20 minutes) for three baits.
- My graph has a title, labeled axes and a key.
- I described what happened when the trail was wiped and explained it with the word pheromone.

FIELD NOTEBOOK

1. **Field Notebook page E1.** Draw a worker ant from above, at least 4 inches long, from a real ant under a magnifying glass or a good photograph. Label the head, antennae, mandibles, thorax, petiole (the narrow “waist”), abdomen and six legs.
2. **Narration (parent keeps).** Write one paragraph of eight to ten sentences explaining how an ant colony gets its work done without a ruler. Include at least one number from the stop and end with what Proverbs 6:6–8 asks of you.

Did you know? Leafcutter ants of the Americas do not eat the leaves they carry. They chew them into a mulch and grow a fungus garden on it, and the fungus is their food. A large leafcutter nest may hold several million workers and move tons of soil. When a young queen leaves to start a new colony, she carries a tiny pellet of the fungus in a pouch in her mouth, like a farmer bringing seed to a new field.

Primary source. *Proverbs 6:6–8 and 30:24–25, King James Version (1611)*

Go to the ant, thou sluggard; consider her ways, and be wise: Which having no guide, overseer, or ruler, Provideth her meat in the summer, and gathereth her food in the harvest. ...

There be four things which are little upon the earth, but they are exceeding wise: The ants are a people not strong, yet they prepare their meat in the summer;

Go deeper. J. Traherne Moggridge, *Harvesting Ants and Trap-Door Spiders* (1873; free at the Biodiversity Heritage Library). Bert Hölldobler and E. O. Wilson, *Journey to the Ants* (1994), a readable tour by two leading ant scientists (it assumes an evolutionary framework; read the observations and weigh the interpretations). Anna Botsford Comstock, *Handbook of Nature Study* (1911; free online), the lessons on ants and the ant nest. Second video topic: harvester ant granaries, or Argentine ants choosing the shortest path.

Goes deeper in. Life Science, high-school Biology unit “Insects and Other Arthropods,” and Gardening & Animals, “Insects in the Garden” (coming soon).

For families. Species counts come from AntWiki and vary as species are named. The 20-quadrillion estimate is Schultheiss et al., *PNAS* (2022); the authors give a wide range. The two-bridge experiment is Goss, Deneubourg and colleagues (1989–1990). The queen longevity record is a laboratory *Lasius niger* queen (about 28–29 years, reported by Kutter and Stumper). Which earlier naturalists doubted ant harvesting is told in

Moggridge's own introduction; the stop keeps the claim general. Lifting figures vary greatly by species and by how they are measured. Check the warm-up and project ants are not fire ants, which sting; observe from a short distance with no bare hands near the trail.

PRACTICE

1. **EASY** According to Proverbs 6:7, what three kinds of leader does the ant lack? Is the queen ant one of them?
2. **EASY** What is a pheromone trail, and why does the trail to a poor food source fade?
3. **MEDIUM** If about 20 quadrillion ants (20,000,000,000,000,000) are alive and about 8 billion people (8,000,000,000), how many ants are there per person?
4. **MEDIUM** What did J. Traherne Moggridge find near Menton, and what claim did it overturn?
5. **CHALLENGE** An ant 1 cm long is scaled up 200 times to 2 meters long, keeping the same shape. By what factor does its strength (muscle cross-section) grow? Its weight? What happens to its strength compared with its weight?
6. **CHALLENGE** In the two-bridge experiment, explain step by step why nearly all the ants end up on the shorter bridge, even though no ant compares the two bridges.

Make it a game • Pheromone Trail. Hide five “food” cards around a room or yard. One player (the scout) finds a card and walks back to the “nest,” dropping a paper scrap every few steps. Other players may only follow scraps, never search on their own. Each player who reaches food drops scraps on the way back too; a leader picks up one scrap from every trail each minute (evaporation). Which food sources end up with the most traffic, and why?

Scripture. “Go to the ant, thou sluggard; consider her ways, and be wise: Which having no guide, overseer, or ruler, Provideth her meat in the summer, and gathereth her food in the harvest.” (Proverbs 6:6–8, KJV)

“Consider her ways” is an invitation to observe, which is the heart of natural science. The ant works without being watched and prepares ahead. Diligence does not need a supervisor; it needs a conscience before God.

Practice: answers

1. A guide, an overseer and a ruler. No: the queen lays eggs but does not give orders; workers respond to signals and to what they meet.
2. A scent path laid by foragers returning with food. The scent evaporates; if few ants find food there, few renew the trail, so it fades.
3. $20,000,000,000,000,000 \div 8,000,000,000 = 2,500,000$, about 2.5 million ants per person.
4. Harvester ant nests with chambers full of stored seeds, and workers carrying seed home and dumping husks. It overturned the claim that ants never store grain and that Proverbs and Aesop were mistaken.

5. Strength grows by $200^2 = 40,000$. Weight grows by $200^3 = 8,000,000$. Strength relative to weight falls by $8,000,000 \div 40,000 = 200$ times. An ant that could lift 20 times its weight would now be able to lift only about 1/10 of its own weight, so it could hardly stand.
6. At first ants pick both bridges about equally and lay scent. Ants on the short bridge reach the food and return sooner, so the short bridge gets fresh scent sooner and more often. Newly arriving ants choose the stronger scent, lay still more, and the difference grows (positive feedback) while scent on the long bridge evaporates. The colony “chooses” the short path though no single ant knows it is shorter.

5.2 HONEYBEES: THE HIVE, THE HEXAGON AND THE DANCE

OBJECTIVES

- Describe the castes and age-based jobs of a honeybee colony and the steps by which nectar becomes honey.
- Explain how the waggle dance gives direction and distance, and why the hexagon is the most economical shape for comb.
- Read Langstroth’s 1853 account of the movable frame and explain why “bee space” changed beekeeping.

Warm-up. Taste a spoonful of honey, then read the label. Where was it made? Now guess: how many flowers did bees visit to make one pound? How many miles did they fly? Write your guesses down; the answers are in the stop.

Video slot. Video coming. Honeybee waggle dance on the comb; a beekeeper opening a Langstroth hive; bees drawing wax comb. Search approved channels (USDA Agricultural Research Service, a university extension service or bee lab such as Cornell or Penn State, Smithsonian, BBC Earth); preview first.

KEY TERMS

worker, queen and drone

The three kinds of honeybee: sterile female workers that do all the labor, one egg-laying queen, and male drones whose only task is to mate with a queen from another colony.

comb

Sheets of six-sided wax cells built by workers to raise young and store honey and pollen.

waggle dance

A figure-eight run a forager makes on the comb. The angle of the straight “waggle” run from vertical shows the food’s direction from the sun, and its length shows the distance.

bee space

A gap of about a quarter to three-eighths of an inch (6–9 mm) that bees leave open as a walkway. Smaller gaps they seal; larger ones they fill with comb.

pollination

Carrying pollen from flower to flower so that plants can make seeds and fruit.

propolis

“Bee glue,” a sticky resin bees collect from tree buds and use to seal cracks in the hive.

CORE IDEAS

One household. A strong honeybee colony in summer holds 20,000 to 60,000 bees, nearly all of them female workers, with one queen and a few hundred to a few thousand drones. The queen may lay up to about 1,500 eggs a day at the height of the season. A summer

worker lives only about five or six weeks, but she works through a series of jobs as she ages: cleaning cells, feeding larvae, making wax from glands on her underside, building comb, receiving nectar, guarding the entrance, and, in her last two or three weeks, flying out to forage. Workers raised in late autumn live for months, clustering through the winter to keep the queen warm by shivering their flight muscles.

From nectar to honey. Nectar is mostly water, often 70 to 80 percent. Foragers carry it home in a honey stomach, and house bees add an enzyme (invertase) that splits table sugar into simpler sugars. They spread it in cells and fan it with their wings until the water falls to about 17 or 18 percent; then they cap the cell with wax. Honey that dry will not spoil. The National Honey Board estimates that to make one pound of honey, bees visit about 2 million flowers and fly about 55,000 miles; one worker makes only about a twelfth of a teaspoon in her lifetime. A spoonful on your toast is the life's work of a dozen bees.

The hexagon. Around A.D. 300, the Greek mathematician Pappus of Alexandria praised the bees for a kind of "geometrical forethought." Only three regular shapes tile a flat surface with no gaps: triangles, squares and hexagons. Of these, the hexagon encloses a given area with the shortest wall, and wax is costly; bees must eat several pounds of honey to make one pound of wax. In 1999 the mathematician Thomas Hales finally proved the "honeycomb conjecture": no way of dividing a plane into equal areas uses less total wall than the regular hexagon. Scientists still debate how bees achieve it. Some argue that cells start round and warm wax is pulled into hexagons by its own surface tension; others have shown bees measuring and shaping walls with their heads and legs. Either way, the result is a structure engineers copy for aircraft panels.

The dance language. The Austrian scientist Karl von Frisch spent decades watching marked bees at glass-walled hives. He showed that a successful forager tells her sisters where food is by dancing on the vertical comb in the dark. For food close by she makes a simple round dance. For food farther away she makes the waggle dance: a straight run, shaking her abdomen, then a loop back. The angle of the straight run from straight up equals the angle of the food from the sun's direction; the longer the waggle run, the farther the food. Von Frisch shared the Nobel Prize in 1973. Later scientists tested his claim with robot bees and radar tracking, and it held.

Choosing a home. When a colony grows crowded, the old queen leaves with about half the workers in a swarm, which hangs in a cluster on a branch. A few hundred scouts search for a hollow tree, and each dances for the site she found. Thomas Seeley of Cornell showed that scouts for a better site dance longer and more often, and that the swarm moves when enough scouts gather at one site. The bees prefer a cavity of about 40 liters, high off the ground with a small entrance facing south. A beekeeper who wants to catch swarms builds a box to those measurements.

The minister's frame. For thousands of years most honey was taken by cutting comb from straw skeps or hollow logs, often killing the colony. The Rev. Lorenzo L. Langstroth, a Congregational minister in Philadelphia whose poor health had driven him from the pulpit, studied bees for relief. In 1851 he noticed that bees always left a passage of about three-

eighths of an inch between comb surfaces. If wooden frames hung in a box with exactly that space around them, the bees would neither glue them down nor build comb across the gap. He patented the movable-frame hive on October 5, 1852, and described it in his book the next year. Nearly every modern hive uses his principle.

Stewardship. Honeybees are not native to the Americas; English settlers brought them in the 1600s. Today managed colonies pollinate almonds, apples, blueberries, melons and many other crops, while thousands of native bee species pollinate wild plants (Stop E10). Beekeepers fight mites, viruses and poor winters, and losses vary greatly from year to year. Scripture speaks of honey as a gift: the promised land flowed “with milk and honey,” and David said God’s judgments are “sweeter also than honey and the honeycomb” (Psalm 19:10).

PICTURE STUDY



The Beekeepers, Pieter Bruegel the Elder, About 1568 · Pen and brown ink on paper · Kupferstichkabinett (Museum of Prints and Drawings), Staatliche Museen zu Berlin
Wikimedia Commons · Public domain

Pieter Bruegel the Elder painted the farm life of the Low Countries (today Belgium and the Netherlands). In this late drawing, three beekeepers in thick clothing and woven face-baskets carry straw skeps, the hives of his day. A boy watches from a tree. Notice that no beekeeper shows a face: Bruegel turns them into strange, faceless workers, almost like the bees themselves.

Look closely

- Find the skeps. How do you think the beekeepers took honey out of a skep with no movable frames?
- Look at the clothing and masks. Which parts of the body are protected, and why?

- Find the boy in the tree. What might he be doing or watching for?

Talk about it

1. Compare a straw skep with Langstroth's hive from the primary source. What could Langstroth's beekeeper do that Bruegel's could not?
2. A Flemish proverb is written on the drawing: roughly, "he who knows where the nest is has the knowledge; he who robs it has the nest." What might Bruegel be saying about knowledge and possession?

Safety first. Honeybees sting to defend the hive. Watch hives only with a beekeeper, stand to the side of the entrance, move slowly and wear light-colored clothes. Anyone with a known bee-sting allergy should not take part near hives, and every family should know the signs of a serious reaction (swelling of the face or throat, trouble breathing) and call 911 if they appear.

HANDS-ON: DANCE THE WAY TO THE FLOWERS

Find a real patch of flowers, measure its direction and distance, and "dance" it for your family to decode, the way a forager would. Then draw a cross-section of Langstroth's hive from the primary source.

You will need

- A compass (or a phone compass) and a notebook
- A large sheet of cardboard propped upright (the "comb") and a marker
- A protractor and a timer
- The primary source in this stop

Steps

1. Go outside in the morning or afternoon. Note the sun's direction with the compass (do not look at the sun). Choose a flowering bush or patch 30 to 200 steps away. Measure its direction and count your steps to it.
2. Find the angle between the sun's direction and the flower patch, measured clockwise. Example: sun in the southeast (135°), flowers due south (180°): the angle is 45° to the right.
3. On the upright cardboard, "straight up" stands for the sun. Draw the waggle run at your angle from vertical. Use a scale: one second of wagging for every 20 steps of distance.
4. Perform the dance with your finger on the board, wagging along the line for the right number of seconds, looping back each time. A family member uses the compass and protractor to find the patch.
5. Read the Langstroth primary source. Draw a cross-section of a hive box showing three frames hanging from the top, each surrounded by a bee space of 3/8 inch. Label it with his words "so as to touch neither the top, bottom, nor sides."

Check your work

- I measured the sun's direction, the flower patch's direction and its distance.
- My dance used the right angle from vertical and the right length of waggle.
- Someone decoded my dance and found the flowers (or came close).
- My hive drawing shows movable frames and the bee space.

FIELD NOTEBOOK

1. **Field Notebook page E2.** Draw a worker, a queen and a drone side by side at the same scale. Label the differences: the queen's long abdomen, the drone's huge eyes and blunt body, the worker's pollen baskets on her hind legs.
2. **Narration (parent keeps).** Write one paragraph telling the life of a single summer worker bee from the day she emerges to her last foraging flight. Include at least four jobs she does and two numbers from the stop.

Did you know? A worker bee beats her wings about 200 to 230 times a second, which makes the buzz. Honey found sealed in ancient Egyptian tombs has been reported still edible after thousands of years, because honey is too sugary and dry for most microbes to grow. And bees can be trained: von Frisch taught them to visit blue cards, which proved they see color, and later scientists showed they see ultraviolet patterns on flowers that are invisible to us.

Primary source. Rev. L. L. Langstroth, *Langstroth on the Hive and the Honey-Bee, A Bee Keeper's Manual* (Northampton: Hopkins, Bridgman & Company, 1853), Project Gutenberg. *Italics are Langstroth's.*

I perceived, however, that one thing was *yet* wanting. The *cutting* of the combs from their attachments to the *sides* of the hive, in order to remove them, was attended with much loss of *time* to myself and to the bees, and in order to *facilitate* this operation, the construction of my hive was necessarily *complicated*. This led me to invent a method by which the combs were attached to MOVABLE FRAMES, and suspended in the hives, *so as to touch neither the top, bottom, nor sides*. By this device, I was able to remove the combs at pleasure, and if desired, I could speedily transfer them, bees and all, *without any cutting*, to another hive. I have experimented largely with hives of this construction, and find that they answer most admirably, all the ends proposed in their invention.

Go deeper. Karl von Frisch, *The Dancing Bees* (English edition 1954), the classic account by the man who decoded the dance. Thomas D. Seeley, *Honeybee Democracy* (2010), on how swarms choose a home. Langstroth's full 1853 book is free at Project Gutenberg. A local beekeepers' association or county extension office often welcomes young visitors to an open-hive day. Second video topic: a swarm choosing a new home.

Goes deeper in. Gardening & Animals, “Beekeeping and Pollinators”; Arithmetic or high-school Geometry, tiling and the hexagon; and Small Business & Economics, “Selling Honey” (coming soon).

For families. Colony sizes, egg-laying rates and life spans vary by season and source; the stop uses common extension-service figures. The flowers-and-miles figures for a pound of honey are National Honey Board estimates. Pappus’s remarks are in Book V of his *Collection*; Hales’s proof was published in 2001 (announced 1999). The wax-forming debate is real (e.g., Karihaloo and colleagues, 2013, versus studies of active shaping). The Bruegel drawing is often dated about 1567–1568; the proverb inscription is translated loosely. The 1853 title page reads “Rev. L. L. Langstroth.” The Egyptian-honey claim is widely repeated but hard to verify in detail; it is given as “reported.” See the safety note before visiting any hive.

PRACTICE

1. **EASY** Name the three kinds of honeybee in a colony and the main job of each.
2. **EASY** In the primary source, what problem with his earlier hive did Langstroth want to solve?
3. **MEDIUM** Nectar is about 75% water and finished honey about 18% water. Starting with 100 grams of nectar, how many grams of honey result? (Hint: the sugar does not change.)
4. **MEDIUM** A forager’s waggle run points 60° to the left of straight up. The sun is in the south (180°). In what compass direction is the food?
5. **CHALLENGE** Find the perimeter of a square, an equilateral triangle and a regular hexagon that each have an area of 1 square centimeter. (Triangle area = $(\sqrt{3}/4)s^2$; hexagon area = $(3\sqrt{3}/2)s^2$.) Which uses the least wall?
6. **CHALLENGE** Using the primary source and the idea of bee space, explain why Langstroth’s frames had to hang “so as to touch neither the top, bottom, nor sides,” and what would happen if the gap were too small or too large.

Make it a game • Waggle Charades. Hide a “flower” (a paper flower or a spoon of honey in a covered cup) somewhere in the house or yard. The dancer, who knows where it is, may not speak or point; she or he may only do a waggle dance on a wall, with “up” meaning the direction of a lamp or window chosen as the “sun.” The first forager to find the flower dances next.

Scripture. “More to be desired are they than gold, yea, than much fine gold: sweeter also than honey and the honeycomb.” (Psalm 19:10, KJV)

David is speaking of “the judgments of the LORD” (verse 9). Honey from the comb was the sweetest thing he knew, the fruit of thousands of tiny lives of work. God’s word is sweeter still, and like honey it keeps.

Practice: answers

1. Workers (sterile females) do all the work: nursing, building, guarding, foraging. The queen lays eggs. Drones (males) mate with queens from other colonies.
2. The combs had to be cut from the sides of the hive to remove them, which wasted time for him and the bees and made the hive complicated.
3. Sugar = 25 g. In honey, sugar is 82%, so honey = $25 \div 0.82 \approx 30.5$ g. About 100 g of nectar makes about 30 g of honey.
4. 60° to the left (counterclockwise) of the sun's direction: $180^\circ - 60^\circ = 120^\circ$, which is east-southeast.
5. Square: $s = 1$, perimeter 4.00 cm. Triangle: $s^2 = 4/\sqrt{3} \approx 2.309$, $s \approx 1.520$, perimeter ≈ 4.56 cm. Hexagon: $s^2 = 2/(3\sqrt{3}) \approx 0.385$, $s \approx 0.620$, perimeter ≈ 3.72 cm. The hexagon uses the least wall, about 7% less than the square and 18% less than the triangle.
6. Bees seal gaps smaller than bee space with propolis, gluing the frame in place, and fill gaps larger than bee space with comb, attaching the frame to the box. Only a gap of about 1/4 to 3/8 inch stays open as a walkway. Frames hanging with that gap on every side stay free, so the beekeeper can lift them out "at pleasure... without any cutting," inspect the brood and take honey without destroying the colony.

5.3 MONARCH BUTTERFLIES: THE LONG ROAD TO THE MOUNTAINS OF MEXICO

OBJECTIVES

- Trace the monarch’s complete metamorphosis and explain how milkweed chemistry protects it.
- Describe the multigenerational migration of eastern monarchs, the “super generation,” and how the winter sites in Mexico were found in 1975.
- Explain the time-compensated sun compass and name what scientists still do not know about monarch navigation.

Warm-up. Get a map of North America and a ruler. Put one finger on Toronto, Canada, and one on Mexico City. Using the scale bar, how far apart are they? A monarch butterfly weighing about half a gram flies that far every autumn, to a place it has never been.

Video slot. Video coming. Monarch butterfly metamorphosis (caterpillar to chrysalis to adult) and the overwintering colonies in the oyamel forests of Michoacán, Mexico. Search approved channels (U.S. Forest Service “Monarch Butterfly” pages, U.S. Fish and Wildlife Service, Monarch Watch, Smithsonian, PBS Nature, BBC Earth); preview first.

KEY TERMS

complete metamorphosis

A life cycle with four very different stages: egg, larva (caterpillar), pupa (chrysalis) and adult.

chrysalis

The hard case of a butterfly pupa, inside which the caterpillar’s body is rebuilt into the adult.

cardenolides

Bitter heart poisons in milkweed sap. Monarch caterpillars store them, which makes both caterpillars and adults distasteful or sickening to birds.

super generation

The late-summer generation of monarchs that does not breed right away, flies south, and lives up to about eight months instead of a few weeks.

mimicry

When one kind of animal resembles another; for example, the viceroy butterfly looks much like the monarch.

sun compass

A way of steering by the sun’s position, corrected for the time of day by an internal clock.

CORE IDEAS

Four lives in one. A monarch female lays her eggs one at a time, usually on the underside of a milkweed leaf, and only on milkweed. In three to five days a tiny caterpillar hatches, eats its eggshell and begins to eat leaves. Over about two weeks it sheds its skin four times and grows to roughly 2,000 times its hatching weight. Then it hangs head-down in a “J,” splits its skin one last time and reveals a jade-green chrysalis dotted with gold. Inside, most of the caterpillar’s body breaks down, and clusters of cells that were waiting since the egg build wings, long legs, antennae and a coiled drinking tube. After about ten days to two weeks, an adult emerges, pumps fluid into its crumpled wings and flies within hours.

A poisoned feast. Milkweed sap carries cardenolides, bitter compounds that affect the heart. Most insects avoid them; the monarch stores them in its body. In the 1960s Lincoln Brower raised monarchs on milkweed and fed them to captive blue jays. A jay that ate one vomited within minutes, and afterward it refused monarchs on sight. The orange and black colors are a warning that birds learn. The viceroy, a smaller orange butterfly, looks so much like the monarch that for a century it was taught as a harmless copycat. In 1991 David Ritland and Brower tested viceroys and found that many birds dislike them too. The two species seem to share and strengthen the same warning. Science corrected its own textbook.

The great migration. In summer, monarchs east of the Rocky Mountains go through three or four short generations, each adult living only two to six weeks. But the butterflies that emerge in late summer are different. Shorter days and cooler nights hold back their breeding, and they turn south. This “super generation” flies as much as 3,000 miles from Canada and the northern United States to a few mountains in central Mexico, feeding on autumn flowers and gaining fat on the way. They spend the winter there, then in spring mate and fly north to lay eggs in Texas and the southern states. Their children and grandchildren finish the trip north. No single monarch makes the round trip, yet each autumn a generation that has never seen Mexico finds the same forests.

Finding the winter home. For decades no scientist knew where the eastern monarchs went. The Canadian zoologist Fred Urquhart and his wife Norah began tagging monarchs in the 1950s with tiny paper labels, recruiting volunteers across North America. Reports pointed toward Mexico. Kenneth Brugger, an American living in Mexico City, and Catalina Aguado (later Catalina Trail) searched the mountains for the Urquharts, asking woodcutters and villagers. On January 2, 1975, they climbed into a fir forest and found trees bent with millions of butterflies. The discovery was announced in *National Geographic* in August 1976. The colonies cluster on oyamel fir trees at about 10,000 feet in Michoacán and the State of Mexico, where it is cool enough to slow the butterflies down but usually not cold enough to kill them. Since 2008 the region has been a World Heritage Site.

How do they find the way? Experiments show that migrating monarchs steer by the sun. Because the sun moves across the sky about 15 degrees an hour, a sun compass only works with a clock. In 2009 Steven Reppert’s laboratory showed that the clock is in the monarch’s antennae: butterflies with painted-over antennae flew in the wrong direction. Later work found a magnetic sense that may help on cloudy days. But how a butterfly finds a few

particular mountainsides, rather than just “southwest,” is still unknown. Honest science says so.

Counting and keeping. Because monarchs pack so tightly in winter, scientists measure the colonies by the area of forest covered. The largest measured total was about 18 hectares in the winter of 1996-97; the smallest was about 0.67 hectares in 2013-14. Estimates of the number of butterflies per hectare vary widely, from about 10 million to more than 50 million, so the total population is uncertain. Numbers rise and fall with weather, logging in the mountains and the amount of milkweed in North America. Western monarchs, from west of the Rockies, winter in groves along the California coast instead. Families, farmers and road crews can help by planting native milkweed and fall flowers, a simple act of the stewardship God gave Adam when He put him in the garden “to dress it and to keep it” (Genesis 2:15).

Appointed times. Jeremiah watched the stork, the turtledove, the crane and the swallow come and go on schedule, and rebuked a people who did not know God’s judgments as well as birds knew their seasons (Jeremiah 8:7). The monarch keeps an appointed time it never learned from a parent. Its faithfulness is a sermon on wings.

PICTURE STUDY



Study of Butterfly and Insects, Jan van Kessel the Elder, About 1655 · Oil on copper (about $4\frac{3}{8} \times 5\frac{7}{8}$ inches)
· National Gallery of Art, Washington, D.C.
Wikimedia Commons · Public domain

Jan van Kessel of Antwerp, a grandson of Jan Brueghel the Elder, painted insects so exactly on small copper plates that naturalists could name many of them. This painting is smaller than a postcard. Van Kessel never saw a monarch, which lives in the Americas, but he painted butterflies, moths and caterpillars together, as Maria Sibylla Merian would half a century later in her studies of metamorphosis.

Look closely

- Find the caterpillar. Does van Kessel show which plant it eats? How does that compare with a monarch, which eats only milkweed?
- Look closely at the butterfly's wings. How did he show the scales, veins and edges?
- Count the different insects. Which can you name as butterfly, moth or something else?

Talk about it

1. Why might a painter choose copper instead of canvas for a picture this small and exact?
2. If you painted a "study" of the monarch's whole life on one small panel, which four stages would you show, and what plant would you include?

HANDS-ON: MILKWEED PATROL AND MIGRATION MATH

Do Part A in summer or early fall if milkweed grows near you; Part B can be done in any season. Both use real measurement.

You will need

- A notebook, a pencil and a hand lens
- A map of North America with a scale bar, a ruler and string
- Optional: access to a milkweed patch (roadside, field edge or garden; ask permission on private land)

Steps

1. **Part A.** Choose ten milkweed plants. On each, gently turn every leaf and count monarch eggs (tiny, cream-colored, ridged, about the size of a pinhead) and caterpillars. Record the plant number, its height, eggs and caterpillars.
2. Calculate the average number of eggs and caterpillars per plant. Do taller plants have more? Make a simple scatter plot: plant height on the bottom, eggs plus caterpillars up the side.
3. **Part B.** On the map, lay string along a likely migration route from your town (or from Toronto) to the winter sites west of Mexico City. Measure it with the scale bar.
4. If a migrating monarch averages 25 to 30 miles a day, how many days would your route take? How many days if it averages 50?
5. Write a short paragraph: what does a butterfly need along this route to finish the trip, and what could your family plant or protect to help?

Check your work

- Part A: I recorded ten plants and calculated averages (or I explained why I skipped Part A).
- Part B: I measured a route and calculated the trip time at two speeds.
- My paragraph names at least two things a migrating monarch needs.

FIELD NOTEBOOK

1. **Field Notebook page E3.** Draw the four stages of the monarch in a circle on a milkweed stem: egg, caterpillar (with its two pairs of black filaments), chrysalis (with the gold dots) and adult. Under each, write how long the stage lasts.
2. **Narration (parent keeps).** Write one paragraph telling the story of a “super generation” monarch born in Minnesota in late August: its flight south, the winter on the fir trees, and its trip north in spring. Include at least three facts from the stop.

Did you know? You can tell a male monarch from a female at a glance: the male has a small black spot (a scent patch) on a vein of each hind wing, and the female’s black veins are thicker. In 1952 the Urquharts’ tags were tiny paper labels glued to the wing; today Monarch Watch volunteers still apply sticker tags, and a few tagged butterflies are found in Mexico each winter, sometimes thousands of miles from where they were tagged.

Go deeper. Monarch Watch (University of Kansas), for tagging, milkweed and migration maps. The Monarch Joint Venture, for identification guides and milkweed by region. Sue Halpern, *Four Wings and a Prayer* (2001), on the scientists who chased the migration. Joyce Sidman, *The Girl Who Drew Butterflies* (2018), on Maria Sibylla Merian and metamorphosis. Second video topic: monarch tagging in autumn.

Goes deeper in. Life Science, high-school Biology unit “Insects and Other Arthropods” (metamorphosis); Geography, “North America: Mountains and Migrations”; and Gardening & Animals, “A Pollinator Garden” (coming soon).

For families. The discovery date, January 2, 1975, and the August 1976 *National Geographic* story are well documented; there was later disagreement over credit between Urquhart and others, and Mexican villagers had of course long known the colonies. The antenna-clock experiment is Merlin, Gegear and Reppert, *Science* (2009). Colony areas are from the annual WWF-Mexico surveys. Butterfly-per-hectare densities vary widely by study; the stop gives a range. The legal status of the monarch under U.S. law has been under review; check the U.S. Fish and Wildlife Service for current status. In the southern United States, plant native milkweeds rather than tropical milkweed, which can keep monarchs breeding into winter and spread a parasite. The picture study is not a monarch; no public-domain painting of a monarch was confirmed for this stop.

PRACTICE

1. **EASY** Name the four stages of a monarch’s complete metamorphosis in order.
2. **EASY** Why do blue jays learn to leave monarchs alone?
3. **MEDIUM** A newly hatched caterpillar weighs about 0.5 milligram and grows about 2,000 times heavier. How much does it weigh when full-grown, in grams?
4. **MEDIUM** Who found the Mexican winter colonies, on what date, and how was the discovery made public?

5. **CHALLENGE** The colonies covered about 18 hectares in 1996–97 and about 0.67 hectares in 2013–14. If one hectare holds about 21 million butterflies, estimate the number of monarchs in each winter. Then explain why scientists say the true numbers are uncertain.
6. **CHALLENGE** A migrating monarch wants to fly southwest. At 9 a.m. the sun is in the southeast, and at 3 p.m. it is in the southwest. How must the butterfly’s angle to the sun change during the day, and why does that require a clock?

Make it a game • Sun Compass Relay. In a yard, choose a “Mexico” flag. A lamp or a person standing on a chair is the “sun.” Every round, the sun moves a few steps along a curve and the caller announces the time. Each “monarch” must take three steps toward Mexico while saying their angle to the sun aloud (“sun on my left shoulder!”). Anyone who drifts off course must go back to start.

Scripture. “Yea, the stork in the heaven knoweth her appointed times; and the turtle and the crane and the swallow observe the time of their coming; but my people know not the judgment of the LORD.” (Jeremiah 8:7, KJV)

The “turtle” here is the turtledove. Jeremiah used migrating birds to shame a people who ignored God. A monarch born in August, never taught by a parent, keeps its appointed time to the mountains of Mexico. How much more should we keep faith with the God who made it?

Practice: answers

1. Egg, larva (caterpillar), pupa (chrysalis), adult.
2. Monarchs store cardenolides from milkweed; a bird that eats one gets sick and vomits, and afterward it recognizes the orange-and-black warning colors.
3. $0.5 \text{ mg} \times 2,000 = 1,000 \text{ mg} = 1 \text{ gram}$.
4. Kenneth Brugger and Catalina Aguado, searching for Fred and Norah Urquhart, on January 2, 1975. It was announced in National Geographic in August 1976.
5. 1996–97: $18 \times 21 \text{ million} \approx 378 \text{ million}$. 2013–14: $0.67 \times 21 \text{ million} \approx 14 \text{ million}$. The density per hectare is itself an estimate that ranges from about 10 to over 50 million in different studies, and clusters vary in thickness, so totals could be off by a factor of two or more. The area is measured well; the count per area is not.
6. At 9 a.m. it must fly about 90° to the right of the sun (sun southeast, heading southwest). At 3 p.m. it must fly almost straight toward the sun. Since the sun moves about 15° per hour, the butterfly must keep changing its angle by the time of day. Without a clock, flying at a fixed angle to the sun would curve its path through the day, so the monarch uses a circadian clock, found in its antennae, to correct its heading.

5.4 SPIDERS: SILK, WEBS AND EIGHT-LEGGED HUNTERS

OBJECTIVES

- Tell how spiders differ from insects and name the parts of a spider's body.
- Explain how a spider makes silk and builds an orb web, and why spider silk interests engineers.
- Describe ballooning and spiders' role as predators, and recognize the two dangerous spiders of North America.

Warm-up. Go outside early on a dewy morning, or mist a bush with a spray bottle, and count how many webs you can see in five minutes. Sort them by shape: wheels, sheets, tangles, funnels. Which shape is most common where you live?

Video slot. Video coming. An orb-weaver spider building its web from start to finish; spider ballooning; jumping spider eyes. Search approved channels (Deep Look from KQED, Smithsonian, BBC Earth, Natural History Museum London, a university entomology department); preview first.

KEY TERMS

arachnid

An arthropod with eight legs, two main body parts and no antennae or wings: spiders, scorpions, ticks and mites.

cephalothorax

The front body section of a spider, a fused head and chest that carries the eyes, fangs, palps and all eight legs.

spinnerets

Small finger-like organs at the tip of the abdomen through which a spider draws out silk.

dragline

The strong safety line a spider trails behind it and uses for the frame and spokes of a web.

orb web

A wheel-shaped web of spokes (radii) and a sticky spiral, built by garden spiders and their relatives.

ballooning

Travel by air: a spider lets out silk threads that lift it on the wind and on the earth's electric field.

CORE IDEAS

Not an insect. A spider is an arachnid, not an insect. Count the differences: eight legs instead of six; two body sections (the cephalothorax and the abdomen) instead of three; no antennae and no wings. Up front are two fangs (chelicerae) connected to venom glands, and

a pair of short, leg-like palps for handling food. Most spiders have eight simple eyes. Web builders see poorly, but jumping spiders have large front eyes with sharp vision, and they can judge a leap precisely. More than 50,000 species have been named, from cave spiders smaller than a pinhead to tarantulas with legs as wide as a dinner plate. Spiders cannot chew; they inject digestive juices and drink their meal.

Silk. Silk begins as a liquid protein stored in glands in the abdomen. As it is pulled out through the spinnerets, the protein molecules line up and lock together into a solid thread. An orb weaver can have as many as seven kinds of silk glands, each making a different silk: dragline, sticky capture thread, wrapping silk, egg-case silk and more. Weight for weight, dragline silk is about as strong as high-grade steel, and it is tougher than steel because it stretches before it breaks. Darwin's bark spider of Madagascar spins webs across streams on bridge lines up to about 80 feet long. Scientists and companies have spent decades trying to make spider silk in factories, using bacteria, yeast and even silkworms with spider genes, but no one has yet matched the spider at large scale.

Building the wheel. An orb weaver begins by letting a thread drift on the breeze until it snags on a branch. That bridge line becomes the top of the frame. She adds more frame threads, then runs spokes from the center to the frame, then lays a temporary dry spiral as scaffolding. Last, working from the outside in, she lays the sticky capture spiral, eating the scaffolding as she goes. The whole web may take less than an hour. Many orb weavers eat their old web every day and recycle the protein into a new one. The spider waits at the hub or in a hiding place with one leg on a signal line, feeling for the vibrations of struggling prey and telling them apart from wind or a leaf.

Flying spiders. On calm, sunny days, young spiders and some small adults climb to the top of a fence post or grass blade, raise the abdomen and let out fine threads until they lift away. This is ballooning. Ships far out at sea have been showered with tiny spiders; Charles Darwin recorded spiders landing on the *Beagle* in 1832 when it was about 60 miles off the coast of Argentina. In 2018, scientists at the University of Bristol showed that spiders can sense the earth's natural electric field, and that electric charges alone can lift them, even with no wind. Spiders have been collected by aircraft thousands of feet up. On autumn mornings, fields covered by these threads glitter with "gossamer."

Hunters without webs. About half of all spiders spin no snare. Wolf spiders run down their prey; the mother carries her egg sac on her spinnerets and then her spiderlings on her back. Trapdoor spiders wait in silk-lined burrows under hinged lids. Fishing spiders run across ponds. The diving bell spider of Europe lives underwater in a bubble of air held in a silk dome. In 1705 Maria Sibylla Merian published a picture of a large South American tarantula eating a hummingbird. European critics called it a fantasy, until Henry Walter Bates saw a big hairy spider with two finches caught in its web on the Amazon in the mid-1800s. Such meals are rare, but they happen.

Friends of the farmer, mostly. Scientists estimate that the world's spiders eat several hundred million tons of insects and other small animals every year, more than the weight of meat and fish eaten by all people. In fields, gardens and houses they keep pests in check.

Nearly all spiders are harmless to people; their fangs are too small or their venom too weak. In North America, two deserve respect. The black widow is shiny black with a red hourglass under the abdomen; its venom affects the nerves. The brown recluse is tan with a darker violin shape on its back and only six eyes; its bite can damage skin. Both hide in quiet, dark places and bite only when pressed against skin.

A web is not a house. Scripture uses the spider's web as a picture of a hope that cannot hold: the hypocrite's "trust shall be a spider's web" (Job 8:14). The web is a marvel of design, yet one sweep of a broom ends it. A life built on anything but God is the same. The lesson is not that the spider is foolish; its web is perfect for what God made it to do. It is that a web cannot bear a man's weight.

PICTURE STUDY



*Plate 18 of Metamorphosis insectorum Surinamensium (guava branch with tarantulas, huntsman spiders, army ants and a ruby-topaz hummingbird), Maria Sibylla Merian (engraved after her watercolor), 1705 · Hand-colored engraving · From Metamorphosis insectorum Surinamensium (Amsterdam, 1705); this copy is in the British Library, London
Wikimedia Commons · CC0*

Maria Sibylla Merian, a German-born artist and naturalist, sailed to the Dutch colony of Surinam in South America in 1699 at the age of 52 to study insects in the wild. Her great book of 1705 showed each creature on the plant where it lived. This is her most famous and most argued-over plate. Critics doubted that a spider could eat a bird; later naturalists found that large tarantulas occasionally do. The genus of these tarantulas is still called *Avicularia*, "little bird."

Look closely

- Count the spiders. How many different kinds do you think Merian shows? What clues (size, hair, web, eyes) tell them apart?
- Find the ants. What are they doing, and how does Merian lead your eye along the branch?
- Look at the hummingbird and its nest. Is this scene shown as it would really look at one moment, or are several events combined?

Talk about it

1. Merian put many events on one branch to teach. Is that honest science, artistic license or both? How should a reader use such a picture?
2. Merian's critics were sure she was wrong, and later naturalists showed she was partly right. What does that teach about judging a claim that seems impossible?

Safety first. Do not handle spiders with bare hands. Use a jar and card or a soft brush. Before reaching into woodpiles, sheds, shoes or boxes, look first, and wear gloves. Learn to recognize the black widow (red hourglass) and brown recluse (violin mark, six eyes) where they live. If someone is bitten and has spreading pain, cramps, a growing sore or feels ill, call a doctor; bring the spider in a jar if it can be caught safely.

HANDS-ON: COLLECT AND MEASURE AN ORB WEB

Preserve a real abandoned orb web on dark paper and measure its design like an engineer.

You will need

- A sheet of black construction paper or poster board
- Spray adhesive or hairspray (a parent sprays) and a small bag of cornstarch or talc
- A ruler, a protractor and a hand lens
- A soft brush or long stick for moving the spider

Steps

1. Find a complete orb web. Gently move the spider away with the stick or brush and let it go on a nearby plant. (It will build a new web tonight.)
2. Lightly dust the web with cornstarch so the threads show white.
3. A parent sprays the black paper with adhesive. Bring the paper up behind the web, hold it flat and press it into the web. Cut the frame threads at the edges with scissors.
4. Count the spokes (radii). Measure the angle between three pairs of neighboring spokes with the protractor and find the average.
5. Measure the spacing between turns of the sticky spiral at three places: near the hub, halfway out and near the edge. Is it even? Measure the web's height and width.
6. Write three sentences: what does the spacing tell you about the size of insects this spider catches? Why might the web be wider at the bottom than the top, or the hub off-center?

Check your work

- The spider was moved away unharmed before I collected the web.
- I counted the radii and measured spoke angles at three places.
- I measured spiral spacing near the hub, middle and edge.
- I wrote a conclusion based on my measurements.

FIELD NOTEBOOK

1. **Field Notebook page E4.** Draw a spider seen from above and from the side. Label the cephalothorax, abdomen, eight legs, chelicerae (fangs), palps, eyes and spinnerets. Beside it, draw an ant and label its three body parts and antennae for comparison.
2. **Narration (parent keeps).** Write one paragraph describing, step by step, how an orb weaver builds her web from the first bridge thread to the sticky spiral, and explain what makes spider silk so remarkable.

Did you know? The bolas spider spins no web at all. At night it hangs from a single line and swings a short thread with a sticky ball on the end. The ball gives off a scent like that of a female moth, and when a male moth flies in to find her, the spider swings the bolas and catches him. And a spider's legs are extended partly by blood pressure, not only by muscles; that is why a dead spider's legs curl up.

Go deeper. Henry Walter Bates, *The Naturalist on the River Amazons* (1863; free at Project Gutenberg), with his account of the bird-killing spider. Anna Botsford Comstock, *Handbook of Nature Study* (1911; free online), the lessons on the orb weaver and other spiders. Rainer F. Foelix, *Biology of Spiders* (3rd ed., 2011), the standard reference for advanced students. The World Spider Catalog (Natural History Museum Bern), for current species counts. Second video topic: the diving bell spider.

Goes deeper in. Life Science, high-school Biology unit "Insects and Other Arthropods"; and Gardening & Animals, "Garden Helpers and Pests" (coming soon).

For families. Species totals are from the World Spider Catalog and rise each year. The strength comparison is per unit weight and depends on the steel and silk compared. The bark spider's bridge lines have been measured up to about 25 meters (Agnarsson et al., 2010). The electric-field ballooning study is Morley and Robert, *Current Biology* (2018). The prey estimate (400–800 million tons a year) is Nyffeler and Birkhofer, *The Science of Nature* (2017). Darwin's ballooning spiders are in his *Journal of Researches* (the voyage of the *Beagle*). No public-domain excerpt could be copied exactly for this stop, so it has no primary-source box. Proverbs 30:28 ("The spider taketh hold with her hands") may refer to a lizard such as a gecko in Hebrew; it is used in Stop E10. Spider bites are rare, and many skin sores blamed on spiders have other causes; see a doctor rather than guess.

PRACTICE

1. **EASY** Give three ways a spider's body differs from an insect's.
2. **EASY** How can you recognize a black widow and a brown recluse?
3. **MEDIUM** List the steps an orb weaver follows in building a web, in order.
4. **MEDIUM** Why did Merian's plate of a spider eating a hummingbird cause argument, and how was it settled?
5. **CHALLENGE** Scientists estimate spiders eat 400 to 800 million metric tons of prey a year. If the world's people number 8 billion, how many kilograms of prey is that per person per year at the middle estimate? How does that compare with a person who eats about 40 kilograms of meat and fish a year?
6. **CHALLENGE** Dragline silk is "about as strong as steel by weight," yet a single thread breaks easily in your fingers. Explain why both are true, and why toughness (stretch before breaking) matters for a web that must stop a flying insect.

Make it a game • Web Vibrations. Tie yarn from a central "hub" to five chairs to make a web. The "spider" sits blindfolded at the hub with fingers on the strands. Players take turns making a "prey" signal (a strong, uneven shake) or a "wind" signal (a slow, gentle sway) on one strand. The spider must point to the right strand and say "prey" or "wind." Score one point for each right call.

Scripture. "So are the paths of all that forget God; and the hypocrite's hope shall perish: Whose hope shall be cut off, and whose trust shall be a spider's web." (Job 8:13-14, KJV)

Bildad spoke these words to Job, and though he applied them wrongly to Job, the picture itself is true. A web is a wonder of design for catching flies, but it cannot hold up a man. Trust in anything but God is as frail as a spider's web.

Practice: answers

1. Any three: eight legs instead of six; two body sections instead of three; no antennae; no wings; chelicerae (fangs) and palps; spinnerets.
2. Black widow: shiny black with a red hourglass under the abdomen. Brown recluse: tan, with a dark violin shape on the cephalothorax and six eyes instead of eight.
3. A bridge line on the breeze; frame threads; spokes (radii) from the hub; a temporary dry spiral; the sticky capture spiral from the outside in, removing the temporary spiral.
4. European critics thought spiders could not kill birds and called the picture a fantasy. Later naturalists, including Henry Walter Bates on the Amazon in the mid-1800s, saw large tarantulas with small birds, so the picture was shown to be possible, though such meals are rare.
5. Middle estimate $600 \text{ million t} = 600,000,000,000 \text{ kg.} \div 8,000,000,000 \text{ people} = 75 \text{ kg per person per year.}$ That is almost twice the 40 kg of meat and fish such a person eats.
6. Strength by weight compares equal masses; a spider thread is extremely thin, so its total breaking force is tiny even though, gram for gram, it rivals steel. A web must absorb the energy of a fast insect. A stiff material would either snap or bounce the insect off; silk

stretches, soaking up the energy as heat and holding the prey, which is why toughness matters more than stiffness.

5.5 BEETLES: “HOW MANIFOLD ARE THY WORKS!”

OBJECTIVES

- Identify a beetle by its elytra and chewing mouthparts and give the numbers that make beetles the largest order of animals.
- Explain the bombardier beetle’s chemical defense and the work of dung beetles, ladybugs and pest beetles, with real numbers and dates.
- Read Darwin’s account of beetle collecting and use one of his collecting methods in a field survey.

Warm-up. Write down every kind of beetle you can name in two minutes. (Ladybug counts; so does firefly!) Then guess: of all the kinds of animals scientists have named, what fraction are beetles? One in fifty? One in ten? One in four? Keep your guess.

Video slot. Video coming. Beetle diversity; the bombardier beetle’s spray in slow motion; dung beetles rolling balls and steering by the stars. Search approved channels (Smithsonian, Natural History Museum London, BBC Earth, Deep Look from KQED, a university entomology department); preview first.

KEY TERMS

Coleoptera

The scientific name of the beetle order, from Greek for “sheath wings.”

elytra

A beetle’s hardened front wings, which meet in a straight line down the back and cover and protect the folded flying wings beneath (singular: elytron).

grub

The larva of a beetle, often a soft, C-shaped worm with a hard head and six short legs.

weevil

A beetle with a long snout tipped with tiny jaws; the largest beetle family, including many crop pests.

scarab

A member of a large beetle family that includes dung beetles, June bugs and the sacred scarab of Egypt.

biological control

Using a pest’s natural enemies, such as a predatory beetle, to keep the pest in check.

CORE IDEAS

The largest family album. Scientists have named about 400,000 species of beetles, roughly one-quarter of all named animals and about two out of every five named insects. Thousands more are described every year, and many tropical forests have never been fully

searched. A well-known saying claims that when a biologist was asked what the study of nature taught about the Creator, he answered that God must have “an inordinate fondness for beetles.” The quotation is usually pinned on J. B. S. Haldane, but no one has found where he wrote or said it. The psalmist put the same wonder better: “O LORD, how manifold are thy works!” (Psalm 104:24).

Sheath wings. The name Coleoptera means “sheath wings.” A beetle’s front wings are hardened into elytra, which close over the back like a case and meet in a straight line. Beneath them the thin hind wings are folded like origami. To fly, the beetle lifts the elytra out of the way and unfolds the hind wings; in most beetles the elytra stay raised and help steady the flight. This armor lets beetles burrow, push under bark and live in soil, water and dung without tearing their wings. All beetles have chewing mouthparts, and all go through complete metamorphosis: egg, grub, pupa, adult. Beetles range from featherwing beetles smaller than a period on this page to the South American titan beetle, more than six inches long.

The bombardier. The bombardier beetle stores two sets of chemicals in separate chambers at the tip of its abdomen: hydroquinones and hydrogen peroxide. When attacked, it squeezes them into a thick-walled reaction chamber lined with enzymes. The mixture reacts violently, heats to about the boiling point of water, and blasts out as a scalding, foul spray with an audible pop. Thomas Eisner and his colleagues filmed the spray at high speed and found it comes in rapid pulses, about 500 per second, which keeps the chamber from overheating. The beetle can aim its nozzle forward, backward or to the side. Many Christians point to the bombardier as a system that works only when all its parts are present; other scientists propose step-by-step origins. The observations themselves, the chambers, the enzymes and the pulsed spray, are agreed by all.

The cleanup crew. Dung beetles bury animal droppings to feed their young, returning nutrients to the soil and removing breeding places for flies. In Australia, native dung beetles were suited to the dry pellets of kangaroos, not to the large, wet pats of cattle brought by settlers; pastures were fouled and bush flies swarmed. Starting in the late 1960s, Australian scientists introduced dozens of dung beetle species from Africa and Europe to do the job. Ancient Egyptians watched scarab beetles roll their dung balls and pictured the god Khepri rolling the sun across the sky. In 2013 Swedish and South African scientists showed that some African dung beetles roll their balls in straight lines at night by steering by the band of the Milky Way. The Egyptians worshiped the beetle; Scripture teaches us to worship the beetle’s Maker.

Friends and foes. In 1888 the cottony cushion scale, an insect pest from Australia, was killing the orange groves of California. The entomologist Albert Koebele went to Australia and sent back the vedalia lady beetle, which eats the scale. Within about two years the pest was under control, one of the first great successes of biological control. A single ladybug may eat thousands of aphids in its lifetime. Other beetles are costly enemies. The boll weevil crossed from Mexico into Texas about 1892 and spread through the Cotton Belt, ruining crops; the farmers of Enterprise, Alabama, switched to peanuts and prospered, and in 1919

they built a monument to the weevil. The emerald ash borer, first found near Detroit in 2002, has killed hundreds of millions of ash trees.

Collectors and watchers. In the 1800s beetle collecting was a popular pastime in Britain, and the young Charles Darwin, studying at Cambridge to become a clergyman, was one of its keenest followers. His account in the primary source shows the zeal and the cost: one beetle in each hand, a third too good to lose, and a burnt tongue. He also invented methods to find rare species where no one else looked. Long before him, Albrecht Dürer in 1505 painted a single stag beetle with such care that it is still one of the most copied nature studies in art. Both men saw that the humblest creature repays a careful look.

PICTURE STUDY



Stag Beetle, Albrecht Dürer, 1505 · Watercolor and gouache on paper (about 5½ × 4½ inches) · J. Paul Getty Museum, Los Angeles
Wikimedia Commons · Public domain

Albrecht Dürer of Nuremberg, the great German artist of the Renaissance, made this study of a male stag beetle in 1505. In his day most people thought insects too lowly for art; making a single beetle the whole subject of a finished picture was new. Dürer probably worked in his studio from sketches and memory. The museum notes that the upper left corner of the paper was added later and that another hand painted the tip of the left antenna.

Look closely

- Find the “antlers.” They are really enlarged jaws (mandibles). Where are the true antennae?
- Look at the shadow. What does it tell you about where the light is and how the beetle stands?

- Look at the elytra. How did Dürer show that they are hard, shiny and curved?

Talk about it

1. Dürer used thick, opaque paint for the hard body and thin, clear washes for the shadow. Why might he have chosen different paints for different parts?
2. Dürer and Darwin both studied beetles closely, more than 300 years apart. What habit of mind do they share, and how could you practice it this week?

HANDS-ON: BEETLE SURVEY: A PITFALL TRAP AND DARWIN'S SIEVE

Survey the beetles of your yard or a park with two methods: a pitfall trap and a version of Darwin's method of searching moss and debris. Identify what you find to family, record it and release every beetle.

You will need

- Two plastic cups (one inside the other) and a trowel
- A flat stone or board and two small pebbles (a rain roof)
- A white sheet or pillowcase and a garden sieve or colander
- A hand lens, a clear jar and a beetle family guide (book or BugGuide.net)

Steps

1. **Pitfall trap.** Dig a hole and set the two cups in it so the rim is exactly level with the soil. Put a few leaves in the cup for cover. Prop the stone or board over it on two pebbles to keep out rain.
2. Check the trap the next morning, and every morning for three days. Tip the catch into the jar, identify each beetle by family (ground beetle, rove beetle, scarab, leaf beetle, weevil, click beetle, lady beetle or other), record it and release it nearby.
3. **Darwin's method.** Read the primary source. Darwin had moss scraped from old trees and searched the rubbish from reed barges. Gather two handfuls of moss, leaf litter or old straw. Shake it through the sieve over the white sheet and watch for movement.
4. Make a tally table of beetle families from both methods. Which method found more kinds? Which found more individuals?
5. Remove the cups and fill the hole when you are done.

Check your work

- My trap was level with the ground and checked every morning; no beetle was left in it.
- I identified at least three beetles to family and released them.
- I tried Darwin's method and compared it with the pitfall trap in a table.

FIELD NOTEBOOK

1. **Field Notebook page E5.** Draw one beetle from your survey, large, from above. Label the head, antennae, mandibles, pronotum (the plate behind the head), elytra and the

line where they meet. Draw a second small sketch with the elytra open and the hind wings spread.

2. **Narration (parent keeps).** Write one paragraph on beetles as helpers and enemies of people, using at least three examples from the stop (for instance the dung beetles of Australia, the vedalia beetle and the boll weevil) with their dates.

Did you know? Click beetles lying on their backs can flip into the air with an audible click, snapping a peg on the chest into a groove; the jump can be several inches high. Some diving beetles carry a bubble of air under their elytra like a scuba tank. And the hardest-shelled beetles, such as the diabolical ironclad beetle of California, can survive being run over by a car.

Primary source. *Charles Darwin, autobiography (written 1876; first published 1887), from The Autobiography of Charles Darwin, Project Gutenberg*

But no pursuit at Cambridge was followed with nearly so much eagerness or gave me so much pleasure as collecting beetles. It was the mere passion for collecting, for I did not dissect them, and rarely compared their external characters with published descriptions, but got them named anyhow. I will give a proof of my zeal: one day, on tearing off some old bark, I saw two rare beetles, and seized one in each hand; then I saw a third and new kind, which I could not bear to lose, so that I popped the one which I held in my right hand into my mouth. Alas! it ejected some intensely acrid fluid, which burnt my tongue so that I was forced to spit the beetle out, which was lost, as was the third one.

I was very successful in collecting, and invented two new methods; I employed a labourer to scrape during the winter, moss off old trees and place it in a large bag, and likewise to collect the rubbish at the bottom of the barges in which reeds are brought from the fens, and thus I got some very rare species.

Go deeper. Arthur V. Evans and Charles L. Bellamy, *An Inordinate Fondness for Beetles* (1996), a richly illustrated survey. Arthur V. Evans, *Beetles of Eastern North America* (2014) or *Beetles of Western North America* (2021), field guides. The Getty Museum's online page for Dürer's *Stag Beetle*. BugGuide.net (Iowa State University) for identifying your finds. Second video topic: the bombardier beetle in slow motion.

Goes deeper in. Life Science, high-school Biology unit "Insects and Other Arthropods" (classification); Gardening & Animals, "Garden Helpers and Pests"; and Art, "Dürer and the Nature Study" (coming soon).

For families. Species counts (about 380,000–400,000 described beetles) vary by source. The "inordinate fondness" remark is attributed to J. B. S. Haldane but unverified; the stop says so. Bombardier pulse rates are from Dean, Aneshansley, Edgerton and Eisner, *Science* (1990); spray temperature near 100 °C. The Milky Way study is Dacke et al., *Current Biology* (2013). The Australian Dung Beetle Project ran from 1965 to 1985 under

CSIRO. The vedalia story (Koebele, 1888–1889) and the Enterprise, Alabama, boll weevil monument (dedicated 1919) are well documented. Darwin is quoted for his beetle-collecting, a harmless and vivid scene; his later theories are not taught here. Darwin studied at Cambridge intending to become a clergyman of the Church of England. Release all beetles after the survey.

PRACTICE

1. **EASY** What are elytra, and what do they protect?
2. **EASY** In the primary source, why did Darwin put a beetle in his mouth, and what happened?
3. **MEDIUM** If about 400,000 beetle species are named among about 1.5 million named animal species, what percentage of animal species are beetles?
4. **MEDIUM** Explain how the vedalia beetle saved California's orange groves and why this is called biological control.
5. **CHALLENGE** A bombardier beetle's spray pulses about 500 times per second. A defensive burst lasts about 1/50 of a second. How many pulses are in one burst? Suggest why a pulsed spray might be better for the beetle than one continuous blast.
6. **CHALLENGE** Darwin says his collecting was "the mere passion for collecting," since he "did not dissect them, and rarely compared their external characters with published descriptions." Was he doing science? Write three or four sentences weighing what was valuable and what was missing in his method.

Make it a game • Beetle or Not?. A caller names an insect or other small animal: ladybug, firefly, cockroach, weevil, earwig, June bug, stinkbug, click beetle, pill bug, water strider. Players stand up if it is a beetle and stay seated if not, then must give one reason ("it has elytra that meet in a straight line"). Answers: beetles are ladybug, firefly, weevil, June bug, click beetle; not beetles are cockroach, earwig, stinkbug (a true bug), pill bug (a crustacean), water strider (a true bug).

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. Psalm 104 walks through the creation, from the cedars to the sea, and ends in praise. Beetles alone, with some 400,000 named kinds, would be enough to fill the earth with God's "riches."

Practice: answers

1. The hardened front wings of a beetle, which cover and protect the folded flying wings and the soft abdomen.
2. He had a rare beetle in each hand and saw a third new kind he did not want to lose, so he put one in his mouth to free a hand. It squirted an acrid fluid that burnt his tongue; he spat it out and lost it, and the third beetle too.
3. $400,000 \div 1,500,000 \approx 0.267$, about 27%, roughly one in four.

4. The cottony cushion scale, a pest from Australia, was killing citrus trees. Albert Koebele brought the vedalia lady beetle, the scale's natural enemy, from Australia in 1888-1889, and it ate the scale until the pest was under control. Using a living enemy instead of poison to control a pest is biological control.
5. $500 \times 1/50 = 10$ pulses. Pulsing lets fresh chemicals flow in between small explosions, so the reaction chamber does not overheat or burst, the beetle uses its chemicals efficiently, and each pulse still delivers a hot, irritating jolt.
6. Sample: Darwin was gathering real specimens and inventing new ways to find rare species, which is part of science: careful collecting and accurate records of where things live. But by his own account he did not study their structure or compare them with descriptions, so he was not yet testing ideas or classifying carefully. Science needs both: wide collecting and close, disciplined comparison. His later habits of patient observation grew from this early zeal.

5.6 FIREFLIES: COLD LIGHT AND CODED FLASHES

OBJECTIVES

- Explain the chemistry of firefly light (luciferin, luciferase, oxygen and ATP) and how the insect switches it on and off.
- Describe how fireflies use flash patterns to find mates, how some predators fake them, and how synchronous fireflies flash together.
- Read Fabre’s account of the glow-worm and show which of his questions later science answered.

Warm-up. Hold your hand near a lit incandescent or halogen bulb (not touching), then near an LED. Which is warmer? A firefly makes light and almost no heat. Think about why that might matter for a small insect that glows for hours.

Video slot. Video coming. Synchronous fireflies of the Great Smoky Mountains; firefly flash patterns; glowing firefly larvae. Search approved channels (National Park Service, Great Smoky Mountains National Park, Smithsonian, Deep Look from KQED, PBS Nature); preview first.

KEY TERMS

bioluminescence

Light made by a living thing through a chemical reaction.

luciferin

The small molecule that gives off light when it is oxidized in a firefly’s lantern.

luciferase

The enzyme that joins luciferin, oxygen and ATP (the cell’s energy molecule) in the light reaction.

lantern

The light organ on the underside of a firefly’s last abdominal segments, packed with light cells and fed by tiny air tubes.

flash pattern

The length, number, color and timing of a firefly’s flashes, which differ by species and act as a signal.

aggressive mimicry

When a predator imitates a harmless signal to lure prey, as when a Photuris female copies the answer flash of another species.

CORE IDEAS

Beetles with lanterns. Fireflies are neither flies nor bugs; they are beetles of the family Lampyridae, with soft elytra and a flattened shield over the head. About 2,000 to 2,200

species have been named worldwide, roughly 170 of them in the United States and Canada. Not all adult fireflies glow; some fly by day and use scent instead. In Europe the best-known kind is the glow-worm, whose wingless female shines from the grass while the winged male searches overhead. Jean-Henri Fabre watched these glow-worms in his garden in Provence, and his account is the primary source for this stop.

The chemistry of cold light. In the lantern cells, the enzyme luciferase joins luciferin with oxygen and ATP, the energy molecule of every cell. The luciferin is left in an excited state and releases its extra energy as a particle of light. Almost none of the energy becomes heat, which is why firefly light is called “cold light.” For years books said the reaction turned about 88 to 90 percent of its molecules into light. In 2008 Japanese chemists measured it carefully and found about 41 percent. That is still remarkable: an old incandescent bulb turns only a few percent of its energy into light. The color, from green to yellow to orange, depends on the exact shape of each species’ luciferase.

The switch. How does a firefly turn its light on and off in a fraction of a second? Fabre, writing about 1900, guessed that the air tubes controlled it, and in the primary source he says the light is a slow oxidation fed by the air supply. He was on the right track. The lantern is threaded with tiny air tubes (tracheae), and the light cells are lined with energy-making mitochondria that normally use up the oxygen. In 2001 American scientists reported that a nerve signal releases nitric oxide, a gas that briefly shuts down the mitochondria. Oxygen then floods past them to the luciferin, and the lantern flashes. When the nitric oxide fades, the light goes out.

A language of light. On a June evening in much of the eastern United States, the common “big dipper” firefly (*Photinus pyralis*) flies low, making a rising J-shaped flash about every five or six seconds. A female in the grass answers with a short flash after a set delay of about two seconds. Each species has its own code of flash length, timing and color, so males and females of the right kind find one another. But the entomologist James Lloyd discovered that females of the genus *Photuris* imitate the answer flashes of other species. When a male of another kind flies down to meet her, she eats him. Lloyd called her a “femme fatale.” From the males she also gains defensive chemicals she cannot make herself.

Flashing together. Travelers to Southeast Asia long reported trees along rivers where thousands of fireflies blinked on and off in unison, and many Western scientists doubted it. In the Great Smoky Mountains of Tennessee, local families had watched the same thing for generations near Elkmont. In the early 1990s a Tennessee naturalist, Lynn Faust, brought the display to the attention of scientists, who confirmed it: the males of *Photinus carolinus* flash five to eight times in quick bursts, then go dark together for several seconds, over whole hillsides. The peak lasts about two weeks in late May or June, and the National Park Service now uses a lottery to limit the crowds. How thousands of insects keep time with no leader is a lively question in mathematics as well as biology.

Glowing young. Every firefly larva glows, even in species whose adults do not. Fabre noticed it and admitted he could not tell what the larva’s light was for. Later research by Thomas Eisner and others found that many fireflies carry bitter defensive steroids called

lucibufagins, and that bats and birds learn to avoid them; the larval glow seems to be a warning, like the monarch's colors. Firefly larvae are hunters of snails, slugs and earthworms, which they paralyze with a bite and digest with injected juices.

Light for others. Firefly luciferase is now a tool in laboratories and hospitals: it can detect tiny amounts of ATP to test whether food-processing surfaces are clean, and it is used to track living cells in medical research. Where fireflies have declined, causes include loss of damp meadows and woodland edges, pesticides and artificial light at night, which drowns out their signals. Families can help by turning off outdoor lights in early summer, leaving some long grass and leaf litter, and avoiding lawn chemicals. Paul told the Philippians to “shine as lights in the world” (Philippians 2:15); a firefly's light is small, but on a dark night it can be seen a long way.

PICTURE STUDY



Catching Fireflies (Hotaru-gari), Kitagawa Utamaro, About 1796–1797 · Color woodblock print, triptych (three sheets), ink and color on paper · Cleveland Museum of Art, Ohio (other impressions are in other museums)

Wikimedia Commons · CC0

In Japan, summer evenings of firefly catching (*hotaru-gari*) were a beloved custom; families caught fireflies with fans and kept them for an evening in little cages. Kitagawa Utamaro, one of the great masters of the Japanese woodblock print, shows such an outing in three joined sheets: a boy wading into a stream, another watching, a young woman sweeping a fan and a girl studying the insects in a carved cage.

Look closely

- Follow the action across all three sheets. Where does your eye start, and where does it end?

- Find the cage. What does the girl's pose tell you about how she feels about the fireflies?
- How does Utamaro show that it is night without making the whole picture dark?

Talk about it

1. A woodblock print is carved and printed one color at a time. Why might it be hard to show tiny points of light in this medium? How did Utamaro solve it, or did he leave them out?
2. Firefly catching was a family custom in Japan for centuries. If you took part, what would you do to make sure the fireflies were released unharmed?

HANDS-ON: READ THE FLASH CODE

Do this on a warm, still evening in late spring or summer when fireflies are out. If none live near you, do Part B only.

You will need

- A stopwatch or phone timer (screen dimmed, or with a red cover)
- A small penlight covered with yellow or green cellophane
- A notebook and a clipboard
- A clear jar with a cloth lid (optional, for a brief look and release)

Steps

1. **Part A.** At dusk, sit still in one spot. Choose one flashing male and time the gap between his flashes for at least five flashes. Record the shape of each flash (dot, streak or J-curve) and the color.
2. Repeat with two more males. Do they flash at the same rhythm? If the patterns differ, you may be seeing two species.
3. Hold the penlight low in the grass. When a male flashes, wait about two seconds and give one short flash. Repeat. Record whether any male turns toward you or lands nearby.
4. **Part B.** Read the primary source. Fabre says a glow-worm lets you read print "letter by letter." Test it with your penlight: in a dark room, cover it with two layers of tissue so it is very dim, and move it along a line of print. How many letters can you read at once? Write how this helps you understand his words "a very feeble illuminant."
5. If you catch a firefly to look at, keep it no more than a few minutes and release it where you found it.

Check your work

- I timed at least three males and recorded flash shape and color.
- I tried the two-second answer flash and recorded the result.
- I did the reading test and connected it to Fabre's words.
- Every firefly was released.

FIELD NOTEBOOK

1. **Field Notebook page E6.** Draw a firefly from below, showing the pale lantern segments. Next to it, draw a “flash chart”: a timeline with dashes for each flash you recorded, one row per firefly.
2. **Narration (parent keeps).** Write one paragraph explaining to a younger child how a firefly makes and controls its light, using the words luciferin, luciferase, oxygen and nitric oxide, and end with one thing a family can do to help fireflies.

Did you know? From the 1960s into the 1990s, a chemical company in St. Louis paid children and families a penny or more per firefly to collect them, because firefly lanterns were the only source of luciferase for research. Today the enzyme is made in the laboratory, so wild fireflies no longer need to be collected. Firefly light can be seen by other fireflies at a distance of many yards on a dark night.

Primary source. *J. Henri Fabre, The Glow-Worm and Other Beetles, chapter I, “The Glow-Worm,” translated by Alexander Teixeira de Mattos, Project Gutenberg*

No better proof could be found of what I have already propounded, namely, that the Glow-worm's light is the effect of a slow oxidization. The light is white, calm and soft to the eyes and suggests a spark dropped by the full moon. Despite its splendour, it is a very feeble illuminant. If we move a Glow-worm along a line of print, in perfect darkness, we can easily make out the letters, one by one, and even words, when these are not too long; but nothing more is visible beyond a narrow zone. A lantern of this kind soon tires the reader's patience. ...

We can understand the object of the feminine beacon; but of what use is all the rest of the pyrotechnic display? To my great regret, I cannot tell. It is and will be, for many a day to come, perhaps for all time, the secret of animal physics, which is deeper than the physics of the books.

Go deeper. Sara Lewis, *Silent Sparks: The Wondrous World of Fireflies* (2016), by a firefly scientist at Tufts University. Lynn Frierson Faust, *Fireflies, Glow-worms, and Lightning Bugs* (2017), a field guide to the fireflies of the eastern and central United States. Fabre's full chapter is free at Project Gutenberg. Great Smoky Mountains National Park's synchronous firefly page, for the yearly lottery. Second video topic: firefly larvae hunting snails.

Goes deeper in. Life Science, high-school Biology unit “Energy in the Cell” (ATP and enzymes) and high-school Chemistry, “Light and Chemical Reactions”; and Art, “Japanese Woodblock Prints” (coming soon).

For families. Species counts vary by source. The 41 percent quantum yield is Ando et al., *Nature Photonics* (2008); older textbooks give about 88 percent. The nitric-oxide switch is Trimmer et al., *Science* (2001). James Lloyd described *Photuris* mimicry in the 1960s and

1970s. Lynn Faust's role at Elkmont and the park lottery are described by the National Park Service; the lottery dates and rules change each year. Lucibufagin work is by Eisner and colleagues (1970s-1990s). The company that bought fireflies was Sigma Chemical of St. Louis. Fabre's glow-worm is *Lampyrus noctiluca*; the excerpt uses the translator's British spelling. Fabre attributes the glow-worm's light to "slow oxidization"; modern chemistry agrees it is an enzyme-driven oxidation. Utamaro's print exists in several impressions; dates vary slightly by museum.

PRACTICE

1. **EASY** What family of insects do fireflies belong to, and what is their scientific family name?
2. **EASY** Name the four things that come together in the lantern to make light.
3. **MEDIUM** In the primary source, what experiment does Fabre describe to show the glow-worm is a "very feeble illuminant," and what question does he admit he cannot answer?
4. **MEDIUM** How does a Photuris female catch males of other species?
5. **CHALLENGE** Older books said the firefly reaction is about 88% efficient; a 2008 study measured about 41%. An incandescent bulb turns about 3% of its energy into light. How many times more efficient is the firefly than the bulb, using the newer figure? Why might the older figure have stayed in textbooks so long?
6. **CHALLENGE** Fabre wrote that the use of the larva's light might stay "perhaps for all time, the secret of animal physics." Using the stop, write three or four sentences explaining what scientists later learned and whether Fabre was right to be cautious.

Make it a game · Find Your Flash. In a dim room or yard at dusk, give each player a small flashlight and a secret flash code on a card (for example, two short; one long; three quick). Half the players are "males" who walk slowly flashing their code; the other half are "females" who stay seated and answer only their own code after a two-second count. Pairs with the same code must find each other. Add one secret "Photuris" player who answers every code. Anyone who walks up to the Photuris is out.

Scripture. "That ye may be blameless and harmless, the sons of God, without rebuke, in the midst of a crooked and perverse nation, among whom ye shine as lights in the world;" (Philippians 2:15, KJV)

Paul wrote this from prison. A firefly's light is small and cool, yet on a dark night it is seen far off, and it is a true signal, not a counterfeit like the Photuris. Christians are called to shine honestly in a dark place.

Practice: answers

1. They are beetles, family Lampyridae.
2. Luciferin, the enzyme luciferase, oxygen and ATP.
3. He moved a glow-worm along a line of print in darkness and could read only a letter or a short word at a time. He could not tell what use the light was to the eggs, larvae and males,

beyond the female's signal to the males.

4. She copies the answer flash of the other species' females. A male flies down expecting a mate, and she catches and eats him (aggressive mimicry).
5. $41 \div 3 \approx 13.7$, about 14 times more efficient. The older figure came from difficult early measurements and was copied from book to book without being re-tested; better instruments in 2008 allowed a careful measurement. A good student checks where a number comes from and when it was measured.
6. Sample: Later researchers found that many fireflies contain bitter defensive chemicals (lucibufagins) and that predators learn to avoid them, so the larval glow probably works as a warning, like a monarch's colors. That answers much of Fabre's question, though details are still studied. Fabre was right to be cautious: he would not claim an answer his observations did not support. His honesty left room for later work.

5.7 DRAGONFLIES: MASTERS OF THE AIR, BORN IN THE WATER

OBJECTIVES

- Describe the dragonfly’s incomplete metamorphosis, including the underwater nymph and its hinged “mask.”
- Explain how four independently driven wings, huge compound eyes and an interception strategy make dragonflies among the most successful hunters known.
- Tell the story of the globe skimmer’s ocean crossing and explain how scientists reasoned their way to it.

Warm-up. Have someone toss a soft ball high in a slow arc. Do not run to where the ball is; run to where it will be, and catch it. You just did what a dragonfly does to a gnat: you intercepted it. Try to describe in words how you knew where to go.

Video slot. Video coming. Dragonfly nymph catching prey with its extendable mask; a dragonfly emerging from its nymph skin; slow-motion dragonfly flight. Search approved channels (Deep Look from KQED, Smithsonian, BBC Earth, U.S. Fish and Wildlife Service, the British Dragonfly Society); preview first.

KEY TERMS

Odonata

The insect order of dragonflies and damselflies, from Greek for “toothed ones,” after their toothed jaws.

nymph (naiad)

The young, wingless water-dwelling stage of a dragonfly, which grows by molting and finally climbs out to become an adult.

incomplete metamorphosis

A life cycle of egg, nymph and adult, with no pupa; the nymph changes gradually, then makes one last great change.

labium (mask)

The nymph’s hinged lower lip, folded under the head and shot forward to grab prey with hooks at its tip.

compound eye

An eye made of thousands of tiny units (ommatidia), each with its own lens; a large dragonfly’s eye may have about 30,000.

interception

Flying toward the point where the prey is going to be, rather than chasing where it is now.

CORE IDEAS

Dragonflies and damselflies. The order Odonata has about 6,000 named species, roughly half dragonflies and half damselflies. You can tell them apart at a glance. A dragonfly is stout, with eyes that nearly meet on top of its head, and it rests with its wings held flat out to the sides like an airplane. A damselfly is slender, with eyes set apart like a hammerhead, and most kinds fold their wings together over the back when resting. Both are hunters, and neither stings or bites people in any way that matters; the old names “devil’s darning needle” and “horse stinger” were false.

A life underwater. Most of a dragonfly’s life is spent not in the air but in a pond, marsh or stream. The female lays eggs in water or plant stems, and the nymph that hatches lives on the bottom for months; in cold places some species stay a nymph for three to five years, while others in warm, temporary pools grow up in weeks. A dragonfly nymph breathes through gills inside its rear end, and by squirting water out it can shoot forward by jet propulsion. Its great weapon is the labium, or “mask,” a hinged lower lip folded under the head. In a fraction of a second it shoots forward, hooks a tadpole, a mosquito larva or even a small fish, and pulls it back to the jaws.

The great change. When it is grown, the nymph climbs a reed at night or at dawn, grips tight and stops moving. Its skin splits down the back, and the adult pulls itself out, rests, then pumps fluid into its crumpled wings and long abdomen. In an hour or two it is ready to fly, though its full colors take days to develop. The empty nymph skin, called an exuvia, stays clinging to the reed. Because there is no resting pupa, this is called incomplete metamorphosis. Solomon wrote that God “hath made every thing beautiful in his time” (Ecclesiastes 3:11): the drab, crawling hunter of the mud becomes a glittering master of the air.

Built for flight. Most insects drive their wings indirectly by flexing the whole thorax. Dragonflies attach powerful flight muscles directly to the base of each of their four wings, so each wing can be moved and twisted separately. They can hover, fly backward, turn on the spot and change the timing of front and hind wings to save energy or gain power. Speeds are hard to measure in the wild; careful studies suggest strong fliers reach roughly 20 to 35 miles per hour in short bursts, while older claims of 60 mph have not held up. Each compound eye of a large dragonfly may have about 30,000 lenses, giving nearly all-around vision, and they see ultraviolet and polarized light that we cannot.

The hunter that predicts. In 2012 a Harvard team filmed dragonflies hunting fruit flies in a large enclosure and found that they caught their prey about 95 percent of the time, a success rate far above lions or hawks. In 2015 scientists showed how: a dragonfly does not simply chase. It keeps the prey at a fixed spot in its vision and steers so that the angle stays constant, flying toward where the prey will be, and it adjusts for its own turns before it makes them. Engineers study this to design guidance systems.

Crossing the ocean. In the Maldiv Islands of the Indian Ocean there is almost no fresh water for dragonfly nymphs, yet every autumn huge numbers of one species, the globe

skimmer (*Pantala flavescens*), arrive. The marine biologist R. Charles Anderson, living there, noticed that they came from the direction of India with the monsoon winds and left toward Africa. He proposed in 2009 that globe skimmers cross the ocean from India to East Africa on high winds and that their children return later, a circuit of perhaps 9,000 to 11,000 miles over several generations, the longest insect migration known. Later studies of the chemical signatures in their wings have supported the idea of long-distance travel. In North America the common green darner makes its own migration south along the coasts each autumn.

Giants in stone, and clean water. Fossils found in France in the 1880s show a dragonfly-like insect, *Meganeura*, with a wingspan of about 27 inches. Museum signs give such fossils an age of about 300 million years; that date is an interpretation, and Christians read it in different ways, but the fossil itself is an observation: insects once grew far larger than any living today. Living dragonflies need clean, healthy water for their nymphs, so biologists use them to judge the health of ponds and streams. A family pond with plants at the edges will often have dragonflies within a season.

PICTURE STUDY



Bellflower and Dragonfly, from an untitled series known as *Large Flowers*, Katsushika Hokusai, About 1830 (the Metropolitan Museum dates its impression to the late 1820s) · Color woodblock print (horizontal ōban, 24.8 × 36 cm) · Metropolitan Museum of Art, New York
Wikimedia Commons · CC0

Katsushika Hokusai, the Japanese master best known for *The Great Wave*, made a series of large flower prints late in life. In this one, Chinese bellflowers (*kikyō*), a flower of early autumn in Japan, crowd across the sheet while a dragonfly hovers above them. In Japanese art the dragonfly (*tombo*) often stood for late summer and for courage, because it flies forward and does not retreat. The blues of this old impression have faded over nearly two hundred years, so look closely.

Look closely

- Find the dragonfly. Is it resting or flying? How can you tell from the wings?
- How does Hokusai arrange the flowers so that the picture feels balanced, with the dragonfly alone in the open space?
- Fresh copies of this design show blue-violet flowers. What colors do you see in this copy, and why might colors fade on paper over time?

Talk about it

1. Count the wings Hokusai drew. Did he show the dragonfly accurately, or simplify it? What would you need to look for to decide whether it is a dragonfly or a damselfly?
2. Hokusai shows two living things from the same season together. What does the pairing say about how he looked at nature?

Safety first. Pond work needs an adult present. Stay off steep or muddy banks, never wade into water you cannot see the bottom of, and wash hands after handling pond water. Return every nymph and creature to the water where it was found.

HANDS-ON: DRAGONFLY PATROL: POND DIP AND HUNTING COUNT

Find dragonfly nymphs in a pond, then watch an adult dragonfly hunt from a perch and measure its success, the way scientists do.

You will need

- A kitchen sieve or aquarium net on a stick and a white plastic tray or dish
- A hand lens and a clear cup
- Binoculars (if you have them), a stopwatch and a clipboard
- A field guide or a dragonfly website for your region

Steps

1. **Pond dip.** With an adult, sweep the net through plants and along the muddy bottom at the pond edge. Empty it into the tray with a little pond water.
2. Look for nymphs: dragonfly nymphs are stout with no tail filaments; damselfly nymphs are slender with three leaf-like gills at the tail. Put one in the clear cup and watch its mask with the hand lens. Return all creatures to the pond.
3. **Hunting count.** On a sunny day, find a dragonfly that keeps returning to the same perch (a stick or reed tip). For 15 minutes, count every flight it makes from the perch.
4. For each flight, record whether it seemed to catch something (look for chewing on return). Estimate the success rate: $\text{catches} \div \text{flights} \times 100$.
5. Compare your number with the 95 percent found in the laboratory. Write two reasons your field number might be different.

Check your work

- I found and identified at least one nymph or exuvia, or recorded that I found none.
- I watched one dragonfly for 15 minutes and recorded every flight.
- I calculated a success rate and gave two reasons it might differ from the lab result.
- Every creature was returned.

FIELD NOTEBOOK

1. **Field Notebook page E7.** Draw a dragonfly and a damselfly side by side, both resting, and label the differences (eyes, wings, body). Below, draw a nymph with its mask folded and then shot out.
2. **Narration (parent keeps).** Write one paragraph telling the life of a dragonfly from egg to adult, ending with one hunting flight. Include the words nymph, mask and interception.

Did you know? Dragonflies have been reported eating hundreds of mosquitoes a day, and their nymphs eat mosquito larvae, so a pond with dragonflies often has fewer mosquitoes nearby. Some male dragonflies guard a stretch of shoreline all day and chase away other males. When a dragonfly gets too hot in the sun, it may point its abdomen straight up at the sky (the “obelisk” posture) to shade its body.

Go deeper. Dennis Paulson, *Dragonflies and Damselflies of the East* (2011) or *of the West* (2009), the standard field guides. Sidney W. Dunkle, *Dragonflies Through Binoculars* (2000). Anna Botsford Comstock, *Handbook of Nature Study* (1911; free online), the lessons on dragonflies and their nymphs. The Museum of Fine Arts, Boston, online page for Hokusai’s print. Second video topic: the globe skimmer’s migration over the Indian Ocean.

Goes deeper in. Life Science, high-school Biology unit “Insects and Other Arthropods” (metamorphosis) and Earth Science, “Ponds and Fresh Water”; and Art, “Japanese Woodblock Prints” (coming soon).

For families. Species counts vary by source (about 6,000–6,400 Odonata). The 95 percent figure is from Combes et al., *Journal of Experimental Biology* (2012), in a laboratory enclosure; the prediction study is Mischiati et al., *Nature* (2015). Speed figures for dragonflies are much debated; the stop gives a cautious range. Anderson’s globe skimmer hypothesis is in *Journal of Tropical Ecology* (2009); later isotope work (Hobson et al., 2012) supports long-distance movement, but the full circuit is still being studied. Hokusai’s series is dated about 1833–1834; impressions are in several museums. The *Meganeura* date is given as a museum interpretation. No public-domain primary source suited this stop, so there is no primary-source box; the project uses field observation instead. See the safety note for pond work.

PRACTICE

1. **EASY** Give two ways to tell a resting dragonfly from a resting damselfly.

2. **EASY** What is the nymph's "mask," and how is it used?
3. **MEDIUM** Why is a dragonfly's life cycle called incomplete metamorphosis, and what is an exuvia?
4. **MEDIUM** A dragonfly made 40 hunting flights in an hour and caught prey on 34. What was its success rate? How does that compare with the lab figure?
5. **CHALLENGE** Explain in your own words how interception differs from pursuit, and why keeping the prey at a constant angle in its vision leads a dragonfly to the meeting point.
6. **CHALLENGE** R. Charles Anderson saw globe skimmers arrive in the Maldives each year though there is almost no fresh water there for nymphs. List the observations and reasoning that led him to propose an ocean-crossing migration, and name one kind of evidence that could test it.

Make it a game • Intercept!. One player (the gnat) walks across a yard along a straight or gently curving path at a steady pace. Another (the dragonfly) starts from the side and must tag the gnat by keeping the gnat at the same angle (for example, always "at my two o'clock") while closing in, never running straight at the gnat. Then try pure chasing. Time both. Which method catches the gnat faster?

Scripture. "He hath made every thing beautiful in his time: also he hath set the world in their heart, so that no man can find out the work that God maketh from the beginning to the end." (Ecclesiastes 3:11, KJV)

A dragonfly nymph spends months or years in the mud before it climbs a reed and becomes beautiful in its time. Solomon adds that God has set a longing to understand in our hearts, yet no one can search out all His work. The study of one insect shows both.

Practice: answers

1. Dragonfly: wings held flat out to the sides, eyes nearly touching, stout body. Damselfly: most fold wings over the back, eyes set apart, slender body.
2. The hinged lower lip (labium), folded under the head; it shoots forward to hook prey and pull it back to the jaws.
3. It has three stages (egg, nymph, adult) and no pupa. An exuvia is the empty nymph skin left on a reed after the adult emerges.
4. $34 \div 40 = 0.85 = 85\%$. That is lower than the 95% measured in the laboratory, where conditions and prey were controlled.
5. Pursuit means flying straight at where the prey is now, so the hunter keeps turning and follows a curved, longer path. Interception means flying toward where the prey will be. If the direction to the prey (its angle in the eye) does not change while the distance shrinks, the two are on a collision course, the same way two ships on a constant bearing will meet. Steering to keep that angle fixed puts the dragonfly on the shortest path to the meeting point.
6. Observations: the Maldives lack the fresh water nymphs need, so the dragonflies were not born there; they arrived in large numbers at a set season with winds from the direction of India and moved on toward Africa; they appear seasonally in East Africa after rains. Reasoning: they must be crossing the ocean, carried by high seasonal winds, and returning in

later generations. Tests: chemical isotope signatures in wings showing where nymphs grew, tracking or radar studies, or records of arrival dates along the route.

5.8 LOCUSTS: THE EIGHTH PLAGUE (EXODUS 10)

OBJECTIVES

- Explain how a solitary grasshopper becomes a swarming locust, with the role of crowding and serotonin, and give the scale of a desert locust swarm in numbers.
- Read Exodus 10 closely and explain the eighth plague as God’s act, including the east wind and the west wind, and the promise of Joel 2:25.
- Tell the story of the Rocky Mountain locust, from the great swarm of 1875 to its disappearance, and weigh the explanations offered.

Warm-up. Catch a grasshopper in a jar (or look at a photo). Measure its body length. Then, if you caught one, release it on open ground and measure how far it jumps. How many body lengths is that? If you could jump the same number of your body lengths, how far would you go?

Video slot. Video coming. Desert locust swarms and hopper bands in East Africa (2019–2021); the change from solitary to gregarious locust. Search approved channels (Food and Agriculture Organization of the United Nations “Desert Locust Watch,” Smithsonian, BBC Earth, a university entomology department); preview first.

KEY TERMS

locust

One of a few grasshopper species that can change form and behavior when crowded and gather in huge marching bands and flying swarms.

solitary and gregarious phases

The two forms of a locust: the shy, green, solitary phase that avoids others, and the boldly colored, restless gregarious phase that seeks them out.

hopper band

A marching mass of wingless young locusts (hoppers) moving together across the ground.

swarm

A flying mass of adult locusts, which may cover hundreds of square kilometers and travel with the wind.

serotonin

A chemical messenger in the nervous system. A rise in serotonin after crowding switches a desert locust toward the gregarious phase.

coast

In the KJV, the border or territory of a land, not only the seashore: “all the coasts of Egypt” means all its territory.

CORE IDEAS

Two insects in one. For a long time entomologists thought the green, solitary grasshopper and the black-and-yellow swarming locust of Africa were different species. In 1921 the Russian-born entomologist Boris Uvarov showed that they are one species in two phases. A desert locust (*Schistocerca gregaria*) living alone in the desert is shy and green and flies at night. When good rains bring a flush of plants, locusts multiply; when the plants dry up, they crowd onto the shrinking green patches. Then they change color, body shape and behavior. They become restless, gather in bands and march, and the adults fly by day in swarms.

The switch. In 2009 a team at Oxford and Cambridge showed what flips the switch. When a solitary locust's hind legs are touched again and again by other locusts for a few hours, the level of serotonin in its nervous system rises, and it begins to behave gregariously. Block the serotonin and crowding does not change it; give serotonin and a lone locust acts like a swarmer. Over generations the change deepens, as crowded mothers produce offspring already set for swarming. A small chemical change in one insect, multiplied by billions, becomes a national disaster.

The scale. A swarm of desert locusts can hold 40 to 80 million locusts in each square kilometer, and large swarms cover hundreds of square kilometers. Each adult weighs about 2 grams and eats roughly its own weight in fresh plants each day. The Food and Agriculture Organization of the United Nations estimates that one square kilometer of swarm eats as much food in a day as about 35,000 people. Swarms ride the wind, often 100 to 150 kilometers a day. In October 1988 swarms from West Africa crossed the Atlantic Ocean and reached the Caribbean, about 5,000 kilometers, in roughly ten days. In plague years the desert locust can invade some 60 countries, about a fifth of the earth's land.

The eighth plague. Exodus 10 places a locust plague in this real world, but it presents it as the act of God, announced in advance and ended at Moses' prayer. Moses warned Pharaoh exactly what would happen "to morrow" if he refused. When Moses stretched out his rod, "the LORD brought an east wind upon the land all that day, and all that night," and in the morning the locusts arrived, from the direction of Arabia and Sinai. They ate everything the hail had left, until there "remained not any green thing." Pharaoh's own servants had begged him: "knowest thou not yet that Egypt is destroyed?" (Exodus 10:7). Then the LORD turned "a mighty strong west wind" and drove every locust into the Red Sea. God used a created thing and a created wind, yet the timing, the scale ("before them there were no such locusts") and the complete removal show His hand. Natural means do not make a miracle less a miracle.

Joel's locusts. Centuries later the prophet Joel saw a locust plague strip Judah, and named four destroyers, "the palmerworm," "the locust," "the cankerworm" and "the caterpillar." Many scholars think these are four Hebrew names for locusts, perhaps at different stages. Joel called the people to "rend your heart, and not your garments" (Joel 2:13), and God promised, "I will restore to you the years that the locust hath eaten" (Joel 2:25).

America's locust. North America had its own locust, the Rocky Mountain locust. In 1874 and 1875 its swarms swept across the Great Plains, eating crops, fence posts, harness leather and the wool off sheep. In 1875 Dr. Albert Child of Nebraska used telegraph reports to estimate one swarm at about 1,800 miles long and 110 miles wide, perhaps the largest gathering of animals ever recorded. In 1877 Governor John Pillsbury of Minnesota proclaimed a day of prayer, and many communities prayed; that summer the swarms lifted and left, and in Cold Spring, Minnesota, settlers built a small chapel in thanks. Within about 25 years the species had vanished: the last living specimens were collected in 1902. The entomologist Jeffrey Lockwood has argued that farmers, by plowing and watering the river valleys where the locusts laid their eggs, destroyed their breeding grounds without knowing it. Christians may thank God for the deliverance and also learn the means He used.

Food and watchfulness. The law of Moses counted some locusts clean to eat (Leviticus 11:22), and John the Baptist lived on "locusts and wild honey" (Matthew 3:4). Dried locusts are about half protein and are still eaten in parts of Africa and Asia. Today the FAO's Desert Locust Watch collects reports from many countries, so teams can spray hopper bands before they take wing. Even so, from 2019 to 2021 East Africa suffered its worst outbreak in decades; Kenya saw swarms bigger than any in about 70 years.

PICTURE STUDY



The Plague of Locusts, James Tissot, About 1896–1902 · Gouache on board · The Jewish Museum, New York
Wikimedia Commons · Public domain

James Tissot was a French painter of fashionable society who, in his fifties, returned to the Christian faith and spent the rest of his life illustrating the Bible. He traveled to Egypt and the Holy Land to study landscapes, dress and light. His Old Testament series, left unfinished at his death in 1902, was completed by assistants. In this picture he tries to paint something nearly unpaintable: a whole sky made of insects.

Look closely

- Where is the horizon? How much of the picture is sky, land and locusts?
- Find the people. How large are they compared with the swarm, and what does that say about the power of the plague?
- Look at the colors. How does Tissot show that the sun is darkened (Exodus 10:15)?

Talk about it

1. Tissot painted from his own visits to Egypt. Which details of the land and buildings help make the scene believable?
2. Read Exodus 10:13-15 in the primary source. Which words do you think Tissot tried hardest to paint? Which are impossible to paint?

HANDS-ON: MAP A PLAGUE: EXODUS 10 AND THE MODERN DESERT LOCUST

Make two maps: one of the eighth plague using the words of Exodus 10, and one of a modern locust outbreak using real data. Then calculate the size of the great American swarm of 1875.

You will need

- An outline map of Egypt, Sinai and the Red Sea and an outline map of Africa and the Middle East
- Colored pencils, a ruler and a calculator
- The primary source and access to the FAO Desert Locust Watch website (or a printed map from it, with a parent)

Steps

1. **Map 1.** On the Egypt map, label the Nile, the Delta, Sinai and the Red Sea with its two northern arms (the Gulfs of Suez and Aqaba). Draw a wide arrow for the “east wind” of Exodus 10:13 and a second for the “mighty strong west wind” of 10:19. Write the verse beside each arrow.
2. Shade the land the locusts covered, using the words “all the land of Egypt” and “all the coasts of Egypt.” Remember that in the KJV “coasts” means borders.
3. **Map 2.** On the Africa and Middle East map, use the FAO Desert Locust Watch maps to shade the countries affected in 2019-2021 (East Africa, Arabia, Iran, Pakistan, India). Draw arrows showing how swarms moved with the seasonal winds.
4. **Calculation.** Albert Child’s 1875 swarm was about 1,800 miles long and 110 miles wide. Find its area in square miles. Compare it with the area of your state (look it up).
5. Write a paragraph: what is the same and what is different between the plague in Exodus 10 and a modern locust plague?

Check your work

- Map 1 shows both winds with their verses and the Red Sea.

- Map 2 shows the 2019–2021 outbreak with wind arrows.
- I calculated the 1875 swarm’s area and compared it with my state.
- My paragraph names at least two likenesses and two differences.

FIELD NOTEBOOK

1. **Field Notebook page E8.** Draw a desert locust in its solitary (green) and gregarious (yellow and black) forms side by side. Label the hind legs (where touch triggers the change), wings, antennae and mouthparts.
2. **Narration (parent keeps).** Write one paragraph retelling the eighth plague as an Egyptian farmer might have seen it, from Moses’ warning to the west wind. Use at least two phrases from the primary source.

Did you know? Locust swarms are so large that they have been tracked by radar and even seen in satellite images of green fields turning brown. Scientists studying the Rocky Mountain locust after it vanished found well-preserved bodies frozen in glaciers in Wyoming and Montana, sometimes called “Grasshopper Glaciers,” where swarms had fallen on the ice long ago.

Primary source. *Exodus 10:4–5, 12–15, 19, King James Version (1611)*

Else, if thou refuse to let my people go, behold, to morrow will I bring the locusts into thy coast: And they shall cover the face of the earth, that one cannot be able to see the earth: and they shall eat the residue of that which is escaped, which remaineth unto you from the hail, and shall eat every tree which groweth for you out of the field: ...

And the LORD said unto Moses, Stretch out thine hand over the land of Egypt for the locusts, that they may come up upon the land of Egypt, and eat every herb of the land, even all that the hail hath left. And Moses stretched forth his rod over the land of Egypt, and the LORD brought an east wind upon the land all that day, and all that night; and when it was morning, the east wind brought the locusts. And the locusts went up over all the land of Egypt, and rested in all the coasts of Egypt: very grievous were they; before them there were no such locusts as they, neither after them shall be such. For they covered the face of the whole earth, so that the land was darkened; and they did eat every herb of the land, and all the fruit of the trees which the hail had left: and there remained not any green thing in the trees, or in the herbs of the field, through all the land of Egypt. ...

And the LORD turned a mighty strong west wind, which took away the locusts, and cast them into the Red sea; there remained not one locust in all the coasts of Egypt.

Go deeper. Jeffrey A. Lockwood, *Locust: The Devastating Rise and Mysterious Disappearance of the Insect That Shaped the American Frontier* (2004). Laura Ingalls

Wilder, *On the Banks of Plum Creek* (1937), the novel chapters on the grasshopper plague in Minnesota, true to the 1870s. The FAO Desert Locust Watch website, with current maps and bulletins. Second video topic: how locust control teams find and treat hopper bands.

Goes deeper in. History, “Moses and the Exodus” and “The Settling of the Great Plains”; Geography, “Deserts and Winds of Africa and Arabia” (coming soon).

For families. Swarm figures (40–80 million per km²; 35,000 people) and the 1988 Atlantic crossing come from the FAO. The serotonin study is Anstey et al., *Science* (2009). Child’s 1875 estimate and the 1902 last specimens are described in Lockwood’s book; his habitat explanation is widely accepted but not certain. Governor Pillsbury’s day of prayer was April 26, 1877; the chapel at Cold Spring is the Assumption (“Grasshopper”) Chapel, rebuilt in 1952. The Hebrew of Exodus 10:19 says “sea wind,” which in Egypt’s geography is usually understood as a wind from the west or northwest; the Hebrew *Yam Suph* is translated “Red sea” in the KJV. The stop does not attempt to date the Exodus. The meaning of Joel’s four insect names is uncertain. Wilder’s novel is a summary recommendation, not quoted.

PRACTICE

1. **EASY** According to the primary source, what did the locusts eat, and what was left?
2. **EASY** What brought the locusts, and what took them away?
3. **MEDIUM** What causes a solitary desert locust to become gregarious?
4. **MEDIUM** A swarm covers 200 km² at 50 million locusts per km², and each eats 2 grams a day. How many metric tons does the swarm eat in a day? (1 metric ton = 1,000,000 grams.)
5. **CHALLENGE** Child’s 1875 swarm was about 1,800 miles long and 110 miles wide. Find its area. California is about 164,000 square miles. How do they compare? If the density was like a desert locust swarm (about 130 million per square mile), how many locusts might it have held? Why is this only a rough estimate?
6. **CHALLENGE** Some people say that if the eighth plague used real locusts and a real wind, it was “just nature.” Using Exodus 10, write three or four sentences answering this claim.

Make it a game • Solitary or Swarm. Everyone starts as a “solitary locust,” walking slowly alone in a marked area. The area slowly shrinks (move the markers in) as the “plants dry up.” Any player whose shoulder is tapped three times by others becomes “gregarious” and must link arms with the tapper and march. Keep shrinking until the whole group is one marching band. Then talk: what made the change spread so fast?

Scripture. “And I will restore to you the years that the locust hath eaten, the cankerworm, and the caterpillar, and the palmerworm, my great army which I sent among you.” (Joel 2:25, KJV)

God calls the locusts “my great army,” for He sent them as a judgment. Yet the same God promises to restore what was lost when His people turn back to Him. Many Christians have taken this verse as a comfort after wasted or painful years.

Practice: answers

1. Every herb of the land and all the fruit of the trees that the hail had left; there remained not any green thing in the trees or the herbs of the field.
2. The LORD brought an east wind that blew all day and all night; then He turned a mighty strong west wind that cast them into the Red Sea.
3. Crowding: repeated touching of its hind legs by other locusts for a few hours raises serotonin in its nervous system, which switches its behavior; over generations, color and body shape change too.
4. $200 \times 50,000,000 = 10,000,000,000$ locusts. $\times 2 \text{ g} = 20,000,000,000 \text{ g} = 20,000$ metric tons a day.
5. $1,800 \times 110 = 198,000$ square miles, about 1.2 times the area of California. $198,000 \times 130,000,000 \approx 25,700,000,000,000$, about 26 trillion. It is rough because the swarm was not a solid rectangle, density varies greatly within and between swarms, and Child’s length and width came from scattered telegraph reports. (Lockwood’s own estimate was several trillion.)
6. Sample: Exodus never hides the means; it names the east wind and the west wind. But it also shows that Moses announced the plague the day before, that it came when he stretched out his rod, that it was worse than any before or after, and that every locust left when God turned the wind, which no ordinary swarm does. God is the Lord of the means He made, and using a wind on His own timetable is still His act. A miracle is not less a miracle because it uses created things.

5.9 JEAN-HENRI FABRE, THE INSECT WATCHER (1823–1915)

OBJECTIVES

- Tell the life of Jean-Henri Fabre, from a poor boyhood in southern France to the harmas at Sérignan and the ten volumes of his *Souvenirs entomologiques*.
- Explain Fabre's method of patient observation and simple experiment, using his correction of Léon Dufour and his test of Darwin's homing question as examples.
- Read Fabre's description of his harmas and design a small experiment of your own in the same spirit.

Warm-up. Go outside and choose one insect. Watch it, and only it, for five full minutes without looking away. Write down everything it does, in order. Was five minutes harder than you expected? Fabre sometimes watched one insect for hours, and came back to it for years.

Video slot. Video coming. Jean-Henri Fabre and his harmas at Sérignan-du-Comtat (now a museum garden of the Muséum national d'Histoire naturelle); Fabre's experiments with hunting wasps and processionary caterpillars. Search approved channels (Muséum national d'Histoire naturelle, Smithsonian, a university entomology department, a travel channel on Provence); preview first.

KEY TERMS

entomology

The scientific study of insects; an entomologist is a person who studies them.

harmas

A Provençal word for a piece of untilled, stony land overgrown with wild plants. Fabre's harmas at Sérignan was his outdoor laboratory for 36 years.

instinct

A complex behavior an animal performs correctly without learning it, such as a wasp stinging its prey in exactly the right place.

experiment

A test in which one condition is changed on purpose while others are kept the same, to see what effect it has.

hunting wasp

A solitary wasp that paralyzes insects or spiders with its sting and stores them, alive, as fresh food for its larvae.

CORE IDEAS

A poor boy who looked. Jean-Henri Fabre was born on December 21, 1823, in the village of Saint-Léons in the rugged Rouergue region of southern France. His parents were poor, and

as a small child he lived with his grandparents on a remote farm, where he watched the animals and plants with a curiosity no one taught him. His family moved often and failed at several small businesses; as a teenager he worked at odd jobs, including selling lemons at a fair, and sometimes slept outdoors. But in 1840 he won a place at the teachers' college in Avignon, and at 18 he became a schoolteacher in Carpentras.

A self-taught scholar. Teaching all day, Fabre taught himself at night. Without regular university classes, he earned degrees in mathematics and the physical sciences, then a doctorate in natural sciences in 1855. He taught in Corsica and then for nearly twenty years at the lycée (high school) in Avignon on a small salary, with a growing family. In the 1850s, a book by the respected naturalist Léon Dufour set his course. Dufour described a wasp, *Cerceris*, that stocked its burrow with jewel beetles that stayed fresh for weeks; he guessed the wasp injected a preserving fluid. Fabre dug up the burrows himself and found the beetles were not dead at all. They were paralyzed: the wasp stung them precisely in the nerve center that controls their legs, so they lived, motionless, as fresh food for its grub. Dufour graciously praised the young teacher's correction, and Fabre had found his life's work.

Setbacks. Fabre tried to escape poverty through chemistry. He developed a better way to extract the red dye of the madder plant, the main crop around Avignon. But in 1868 German chemists made the same dye, alizarin, in the laboratory, and within a few years the madder fields and his hopes were gone. That same year the Minister of Public Instruction, Victor Duruy, who admired him, had him made a knight of the Legion of Honor and presented him to the Emperor Napoleon III. Fabre also gave free evening science classes for adults, including young women. Some in Avignon were offended that he taught girls how flowers produce seed, and in 1870 he lost his lodging and left his teaching post. The English philosopher John Stuart Mill, a friend from their botanizing walks, lent him money to move his family to the nearby town of Orange.

The harmas. For the next years Fabre supported his family by writing clear, lively science textbooks for schools, which sold well. In 1879, at 55, he bought a stony, weedy plot with a house at Sérignan-du-Comtat, near Orange. He called it his harmas, and in the primary source he explains why he wanted it. That same year he published the first volume of his *Souvenirs entomologiques* ("Entomological Memories"). The tenth and last appeared in 1907. In them he told of mason bees, hunting wasps, dung beetles, the sacred scarab, glow-worms and spiders, in a warm, personal style that drew in readers who had never cared about insects.

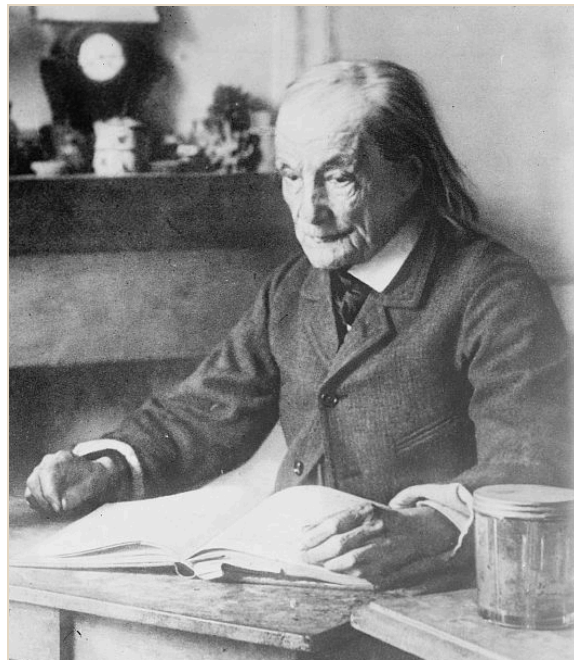
The method. Fabre distrusted conclusions drawn only from dead specimens in drawers. He watched living insects in their own places and asked questions by experiment. He placed pine processionary caterpillars on the rim of a large garden vase, where they followed one another's silk in a circle for about a week before breaking the loop. He kept a female great peacock moth under a wire cover and counted the males who came to her through the night from far away, then tested whether they found her by sight or by scent. Charles Darwin, who called Fabre an inimitable observer, wrote to suggest an experiment on how mason bees find home; Fabre carried bees away in closed boxes, spun them about, released them miles off,

and found that many still came home. Fabre rejected Darwin's theory of the origin of species, and said so plainly, but the two corresponded with respect.

Late honor. For most of his life Fabre was known mainly to specialists and to the readers of his schoolbooks. Then, when he was in his eighties, writers and scientists took up his cause. A jubilee was held for him at Sérignan in 1910, he was proposed for the Nobel Prize in Literature, and in 1913 the President of France, Raymond Poincaré, came to visit him. His books were translated into English and many other languages. He died at the harmas on October 11, 1915, aged 91, during the First World War. His house and garden are now a museum.

Wonder and humility. Fabre knew how little he knew. Again and again he ends a chapter by admitting what he cannot explain, as he did with the glow-worm (Stop E6). He spoke of the Creator and saw in instinct an order no insect could have designed for itself. He shows a student what Psalm 111:2 means: "The works of the LORD are great, sought out of all them that have pleasure therein." His tools were a magnifying glass, a notebook, glass jars, a little ground and endless patience.

PICTURE STUDY



Jean-Henri Fabre seated at a table, Bain News Service (photographer not known), Early 1900s · Photograph · Library of Congress, Prints and Photographs Division (Bain News Service collection), Washington, D.C.
Wikimedia Commons · Public domain

Photographs of Fabre in his last years were printed in newspapers and books after his 1910 jubilee and made his face famous. This one, sent out by the Bain News Service of New York, shows him without his usual wide black hat, seated at a table with an open book and a covered glass jar, like the jars he used to keep living insects for study. The photographer's name and the exact date are not known.

Look closely

- Look at Fabre's face and hands. What do they suggest about his age and his life?
- What objects can you see around him? Which are tools of a scientist and which of a writer?
- Is the photograph posed or candid? What clues tell you?

Talk about it

1. Photographers of the early 1900s needed people to hold still. How might that have shaped the way Fabre appears?
2. If someone photographed you at your study table, what tools would show what kind of student you are?

HANDS-ON: YOUR OWN HARMAS: A FABRE-STYLE EXPERIMENT

Fabre said his questions and answers had "experiment for their language." Design and run a fair, gentle experiment with pill bugs (roly-polies), which are easy to find and harmless. (They are crustaceans, not insects, but Fabre would have studied them happily.)

You will need

- Ten pill bugs from under a log or stone
- A shoebox or shallow tray with a lid that covers half of it
- Two paper towels (one damp, one dry), a timer and a notebook

Steps

1. Read the primary source. Write one question you could ask pill bugs "by experiment," for example: "Do pill bugs prefer damp or dry ground?"
2. Write a hypothesis and a prediction: "If pill bugs prefer damp places, then after ten minutes more will be on the damp side."
3. Set up the box: damp towel on one side, dry on the other, both sides uncovered and equally lit. (Change only one thing at a time.) Put all ten pill bugs in the center.
4. Count how many are on each side every two minutes for ten minutes. Then repeat the whole test two more times, switching which side is damp to rule out a preference for one end of the box.
5. Total your results. Was your hypothesis supported? Write what you would test next (for example, light and dark) and return the pill bugs where you found them.

Check your work

- I wrote a question, a hypothesis and a prediction before testing.
- I changed only one condition and repeated the test three times, switching sides.
- My results are in a table and my conclusion follows from them.
- The pill bugs were returned unharmed.

FIELD NOTEBOOK

1. **Field Notebook page E9.** Make a map of your own “harmas”: one patch of yard or park about three steps square. Mark plants, stones and any insect homes. Visit it three times this week at different hours and list the creatures you see each time.
2. **Narration (parent keeps).** Write one paragraph telling Fabre’s life in order, from Saint-Léons to the harmas. Include his correction of Dufour, one setback and one honor, and end with one habit of his you want to copy.

Did you know? Fabre was a fine painter as well as a writer: he made hundreds of careful watercolors of the mushrooms of his region, which are now kept at the harmas. He also wrote poems in Provençal, the old language of southern France. The great French writer Victor Hugo is said to have called him “the Homer of insects,” though the phrase is often credited to others.

Primary source. *J. Henri Fabre, The Life of the Fly, chapter I, “The Harmas,” translated by Alexander Teixeira de Mattos (1913), Project Gutenberg. The bracketed note is in the edition.*

This is what I wished for, hoc erat in votis: a bit of land, oh, not so very large, but fenced in, to avoid the drawbacks of a public way; an abandoned, barren, sun scorched bit of land, favored by thistles and by wasps and bees. Here, without fear of being troubled by the passersby, I could consult the *Ammophila* and the *Sphex* [two digger or hunting wasps] and engage in that difficult conversation whose questions and answers have experiment for their language; here, without distant expeditions that take up my time, without tiring rambles that strain my nerves, I could contrive my plans of attack, lay my ambushes and watch their effects at every hour of the day. ...

While waiting for the fashion to change, I open my harmas laboratory of living entomology; and this laboratory shall not cost the ratepayers one farthing.

Go deeper. Fabre’s own books in English, free at Project Gutenberg: *The Life of the Fly*, *The Mason-Bees*, *The Life of the Spider* and *The Glow-Worm and Other Beetles*. Edwin Way Teale, ed., *The Insect World of J. Henri Fabre* (1949), the best single-volume selection. Augustin Fabre, *The Life of Jean Henri Fabre, the Entomologist* (English translation 1921; free at Project Gutenberg), by a relative who knew him. The Muséum national d’Histoire naturelle’s page for the Harmas Jean-Henri Fabre. Second video topic: the hunting wasp *Cerceris* and its beetle prey.

Goes deeper in. Life Science, high-school Biology unit “Insects and Other Arthropods” and the unit “The Scientific Method”; Literature, “Great Nature Writers”; and History, “France in the 1800s” (coming soon).

For families. Dates (born December 21, 1823; harmas bought 1879; *Souvenirs* 1879–1907; died October 11, 1915) are standard. The Dufour correction concerns *Cerceris* and buprestid beetles (published 1855). The madder and alizarin story, the 1868 Legion of Honor through Victor Duruy, the 1870 departure from Avignon and John Stuart Mill’s loan are told in Fabre’s biographies; details vary slightly. Darwin’s phrase “inimitable observer” is widely quoted from his published writings; the exact place is not given here. The homing-bee experiment is in the *Souvenirs*. Fabre was proposed for the Nobel Prize in Literature in his last years but did not receive it. The “Homer of insects” phrase is variously attributed and is given here as uncertain. Fabre’s exact religious views are debated; he wrote often of the Creator and opposed materialism, and the stop does not repeat unverified quotations about his faith. The picture-study photograph has no confirmed photographer or date; choose any public-domain photograph of Fabre made before 1915.

PRACTICE

1. **EASY** What is a harmas, and where was Fabre’s?
2. **EASY** In the primary source, name two things Fabre wanted to avoid by having his own fenced harmas.
3. **MEDIUM** What did Léon Dufour think about the beetles in a *Cerceris* wasp’s burrow, and what did Fabre show?
4. **MEDIUM** How old was Fabre when he bought the harmas, when the last volume of the *Souvenirs* appeared, and when he died?
5. **CHALLENGE** Fabre wrote that his questions and answers had “experiment for their language.” Using the processionary caterpillar test or the mason-bee homing test, explain what question Fabre was asking and how his experiment answered it.
6. **CHALLENGE** Fabre rejected Darwin’s theory but admired Darwin and tested his suggestion; Darwin admired Fabre though they disagreed. Write four or five sentences on what this teaches about disagreement in science and how a Christian student should handle it.

Make it a game · Fabre’s Notebook. One player secretly chooses a simple “insect rule” to act out (for example, always turning left at an obstacle, or following the person ahead). The player crawls or walks around a room following the rule while others watch silently and take notes. Watchers may then set one “experiment” each, such as placing an obstacle, to test their guesses. The first to state the rule exactly, with evidence from an experiment, wins.

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

This verse was carved over the door of the Cavendish physics laboratory at Cambridge in Latin. Fabre spent his life seeking out the works of God in a weedy patch of ground and found them great. Delight is the beginning of good study.

Practice: answers

1. A Provençal word for a stony, untilled patch of land overgrown with wild plants. Fabre's was at Sérignan-du-Comtat, near Orange, in southern France; he bought it in 1879.
2. Any two: the drawbacks of a public way; being troubled by passersby; distant expeditions that take up time; tiring rambles that strain his nerves.
3. Dufour thought the beetles were dead and kept fresh by a preserving fluid the wasp injected. Fabre showed they were alive but paralyzed: the wasp stung their nerve center, so they stayed fresh as living food for the wasp's larva.
4. Born December 1823; about 55 in 1879, 83 in 1907 (he turned 84 that December), and 91 at his death in October 1915.
5. Sample (mason bees): Question: do mason bees find home by remembering the twists and turns of the outward trip? Fabre carried bees away in a closed box, whirled the box to confuse any route memory, and released them far from home. Many still returned, so they were not tracing the outward path; they must use some other sense of direction. Sample (caterpillars): Question: do processionary caterpillars follow a goal or only the silk thread ahead? On a closed circle on the vase rim they kept circling for about a week, showing they follow the trail, not a goal.
6. Sample: Fabre and Darwin disagreed about the biggest question in biology, yet each respected the other's honest work, and Fabre carried out Darwin's proposed experiment fairly and reported what he found. Disagreement in science is settled by evidence, careful testing and honest reporting, not by insults. A Christian student can hold firm convictions and still treat opponents with courtesy, test their claims fairly and admit good observations wherever they come from. Proverbs 18:17 notes that a case sounds right until the other side examines it; listening carefully is part of wisdom.

5.10 MAKE A BUG HOTEL: A HOME FOR SOLITARY BEES

OBJECTIVES

- Explain how solitary bees differ from honeybees and how a mason bee builds and provisions her nest.
- Design and build a bee hotel with correct tube sizes, depth, shelter and placement, and plan how to keep it clean.
- Weigh the evidence for and against bee hotels and keep a season-long record of what checks in.

Warm-up. Walk around your house and yard and look for small round holes: in old fence posts, dead branches, brick mortar, hollow plant stems or bare soil. Count them and measure a few with a ruler. Holes about the width of a pencil may be the doors of solitary bees or wasps.

Video slot. Video coming. Mason bees (blue orchard bees) and leafcutter bees nesting in tubes; how to build and clean a bee hotel. Search approved channels (Xerces Society, USDA Agricultural Research Service, a university extension service such as Penn State or Oregon State, Smithsonian); preview first.

KEY TERMS

solitary bee

A bee in which each female builds and stocks her own nest with no queen, workers or hive; most of the world's bee species are solitary.

mason bee

A solitary bee of the genus *Osmia* that nests in existing holes and seals her cells with mud; the blue orchard bee is a common North American kind.

brood cell

One chamber in a nest tube holding a ball of pollen and nectar with a single egg, sealed off from the next cell.

nesting tube

A hollow stem, paper tube or drilled hole closed at one end where a cavity-nesting bee or wasp lays her eggs.

parasitoid

An insect, often a tiny wasp, whose larva feeds on and kills one host, such as a bee larva in its cell.

pollinator

An animal that carries pollen between flowers; bees are the most important pollinators of most fruits and wildflowers.

CORE IDEAS

Bees without hives. When most people think of bees they picture a honeybee hive (Stop E2). But of the roughly 20,000 bee species in the world, and about 4,000 native to the United States and Canada, the great majority are solitary. Each female builds her own nest and raises her young alone. There is no queen, no worker caste and no honey to defend, so most solitary bees are gentle and rarely sting. About seven in ten kinds dig nests in bare soil. Most of the rest nest in ready-made cavities: old beetle tunnels in dead wood, hollow plant stems or cracks. A “bug hotel” or bee hotel offers these cavity-nesters a place to live.

A mason bee’s nursery. In early spring a female blue orchard bee (*Osmia lignaria*), dark metallic blue and a little smaller than a honeybee, chooses a tunnel about the width of a pencil. She gathers pollen and nectar into a moist loaf at the far end, lays one egg on it and seals the cell with a wall of mud. Then she builds another cell in front of it, and another, until the tube is full, and closes the entrance with a thick mud plug. A female can control whether each egg becomes a daughter or a son, and she usually lays daughters in the deep, safe cells at the back and sons near the front. The larva eats its loaf, spins a cocoon and spends the summer and winter inside. Next spring the males, nearest the door, emerge first.

Small but useful. Mason bees carry pollen loose and dry on hairs under the abdomen, so it falls easily onto flowers, and they fly in cool, cloudy weather when honeybees stay home. Fruit growers use them in orchards, and some report that a few hundred nesting females can pollinate an acre of apples or cherries. Leafcutter bees, which line their cells with neat circles cut from leaves, nest in tubes in summer. Solitary wasps use the tubes too: some stock their cells with paralyzed caterpillars or spiders, just as Fabre described in the hunting wasps he studied (Stop E9).

Building it right. Bees are particular. Most cavity-nesting bees use holes from about 1/8 to 3/8 inch (3 to 10 mm) across; mason bees prefer about 5/16 inch (8 mm). Tubes should be about 6 inches (15 cm) deep, since shallow tubes hold mostly sons, and closed at the back. Insides must be smooth, with no splinters to tear wings. The hotel needs a roof that overhangs about two inches to keep rain out, and it should be fixed firmly so it does not swing. Mount it 3 to 6 feet above the ground, facing the morning sun (southeast in North America), within a few hundred feet of spring flowers and a patch of damp clay or mud for mason bees.

The honest problem. Bee hotels are popular, and some sold in stores are little more than decorations stuffed with pine cones, straw and wide bamboo. In 2015 two Canadian researchers checked about 600 bee hotels around Toronto over three years. Native bees did use them, but so did introduced bees from Europe and Asia, and many cells were taken over by parasitoid wasps. Hotels left for years without cleaning can build up mites, fungus and parasites, so that they harm the bees they meant to help. The lesson is not “don’t build one,” but “build it well and keep it.” Use paper liners or removable tubes, replace them every year, keep several small hotels rather than one giant one, and remember the ground-nesters by leaving a sunny patch of bare soil.

Keeping a record. A bee hotel is also a laboratory. Over one season a careful observer can learn which tubes fill first, which diameters each kind of bee chooses, what material they plug with (mud, chewed leaves, resin or grass) and when they emerge. These are the same kinds of notes Fabre kept at his harnas. Many university and citizen-science projects welcome such records.

Little and wise. Agur, whose words are recorded in Proverbs 30, wrote of “four things which are little upon the earth, but they are exceeding wise”: the ants, the conies, the locusts and the spider. They appear on this trail: the ant that stores without a ruler (Stop E1), the locusts that march “by bands” (Stop E8), the spider in kings’ palaces (Stop E4). Building a home for small creatures is a way of practicing the work God gave Adam, to dress and keep the garden (Genesis 2:15), and of learning wisdom from the little things.

PICTURE STUDY



Picture Book of Selected Insects (Ehon mushi erami), Kitagawa Utamaro, 1788 · Two woodblock-printed books; ink, color and mica on paper (each about 9¾ × 7 inches) · The Metropolitan Museum of Art, New York (2013.852a, b), and other collections
Wikimedia Commons · CC0

In 1788 the young Kitagawa Utamaro (whose firefly print appears in Stop E6) designed this picture book of fifteen double-page scenes of garden plants and small creatures. Each picture is paired with comic poems by different poets, written as if in a contest between the insects. The Metropolitan Museum calls it a pivotal work that established Utamaro’s career. The prints use mica to give a shimmer, like light on an insect’s wing.

Look closely

- Choose one double page. Count the creatures. Which are insects (six legs) and which are not?

- How does Utamaro show the texture of a leaf, a wing or a shell with only carved lines and flat color?
- Where does he place the creatures: in the center, at the edges, hidden among plants? Why?

Talk about it

1. Utamaro shows insects in their own small world among plants, much as a bee hotel invites them into yours. What would a page of your yard's "selected insects" include?
2. Why might an artist famous for pictures of people have chosen insects for the book that made his name?

Safety first. An adult should do or closely supervise all drilling and sawing; wear safety glasses and clamp the wood. Use untreated wood only (treated lumber is toxic to bees). Mount the hotel securely at a height an adult can reach from the ground, not from a ladder. If paper wasps or yellowjackets build a nest on the hotel, keep away and ask an adult to deal with it.

HANDS-ON: BUILD, PLACE AND KEEP A BEE HOTEL

Build a small, well-designed bee hotel, place it correctly, and keep a season-long record. Choose Option A (drilled block with paper liners) or Option B (a can of paper tubes).

You will need

- Option A: an untreated 4 × 4 or 2 × 6 board about 8 inches long, a drill with 5/16-inch and 1/4-inch bits at least 6 inches long, and paper liners or rolled parchment tubes to fit the holes
- Option B: a clean tin can or a 4-inch length of PVC pipe, with a closed back (a cap or a wood block), and 30 to 40 paper nesting tubes or hollow plant stems (bamboo with nodes, teasel, sumac) about 6 inches long
- A scrap of wood or shingle for a roof, screws and a sturdy post, fence or wall
- A notebook, a ruler and a camera or sketchbook

Steps

1. Plan: draw your design with measurements. Use mostly 5/16-inch (8 mm) holes for mason bees and some 1/4-inch (6 mm) holes for smaller bees, about 3/4 inch apart, 6 inches deep, closed at the back.
2. Build: an adult drills the holes (Option A) or packs the tubes tightly into the can so they cannot slide (Option B). Sand rough openings. Add a roof that overhangs the front by about two inches.
3. Place: before early spring, mount it firmly 3 to 6 feet up, facing southeast, where it gets morning sun. Check that spring flowers and a patch of damp, clay-rich mud are nearby; if not, make a mud patch.

4. Record: every week from spring to fall, count the plugged tubes and note the plug material (mud, leaf, resin, grass) and the date. Note any visitors you see entering, and any parasitic wasps lingering at the holes.
5. Keep: in fall, move the hotel to an unheated shed or garage to protect it from birds and wet. Next spring, put fresh liners or tubes in place and set the old ones nearby so bees can emerge. Never reuse liners year after year.

Check your work

- My design drawing shows hole sizes, depth, spacing and the roof.
- The hotel is closed at the back, smooth inside, roofed and firmly mounted facing the morning sun.
- I kept at least eight weekly records with dates, counts and plug types.
- I wrote a plan for cleaning and replacing tubes each year.

FIELD NOTEBOOK

1. **Field Notebook page E10.** Draw a cut-away view of a mason bee's nest tube: the pollen loaves, eggs or cocoons, mud walls and the final plug. Label which cells hold daughters and which hold sons.
2. **Narration (parent keeps).** Write one paragraph arguing for or against building bee hotels, using the 2015 Toronto study and at least two design rules. End with your own decision and why.

Did you know? Some solitary bees are tiny: certain sweat bees are only a few millimeters long. Others are large and noisy, like the carpenter bees that drill their own tunnels in porch beams. Male carpenter bees hover at your face and look fierce, but males have no sting at all. And a blue orchard bee female may make 15 to 20 trips for each cell's pollen loaf.

Go deeper. The Xerces Society, "Nests for Native Bees" and its other free guides on pollinator habitat. Joseph S. Wilson and Olivia Messinger Carril, *The Bees in Your Backyard: A Guide to North America's Bees* (2016). Heather Holm, *Bees: An Identification and Native Plant Forage Guide* (2017). J. Scott MacIvor and Laurence Packer, "'Bee Hotels' as Tools for Native Pollinator Conservation: A Premature Verdict?" *PLoS ONE* (2015), free online. Second video topic: harvesting and cleaning mason bee cocoons.

Goes deeper in. Gardening & Animals, "A Pollinator Garden" and "Beekeeping and Pollinators"; and Life Science, high-school Biology unit "Ecology and Stewardship" (coming soon).

For families. Bee species totals are approximate (about 20,000 worldwide and about 4,000 in the United States and Canada). The share of ground-nesters (about 70 percent) is a common estimate. Hole sizes, depth and placement follow Xerces Society and university extension guidance. The orchard pollination figure is reported by growers and

varies widely; it is given cautiously. The Toronto study is MacIvor and Packer, *PLoS ONE* (2015). In Proverbs 30:26 the “conies” are rock hyraxes, and in 30:28 the Hebrew word the KJV renders “spider” may mean a lizard such as a gecko. This stop has no primary-source box; the project is a season-long field record. See the safety note before drilling.

PRACTICE

1. **EASY** Give two differences between a solitary bee and a honeybee.
2. **EASY** What size hole and what depth do mason bees prefer?
3. **MEDIUM** Why should nest tubes be deep rather than shallow?
4. **MEDIUM** A tube is 6 inches deep. Each mason bee cell is about 3/8 inch long plus a 1/8-inch mud wall, and the entrance plug and empty vestibule take 1 inch. How many cells fit in the tube?
5. **CHALLENGE** In the Toronto study, introduced bees and parasitoid wasps used many bee hotels. List three design or care choices that could tip a hotel toward helping native bees, and explain each.
6. **CHALLENGE** Proverbs 30:24–28 names four little creatures that are “exceeding wise.” Choose two that appear on this trail and, using facts from their stops, explain in four or five sentences what wisdom each shows.

Make it a game • Who Checked In? Make clue cards for guests at a bee hotel: “plug of mud” (mason bee), “plug of neat leaf circles” (leafcutter bee), “plug of grass stems” (grass-carrying wasp), “plug of resin” (resin bee), “paralyzed caterpillars inside” (potter or mason wasp), “tiny metallic wasp lingering at the hole” (parasitoid). Read a clue; the first player to name the guest keeps the card. Then try it with your own hotel’s real plugs.

Scripture. “There be four things which are little upon the earth, but they are exceeding wise: The ants are a people not strong, yet they prepare their meat in the summer; The conies are but a feeble folk, yet make they their houses in the rocks; The locusts have no king, yet go they forth all of them by bands; The spider taketh hold with her hands, and is in kings’ palaces.” (Proverbs 30:24–28, KJV)

Agur saw wisdom in the smallest creatures: foresight, safe homes, order and persistence. A bee hotel is a little house in the rocks for creatures that are “not strong.” Caring for them is part of the stewardship God gave mankind, and watching them is a school in wisdom.

Practice: answers

1. Any two: each solitary female builds her own nest; there is no queen or worker caste; no hive or stored honey; solitary bees are usually gentle and rarely sting; most nest in soil or holes rather than wax comb.
2. About 5/16 inch (8 mm) across and about 6 inches (15 cm) deep, closed at the back.
3. A mason bee lays daughters in the deep cells at the back and sons near the front. Shallow tubes leave room mostly for sons, so the next year’s population has fewer egg-laying females.

4. Usable length = $6 - 1 = 5$ inches. Each cell plus wall = $\frac{3}{8} + \frac{1}{8} = \frac{1}{2}$ inch. $5 \div \frac{1}{2} = 10$ cells.
5. Sample: (1) Use mostly 5/16-inch and smaller holes suited to native mason and small leafcutter bees, since some introduced species favor other sizes. (2) Use paper liners and replace them every year, so parasites, mites and mold do not build up. (3) Keep several small hotels spread apart rather than one large one, so parasitoids cannot easily find many nests in one place. Also: store over winter in a shed; plant native spring flowers nearby; provide mud for native mason bees.
6. Sample: The ants “prepare their meat in the summer”; harvester ants store seed for the dry season, and colonies organize their work by simple signals with no ruler, which shows foresight and diligence (Stop E1). The locusts “have no king, yet go they forth all of them by bands”; crowded desert locusts change and march together in vast bands with no leader (Stop E8). Each is small and weak alone, but by order, foresight and working together it does great things. The lesson for us is that wisdom is not size or strength but living according to the order God built in.

TRAIL 5 BADGE QUIZZES

The badge quizzes are optional. Answer in complete sentences, and show work on any calculation. Four right out of five on each quiz earns that badge. Badges and the certificate are earned by doing the stops, not by scores; a parent may accept an oral answer.

Badge quiz 1 (Stops 1–5)

1. Proverbs 6:7 says the ant has “no guide, overseer, or ruler.” Explain how a colony finds and uses a good food source without a leader.
2. What do the angle and the length of the waggle run tell other bees? What was Langstroth’s “bee space,” and why did it matter?
3. What is the monarch’s “super generation,” and where do eastern monarchs spend the winter?
4. Give three ways a spider differs from an insect, and explain what ballooning is.
5. About what fraction of named animal species are beetles? Describe the bombardier beetle’s defense.

Badge quiz 2 (Stops 6–10)

6. Name the parts of the firefly’s light reaction and explain how the firefly switches its light on.
7. How do dragonflies catch prey about 95 percent of the time in laboratory tests?
8. According to Exodus 10, what brought the locusts and what removed them? What turns a solitary desert locust into a swarming one?
9. What did Fabre discover about the beetles in the burrow of the *Cerceris* wasp, and what was his harmas?
10. Give three rules for a well-made bee hotel and one reason bee hotels can do harm if neglected.

TRAIL CERTIFICATE: SMALL CREATURES FIELD NOTEBOOK AND TRAIL E CERTIFICATE

Gather the ten Field Notebook pages from this trail into one bound notebook titled “Small Creatures: A Field Notebook,” with your name and the dates you began and finished.

Include the data and graphs from at least three projects (for example, the ant trail experiment, the beetle survey, the firefly flash count, the dragonfly hunting count or the pill bug experiment), and your bee hotel record if you built one.

Add the ten narration paragraphs, kept by a parent, and one page copying a primary source from the trail in your best handwriting with a short reflection on what it teaches.

When the notebook is complete, a parent reviews it with the rubric and signs the Trail E certificate.

- **Observation:** Drawings are made from real specimens or careful study of photographs, are accurately labeled, and show close looking (body parts, proportions, behaviors).

- **Data and method:** At least three projects include a question or hypothesis, a clear table of measurements, a labeled graph and a conclusion that follows from the data.
- **Narration and sources:** Narration paragraphs are accurate, in the student's own words, use the trail's key terms and quote primary sources exactly where used.
- **Stewardship and care:** Living creatures were handled gently and released, safety notes were followed, and the student can explain one way to care for small creatures at home.

Answer key

1. A forager who finds food lays a pheromone trail home; others follow it and, if they find food, lay more scent. Good sources gain strong trails and many ants, while trails to poor sources evaporate. No ant gives orders; simple responses by many ants produce the colony's choice.
2. The angle of the waggle run from vertical shows the food's direction relative to the sun; the length of the waggle shows the distance. Bee space is a gap of about 1/4 to 3/8 inch that bees leave open; frames hung with that gap all around stay free, so combs can be removed without cutting or killing the colony.
3. The late-summer generation that delays breeding, migrates south up to about 3,000 miles and lives up to about eight months. Eastern monarchs winter in oyamel fir forests at about 10,000 feet in the mountains of Michoacán and the State of Mexico.
4. Any three: eight legs, two body sections, no antennae, no wings, fangs (chelicerae) and spinnerets. Ballooning is travel through the air on silk threads lifted by wind and the earth's electric field.
5. About one-quarter (some 400,000 species). It mixes hydroquinones and hydrogen peroxide in a reaction chamber with enzymes, producing a near-boiling, irritating spray fired in rapid pulses (about 500 a second) that it can aim.
6. Luciferin, the enzyme luciferase, oxygen and ATP. A nerve signal releases nitric oxide, which briefly shuts down the mitochondria in the lantern so oxygen reaches the luciferin and the light flashes.
7. They intercept rather than chase: they keep the prey at a constant angle in their vision and steer toward where it will be, using four independently controlled wings and huge compound eyes.
8. The LORD brought an east wind all day and all night, and then turned a mighty strong west wind that cast the locusts into the Red Sea. Crowding: repeated touching of the hind legs raises serotonin, switching the locust to the gregarious phase.
9. They were not dead and preserved, as Léon Dufour thought, but paralyzed by a precise sting, so they stayed fresh as living food for the wasp's larva. The harmas was his stony, weedy plot at Sérignan, bought in 1879, which he used as an outdoor laboratory of living insects.
10. Any three: holes about 1/8 to 3/8 inch, mostly 5/16 inch for mason bees; about 6 inches deep and closed at the back; smooth inside; a roof overhang; firmly mounted 3–6 feet up facing the morning sun; near flowers and mud. If tubes are never cleaned or replaced, mites, mold and parasitoids build up and kill the bees.

ANIMALS TRAIL F: ANIMALS DOING AMAZING THINGS

The sixth trail of the Animals track studies what animals can do: bats and dolphins that see with sound, creatures that hide in plain sight, hibernators that let their bodies go nearly cold, beavers and weaver birds that build, partners that live together, the sea otter and its rock, record-setting migrations, the sled dogs of the 1925 serum run to Nome, inventions engineers copied from creatures, and Adam naming the animals in Genesis 2. Each stop has a short reading with numbers and history, a picture study, a hands-on project or experiment, a narration, practice problems, a game and a passage of Scripture.

This is the  **Expert** level, for students 14 and up, working mostly on their own for 35 to 50 minutes a stop. Expert stops add primary sources (Herodotus, Gilbert White, Enos Mills, Wilbur Wright and Genesis), real measurements and calculations, “honest complexity” sections that show where scientists disagree or once got it wrong, and a “Go deeper” list of books, museum pages and a second video topic. Each stop asks for one written narration paragraph that the parent keeps. The track is creation-friendly: animals are described as God’s handiwork, made “after his kind,” and conservation is taught as good stewardship (Genesis 2:15).

Stops 1–5 earn the **Amazing Animals Expert badge, part 1**, and stops 6–10 earn part 2 and the **Trail F certificate**. The two badge quizzes at the end are optional; badges and the certificate are earned by completing the stops and the Field Notebook.

BEFORE YOU BEGIN

- Comfortable with ratios, percents, unit conversions and the formula distance = speed × time.
- Able to read a nineteenth-century or King James text slowly and summarize it in your own words; Trails A–E are helpful but not required.

MASTERY CHECKLIST

- ☐ I can explain echolocation, camouflage and hibernation with at least one number or measurement for each.
- ☐ I can describe how beavers, weaver birds and sea otters build or use tools, and how sea otters protect kelp forests.
- ☐ I can classify partnerships as mutualism, commensalism or parasitism and tell where a real example does not fit neatly.
- ☐ I can tell the story of the 1925 serum run and of the Wright brothers’ wing warping accurately, with dates and credit to all who earned it.
- ☐ I can read a primary source critically, separating what the writer observed from what he could not know, and write a binomial name correctly.

OPTIONAL BOOKS AND RESOURCES

- **Project Gutenberg** (<https://www.gutenberg.org>): Free full texts of the trail's primary sources: Gilbert White's *Natural History of Selborne* (#1408), Herodotus's *Account of Egypt* (#2131), Enos Mills's *In Beaver World* (#42282) and the Wrights' *Early History of the Airplane* (#25420).
- **Biodiversity Heritage Library** (<https://www.biodiversitylibrary.org>): Free scans of Thayer's *Concealing-Coloration*, Audubon's *Quadrupeds*, John Ray and Linnaeus's *Systema Naturae*.
- **Cornell Lab of Ornithology (All About Birds, eBird, BirdCast)** (<https://www.allaboutbirds.org>): Free species pages, migration forecasts and a place to record the migrants you see for Stop F7.
- **Smithsonian National Air and Space Museum: the 1903 Wright Flyer** (<https://airandspace.si.edu>): Photographs and history of the Wright Flyer for Stop F9.

6.1 ECHOLOCATION: SEEING WITH SOUND

OBJECTIVES

- Explain how a bat or dolphin builds a picture of its world from echoes, using the speed of sound to find distance.
- Trace the history of the “bat problem” from Spallanzani (1793) to Griffin and Galambos (1938-1944).
- Calculate echo delays and wavelengths and explain why high-pitched calls find small prey.

Warm-up. Stand in a large empty room or a stairwell and clap once. Then stand outside in an open field and clap. What changed? Now close your eyes, have someone hold a large book a few inches from your face, and hum or say “shh” steadily. Many people can sense the book without seeing it. You have just used the faint beginnings of echolocation.

Video slot. Video coming. Bat echolocation slowed down: a bat-detector recording of the “feeding buzz,” high-speed video of a bat catching a moth, and dolphin echolocation in U.S. Navy or aquarium research. Search approved channels (Smithsonian Channel, BBC Earth, National Park Service, Bat Conservation International, Monterey Bay Aquarium); preview first.

KEY TERMS

echolocation

Finding objects by sending out sounds and listening to the echoes that bounce back. The word was coined by Donald Griffin in 1944.

ultrasound

Sound too high for human ears, above about 20,000 vibrations per second (20 kilohertz, kHz).

frequency

The number of sound vibrations per second, measured in hertz (Hz); we hear high frequency as high pitch.

wavelength

The length of one sound wave: the speed of sound divided by the frequency. Objects much smaller than the wavelength return little echo.

feeding buzz

The rapid burst of calls, up to roughly 200 per second, a bat makes in the last moment before it catches an insect.

melon

The fatty, rounded organ in a dolphin’s forehead that focuses its clicks into a beam.

CORE IDEAS

The bat problem. In 1793 Lazzaro Spallanzani, an Italian priest and professor at the University of Pavia, noticed something strange. His owls could not fly in a pitch-dark room, but his bats could, weaving between silk threads he had strung across the room without touching them. He blinded some of the bats, and they still flew well. The next year a Swiss surgeon, Charles Jurine, plugged bats' ears with wax, and they blundered into walls. So the bats were somehow "seeing" with their ears. But no one could hear the bats making any sound, and many scholars thought the idea was silly. The puzzle sat unsolved for almost 150 years.

The answer arrives. In 1938 a Harvard student named Donald Griffin brought a cage of bats to the physicist George Washington Pierce, who had built a device that could pick up sounds too high for human ears. When the bats flew past the microphone, the machine crackled with calls. With Robert Galambos, Griffin showed that bats shout in **ultrasound** and steer by the echoes; when their mouths or ears were covered, they struck obstacles. In 1944 Griffin gave the skill a name: **echolocation**. Spallanzani's careful experiment had been right all along; it was simply waiting for a tool that could measure what he could not hear.

The physics. Sound travels through air at about 343 meters per second (about 1,125 feet per second) at room temperature. If a moth is 1.7 meters away, the call goes out 1.7 meters and the echo comes back 1.7 meters, a 3.4-meter trip that takes about 0.01 second, or 10 milliseconds. A bat's brain measures that delay and turns it into distance. It compares the echo reaching its left ear with the one reaching its right ear to tell direction. It uses the loudness of the echo to judge size, and changes in pitch (the Doppler effect) to tell whether something is moving toward it or away. Why such high pitches? The **wavelength** of a 50 kHz call is only about 7 millimeters, small enough to bounce well off a gnat. A low hum with a wavelength of a meter would pass around an insect almost as if it were not there.

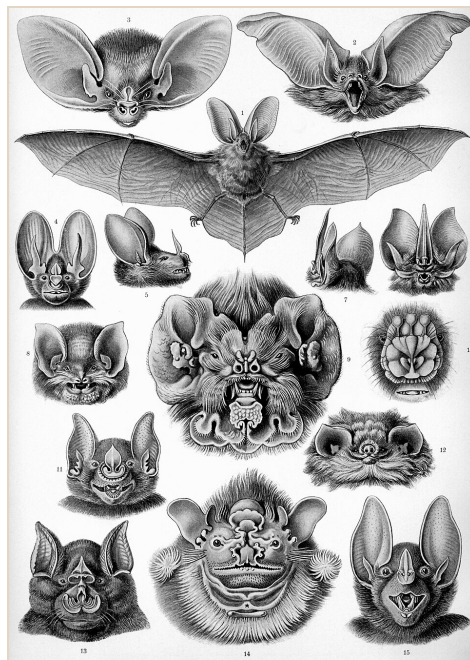
Built for the job. Some bats call as loudly as a smoke alarm held next to your ear. To keep from deafening themselves, many contract tiny muscles in the middle ear with each call, then relax them in time to hear the echo. As a bat closes on an insect it calls faster and faster, from about 10 calls a second while searching to the **feeding buzz** of up to about 200 a second at the end. Horseshoe bats even lower the pitch of their calls as they speed up so that the echo comes back in the narrow band their ears hear best. Not every bat echolocates: of more than 1,400 kinds of bats, most of the large fruit bats of Africa, Asia and Australia find their way by sight and smell.

Echoes in the sea. Toothed whales, including dolphins and sperm whales, echolocate underwater, where sound travels more than four times faster than in air (about 1,500 meters per second). A dolphin makes clicks in its nasal passages, focuses them through the fatty **melon** in its forehead and "hears" the echoes through fat in its lower jaw. In tests by U.S. Navy researchers, bottlenose dolphins have detected small metal balls more than 100 meters away and told objects apart by what they were made of. Two kinds of birds also echolocate: the oilbird of South America and the cave swiftlets of Asia, both using clicks people can hear, to find their way in dark caves.

Honest complexity. Echolocation is not a perfect super-sense. Echoes are faint (an echo from a moth may be a tiny fraction of the call's strength), rain and clutter confuse it, and some prey fight back. Many moths have ears tuned to bat calls and dive or loop when they hear one; some tiger moths click back, which seems to warn bats that they taste bad, and at least one kind appears to jam the bat's sonar. Scientists still debate exactly how a bat's brain sorts out its own echoes when dozens of bats hunt in one place. These are open questions, not settled ones.

“He that planted the ear.” People built ship sonar in the twentieth century, after the *Titanic* disaster of 1912 and the submarine warfare of World War I made engineers want to “see” underwater. The bat and dolphin had been doing it all along, with equipment that fits in a skull the size of a thumb or a melon. The psalmist asked, “He that planted the ear, shall he not hear?” The more carefully we study the ear of a bat, the more that question turns to wonder at the One who planted it.

PICTURE STUDY



Chiroptera (Bats), Plate 67 of *Kunstformen der Natur (Art Forms in Nature)*, Ernst Haeckel, 1904 · Color lithograph (printed from Haeckel's drawings) · From the book *Kunstformen der Natur*; copies in many libraries and on the Biodiversity Heritage Library
Wikimedia Commons · Public domain

The German zoologist Ernst Haeckel drew the faces of bats from many lands and arranged them like a decorative pattern. Haeckel held views about origins that this course does not share, but his drawings are careful and beautiful. Look closely: these strange faces are sound equipment. Large ears catch faint echoes, and the folded “nose leaves” of some bats help shape and aim calls sent out through the nose.

Look closely

- Compare the ears. Find the largest pair relative to the head, and the smallest.
- Find the bats with a leaf or horseshoe shape on the nose. These are mostly bats that call through their noses.
- Look at the bat in the center with wings spread. Count the long finger bones in the wing.

Talk about it

1. If a bat's ears and nose are shaped to send and catch sound, what might a very large ear tell you about how that bat hunts?
2. Haeckel arranged real animals into a symmetrical design. Is that good science, good art, or both? Explain.

Safety first. For the echo project, work in a parking lot, empty field or schoolyard with a parent, well away from traffic. Never step backward toward a road while measuring.

HANDS-ON: MEASURE THE SPEED OF SOUND WITH AN ECHO

Bats measure distance by timing echoes. You can turn the problem around: if you know the distance to a wall, timing the echo tells you the speed of sound. This is the same method used by scientists in the 1600s and 1700s.

You will need

- A large flat wall with open ground in front of it (the side of a gym, warehouse or church)
- A long tape measure, or a pace you have measured
- Two wooden blocks to clap together, or your hands
- A stopwatch (a phone timer works) and a helper
- Field Notebook and calculator

Steps

1. Measure a spot 50 to 100 meters straight out from the wall. Write the distance down.
2. Clap the blocks once, sharply, and listen for the echo. Move until the echo is clear.
3. Now clap in a steady rhythm, adjusting your speed until each clap lands exactly on the echo of the one before. Your helper times 20 claps.
4. Each interval between claps equals the time for sound to travel to the wall and back. Divide the total time by 20 to get one interval.
5. Compute speed = $(2 \times \text{distance}) \div \text{interval}$. Repeat three times and average.
6. Compare your answer with 343 m/s. Write two reasons your answer might differ (reaction time, temperature, wind, measuring error).

Check your work

- I recorded the distance, three timings and my average.

- I showed the formula and the arithmetic.
- I named at least two sources of error and which way each would push my answer.

FIELD NOTEBOOK

1. **Narration.** Without looking back at the lesson, write one paragraph telling how scientists solved the “bat problem,” from Spallanzani’s dark room to Griffin’s microphone. Include at least one date and explain what Jurine’s experiment proved. Your parent keeps this page.
2. Draw a bat hunting a moth. Show the outgoing call as wide arcs and the returning echo as smaller arcs. Label: call, echo, distance, time delay.
3. Copy White’s description of his tame bat (see the primary source) and underline every detail he observed with his own eyes.

Did you know? A single little brown bat may catch hundreds of small insects in an hour of hunting, which is why farmers and gardeners count bats as friends. Bats are mammals, not birds; Leviticus 11:19 lists the bat among flying creatures in the clean-and-unclean food laws, sorting by how creatures live rather than by modern classification. Some blind people have trained themselves to echolocate by tongue clicks well enough to ride a bicycle.

Primary source. *Gilbert White, The Natural History of Selborne, Letter XI to Thomas Pennant (1767); Project Gutenberg eBook #1408.*

I was much entertained last summer with a tame bat, which would take flies out of a person's hand. If you gave it anything to eat, it brought its wings round before the mouth, hovering and hiding its head in the manner of birds of prey when they feed. The adroitness it showed in shearing off the wings of the flies, which were always rejected, was worthy of observation, and pleased me much.

White, a country parson, was one of the finest observers of animals in English history. Notice what he could see and what he could not: he watched his bat eat but had no way to know how it found flies in the dark. Practice question 6 asks you to think like him.

Go deeper. Donald R. Griffin, *Listening in the Dark* (1958), the classic account by the man who solved the puzzle; Gilbert White, *The Natural History of Selborne* (free on Project Gutenberg); Bat Conservation International (batcon.org) for species pages and bat-detector recordings; a second video topic: “how dolphins echolocate” or “tiger moths jamming bat sonar.”

Goes deeper in. Life Science (high school), the unit on the senses and the nervous system (coming soon); Arithmetic and physics practice with rates (distance = speed × time).

For families. Spallanzani's experiments date from 1793 and Jurine's from 1794; Griffin and Galambos worked with G. W. Pierce's ultrasonic detector at Harvard beginning in 1938, and Griffin coined "echolocation" in 1944. The speed of sound used here (343 m/s) is for dry air at 20 °C. Call rates and frequencies vary widely by species; the figures given are typical ranges. The dolphin detection distance is hedged ("more than 100 meters") because results differ by target and test. Haeckel was a leading promoter of evolutionary theory; his plate is used for its accurate drawing only. Spallanzani's blinding of bats would be judged harsh today; it was common laboratory practice in his day and is mentioned plainly.

PRACTICE

1. **EASY** What did Jurine's 1794 experiment show that Spallanzani's did not?
2. **EASY** Why could no one in 1793 hear the bats' calls?
3. **MEDIUM** Name three things a bat can learn from an echo besides "something is there."
4. **CHALLENGE** A bat calls when a moth is 5 meters away. Using 343 m/s for the speed of sound, how long until the echo returns? A dolphin clicks at a fish 5 meters away in water (1,500 m/s). How long for its echo?
5. **CHALLENGE** Wavelength = speed ÷ frequency. Find the wavelength in air of (a) a 2,000 Hz sound a person can hear and (b) a 50,000 Hz bat call. Use your answers to explain why bats use ultrasound to hunt gnats about 3 mm long.
6. **MEDIUM** Read Gilbert White's primary source. List two things White directly observed and one question his observation could not answer.

Make it a game • Bat and Moth. Played indoors on soft ground or outside on grass. One player, the Bat, is blindfolded inside a circle of players. Two or three Moths walk slowly inside the circle. When the Bat calls "Bat!", every Moth must answer "Moth!" at once. The Bat moves toward the sounds and tries to tag a Moth. A tagged Moth becomes the next Bat. Walking only; the circle keeps the Bat safe.

Scripture. "He that planted the ear, shall he not hear? he that formed the eye, shall he not see?" (Psalm 94:9, KJV)

The psalmist argues from design to the Designer: the One who made ears and eyes is not deaf or blind. A bat's ears, tuned to echoes thousands of times fainter than its call, make the argument even stronger.

Practice: answers

1. Spallanzani showed bats did not need their eyes; Jurine plugged their ears and the bats crashed, showing they needed their ears to fly in the dark.
2. Most bat calls are ultrasound, above about 20 kHz, too high for human ears. It took Pierce's electronic detector to reveal them.
3. Any three: distance (from the time delay), direction (comparing the two ears), size (loudness of the echo), whether it is moving and which way (Doppler shift in pitch), texture or

wingbeats (flutter in the echo).

4. Bat: round trip $10 \text{ m} \div 343 \text{ m/s} \approx 0.029 \text{ s}$ (about 29 milliseconds). Dolphin: $10 \text{ m} \div 1,500 \text{ m/s} \approx 0.0067 \text{ s}$ (about 6.7 milliseconds), more than four times faster.
5. (a) $343 \div 2,000 \approx 0.17 \text{ m}$ (17 cm). (b) $343 \div 50,000 \approx 0.0069 \text{ m}$ (about 7 mm). A 17 cm wave mostly passes around a 3 mm gnat and returns almost no echo; a 7 mm wave is close to the gnat's size and reflects much better, so high pitch lets the bat detect tiny prey.
6. Observed (any two): the bat took flies from a hand; it wrapped its wings around its mouth while eating; it sheared off and dropped the flies' wings. Unanswered: how a bat finds flies in the dark (or any similar question about senses he could not test).

6.2 CAMOUFLAGE: THE ART OF NOT BEING SEEN

OBJECTIVES

- Name and explain five kinds of camouflage: background matching, countershading, disruptive coloration, masquerade and color change.
- Explain Thayer's law of countershading and test it with an experiment.
- Weigh a scientific claim fairly, separating what Abbott Thayer got right from where he went too far.

Warm-up. Go outside and pick up something small and plain: a gray pebble, a brown leaf, a pinecone. Set it down where it is hardest to see, then where it is easiest. Have someone else try to find it from five steps away. What made the difference: color, shape, shadow or pattern?

Video slot. Video coming. Cuttlefish and octopus changing color and texture to match the seafloor; leaf insects and stick insects; ptarmigan and snowshoe hare in winter coats. Search approved channels (Smithsonian Channel, BBC Earth, Monterey Bay Aquarium, Woods Hole Oceanographic Institution, National Park Service); preview first.

KEY TERMS

camouflage

Coloring, pattern, shape or behavior that keeps an animal from being noticed or recognized.

countershading

Being darker on top and lighter underneath, which cancels the shadow sunlight casts on the lower body and makes a solid animal look flat (Thayer's law).

disruptive coloration

Bold patches or stripes that break up an animal's outline so the eye cannot find its true shape.

masquerade

Looking like an uninteresting object, such as a twig, leaf, stone or bird dropping, so a predator sees the animal but does not recognize it as food.

chromatophore

A tiny elastic sac of pigment in the skin of an octopus, squid or cuttlefish, stretched open or squeezed shut by muscles to change color in a fraction of a second.

molt

To shed and replace fur or feathers; ptarmigans and snowshoe hares molt from brown to white for winter.

CORE IDEAS

An artist looks at a duck. Abbott Handerson Thayer (1849–1921) was a New Hampshire painter famous for portraits of angels and young women. He was also an outdoorsman, and he noticed something every hunter had seen but no one had explained: a resting grouse or duck, which is plainly brown, simply vanishes against the ground. In 1896 he published his answer in a bird journal, *The Auk*, and demonstrated it with painted wooden decoys.

Sunlight falls from above, so the top of any round object is bright and its underside is in shadow. That light-and-dark shading is how our eyes see solid shapes. But most animals are darker on the back and paler on the belly. The dark back absorbs the bright light; the pale belly brightens the shadow. The two cancel, and the animal looks flat and blends into its background. This is **countershading**, still called Thayer's law. It is found in deer, rabbits, many fish, sharks and penguins.

Five ways to hide. The simplest camouflage is **background matching**: a brown moth on brown bark, a sandy flounder on sand. **Disruptive coloration** uses bold patches that break the outline, so a predator sees shapes but not a fawn or a leopard. **Masquerade** is different: the predator sees the animal clearly but mistakes it for a thing not worth eating. Stick insects look like twigs, leaf insects copy even the veins and brown "bite marks" of a leaf, and some young caterpillars look exactly like bird droppings. Then there is **color change**, either slow, by seasonal molt, or fast, by nerves and muscles. Many animals combine several methods at once, and most add a fifth ingredient: they hold perfectly still.

Changing with the seasons. The snowshoe hare of Canada and the northern United States is brown in summer and white in winter, and so is the willow ptarmigan, a grouse of the Arctic. Both change by **molt**ing, growing a new coat or new feathers over several weeks. The trigger is not snow but day length: as autumn days shorten, a hormone signal starts the change. That design works well because snow usually arrives on time. When it is late, a white hare on brown ground is plainly visible for a few weeks. The ptarmigan has an extra trick: its feathered feet act like snowshoes, and in winter it burrows into snow to rest.

Masters of the seafloor. Cuttlefish, octopus and squid can change color, pattern and even the texture of their skin in less than a second. Their skin holds thousands of **chromatophores**, tiny sacs of yellow, red, brown or black pigment, each ringed by muscles wired to the brain. When the muscles pull, the sac spreads like a dot of ink; when they relax, it shrinks to a speck. Below them, reflecting cells add white, blue and green shimmer. An octopus can also raise little bumps called papillae to copy the roughness of coral or seaweed. Here is a mystery: tests show most cuttlefish and octopus eyes have only one kind of color receptor, so they should be color-blind, yet they match colors well. Scientists are still working out how.

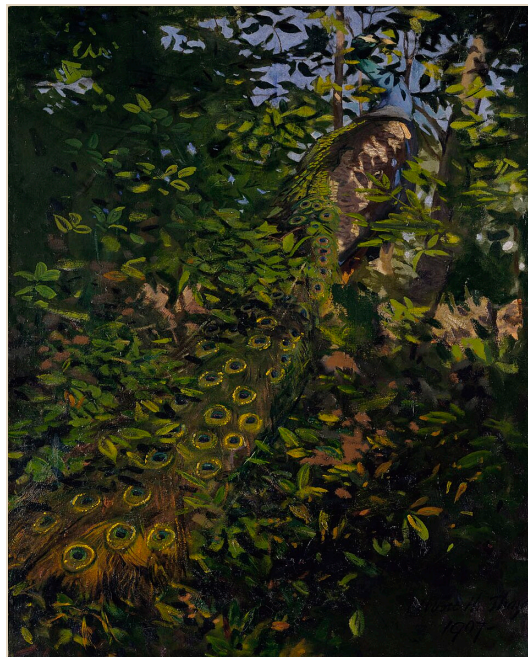
Thayer goes too far. Thayer and his son Gerald published *Concealing-Coloration in the Animal Kingdom* in 1909. It was full of brilliant observations, but Thayer came to believe that *all* animal coloring was for hiding. He argued that flamingos are pink to match a sunset sky and that the peacock's gorgeous tail blends into forest leaves. Theodore Roosevelt, a serious naturalist who had watched many of these animals in the wild, answered him in a long

article in 1911 and pointed out that many bright colors are meant to be seen: as warnings, as signals to mates, or for no reason anyone has found. Most scientists agreed with Roosevelt. The lesson is valuable: a true idea can be pushed past its evidence. A good thinker asks, “How far does the evidence actually go?”

Soldiers learn from animals. In World War I the French army formed a unit of artists, the *camoufleurs*, to paint guns and observation posts, and other armies followed. Thayer wrote letters urging countershaded uniforms and ships. The British artist Norman Wilkinson went the other way with “dazzle” painting in 1917: wild stripes on ships did not hide them but made it hard for a submarine captain to judge a ship’s speed and heading, much like the disruptive stripes of a zebra herd. The design ideas came from watching creatures.

Who taught the hare? No hare decides to turn white, and no cuttlefish studies its background in a book. The knowledge is built in. Job told his friends to “ask now the beasts, and they shall teach thee.” Camouflage teaches that the Creator cares for small, defenseless creatures and gives them protection suited to their homes, and it teaches us to look more carefully at the world, since much of it is hidden in plain sight.

PICTURE STUDY



Peacock in the Woods, study for the book Concealing-Coloration in the Animal Kingdom, Abbott Handerson Thayer and Richard S. Meryman, 1907 · Oil on canvas · Smithsonian American Art Museum, Washington, D.C.

[Wikimedia Commons](#) · Public domain

Thayer and his young assistant Richard Meryman painted this canvas to prove that even a peacock could vanish in its natural home. It became the frontispiece of the Thayers’ 1909 book. It is a handsome painting and a famous argument, and many naturalists of the day thought the argument went too far.

Look closely

- Before you look closely, glance at the picture for two seconds, then look away. What did you notice first?
- Now find where the peacock's blues and greens repeat in the background. Did the artists choose a background to match the bird, or the bird to match the background?
- Find the "eyes" on the tail feathers. Do they help the bird hide or make it stand out?

Talk about it

1. Is this painting good evidence that peacocks are camouflaged in the wild? What would better evidence look like?
2. Roosevelt said bright colors are often meant to be seen. Which do you think is truer of the peacock, and why?

HANDS-ON: TESTING THAYER'S LAW

Thayer proved countershading with painted decoys. Repeat his test with two tubes and a sunny day.

You will need

- Two cardboard tubes (paper-towel tubes) or two short pieces of thick dowel
- Gray, black and white craft paint, and a brush
- Two pieces of stiff wire or straightened paper clips for legs
- A sunny patch of plain ground (bare soil, gravel or dry grass)
- Field Notebook

Steps

1. Paint tube A one even middle gray all over.
2. Paint tube B with countershading: dark gray along the top, blending to middle gray on the sides and nearly white underneath. Blend the band gradually, with no sharp lines.
3. When dry, push wire legs into each so the tubes stand an inch or two above the ground, side by side, about a foot apart, in full sun.
4. Step back 10, 20 and 30 paces. At each distance, write which tube is harder to see and whether either looks flat instead of round.
5. Ask someone who has not seen the setup to walk toward it and say when they first notice each tube.
6. Write a short conclusion: did your result support Thayer's law? What would you change to make the test fairer?

Check your work

- Both tubes were tested in the same light, at the same height and on the same ground.
- I recorded results at three distances and from a second observer.

- My conclusion states whether the evidence supported the claim and names one weakness in my test.

FIELD NOTEBOOK

1. **Narration.** Write one paragraph explaining Thayer's law to someone who has never heard of it, then a sentence or two on where Thayer went too far and who answered him. Your parent keeps this page.
2. Make a five-box chart, one for each kind of camouflage. In each box draw one animal from memory or a field guide and write one sentence on how it hides.
3. Sketch a round ball lit from above. Then sketch the same ball countershaded. Label which looks solid and which looks flat.

Did you know? Some animals are camouflaged by their own behavior. Decorator crabs plant bits of seaweed and sponge on their shells, and the larvae of some lacewings carry debris on their backs. The leafy sea dragon of southern Australia wears skin flaps that look like drifting kelp and sways slowly as if moved by the water.

Go deeper. Gerald H. Thayer and Abbott H. Thayer, *Concealing-Coloration in the Animal Kingdom* (1909; free scans on the Internet Archive and the Biodiversity Heritage Library); Theodore Roosevelt, "Revealing and Concealing Coloration in Birds and Mammals," *Bulletin of the American Museum of Natural History* (1911); the Smithsonian American Art Museum's online page for *Peacock in the Woods*; a second video topic: "dazzle camouflage ships of World War I."

Goes deeper in. Life Science (high school), the unit on animal structure and behavior (coming soon); Art, for light, shadow and modeling form.

For families. Thayer's countershading paper appeared in *The Auk* in 1896; the book by Gerald and Abbott Thayer appeared in 1909, with *Peacock in the Woods* (1907, Smithsonian American Art Museum) as its frontispiece. Roosevelt's critique was published in 1911. No primary source excerpt is given in this stop because the Thayer and Roosevelt texts are not available from this course's approved archives; the Go deeper links lead to free scans. Research on cuttlefish color vision is ongoing, so the stop presents it as an open question. Camouflage is described here as design suited to each creature's home, without evolutionary storytelling.

PRACTICE

1. **EASY** What is the difference between background matching and masquerade?
2. **EASY** What triggers a snowshoe hare to turn white: snow, cold or day length?
3. **MEDIUM** Explain how a cuttlefish changes color in less than a second.
4. **CHALLENGE** A shark is dark gray on top and white underneath. Explain how this helps it whether a fish sees it from above or from below.

5. **CHALLENGE** Thayer claimed flamingos are pink so they vanish against the sunset sky. Design a fair test of his claim, and give one fact that counts against it.
6. **MEDIUM** Why did dazzle-painted ships in 1917 not need to be invisible to work?

Make it a game • Camouflage Hunt. One player hides ten objects outdoors in a small marked area: some brightly colored (a red bead, a blue button) and some plain (a brown twig, a gray pebble, a green yarn piece in grass). The other players have two minutes to find them. Count which colors were found first and which were missed. Then switch hiders. Write the results in your Field Notebook: which camouflage worked 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. Who knoweth not in all these that the hand of the LORD hath wrought this?” (Job 12:7–9, KJV)

Job tells his friends to learn from the creatures. A hidden moth or a vanishing cuttlefish teaches us to look closely, and it points to the hand that made them.

Practice: answers

1. In background matching the predator does not see the animal at all because it blends in; in masquerade the predator sees it but mistakes it for something uninteresting, like a twig or leaf.
2. Day length. Shortening autumn days start the molt, not the snow itself.
3. Its skin has thousands of chromatophores, pigment sacs ringed by muscles controlled by nerves. When muscles pull, the sac spreads and shows its color; when they relax, it shrinks. Reflecting cells underneath add white and shimmering colors.
4. From above, the fish looks down at a dark back against the dark depths below. From below, the fish looks up at a white belly against bright sunlit water above. Either way the shark matches what lies behind it. (Countershading also cancels the shadow on its underside when seen from the side.)
5. A fair test: observe or model how visible flamingos are to their actual predators at different times of day and from the angles predators actually approach (mostly from the ground and water, not against the sky), comparing pink birds with gray or white models. Facts against it (any one): flamingos stand and feed for most of the day in broad daylight, not just at sunset; predators usually approach from the ground; flamingos feed in large, noisy, conspicuous flocks; their pink color comes from their diet and is also used in group displays. Roosevelt argued such colors are not concealment.
6. The stripes were meant to confuse, not hide. They made it hard for a submarine captain to judge the ship’s speed, heading and distance, so torpedoes were aimed poorly, much as a zebra herd’s stripes may confuse a lion.

6.3 HIBERNATION: WINTER'S LONG SLEEP

OBJECTIVES

- Distinguish torpor, hibernation, the winter sleep of bears and the freezing of wood frogs.
- Use numbers (body temperature, heart rate, fat loss) to explain how hibernation saves energy.
- Explain why disturbing hibernating bats is harmful and how good stewardship protects them.

Warm-up. Take your pulse for 15 seconds and multiply by 4. Write it down. A hibernating woodchuck's heart may beat only about 5 times a minute. How many of your heartbeats happen in the time it takes the woodchuck's heart to beat once?

Video slot. Video coming. Arctic ground squirrels hibernating, a black bear den camera with newborn cubs, and a wood frog freezing and thawing. Search approved channels (National Park Service, U.S. Fish and Wildlife Service, Alaska Department of Fish and Game, University of Alaska Fairbanks, BBC Earth); preview first.

KEY TERMS

hibernation

A long, deep, controlled drop in body temperature, heart rate and breathing that lets an animal survive a season with little food.

torpor

A short period (hours to days) of lowered body temperature and slowed body processes; hibernation is a long series of torpor bouts.

metabolism

All the chemical work by which the body turns food into energy; its rate tells how fast fuel is burned.

arousal

A brief rewarming in the middle of hibernation; arousals use a large share of the stored fat.

cryoprotectant

A substance, such as glucose in a wood frog, that protects cells from damage by freezing.

brumation

The winter dormancy of reptiles such as snakes and turtles, whose body temperature follows their surroundings.

CORE IDEAS

The problem of winter. A warm-blooded animal is a furnace. To keep its body near 37 °C (98.6 °F) in a cold world, it must burn food constantly, and winter is exactly when food runs short. Many birds solve the problem by leaving (Stop F7). Some mammals store food and stay active, like the red squirrel with its cone piles. Others do something more daring: they let the furnace go almost out. That is **hibernation**, and it is not ordinary sleep. Sleep is a brain state; hibernation is a whole-body slowdown of **metabolism**, controlled and reversible.

How far down? A woodchuck (groundhog) in summer has a body temperature near 37 °C and a heart rate of about 80 beats a minute. In deep hibernation its body cools to a few degrees above freezing, its heart slows to around 5 beats a minute, and it may take a breath only every several minutes. The champion is the arctic ground squirrel of Alaska. In 1989 the physiologist Brian Barnes measured hibernating squirrels whose body temperature fell to about −2.9 °C (27 °F), below the freezing point of water, yet their blood did not freeze. It was “supercooled,” held liquid by the absence of ice crystals to start freezing. For seven or eight months the squirrel lives on fat stored in late summer.

The puzzle of waking. Hibernators do not stay cold the whole winter. Every week or few weeks, they shiver and burn special brown fat to rewarm to normal temperature for less than a day, then cool down again. These **arousals** are expensive: researchers estimate that they use most of the energy a hibernator spends all winter. Why do it? No one is fully sure. Leading ideas are that the body must rewarm to sleep properly, to clear waste, or to repair the immune system. It is one of the honest unknowns of this subject.

Bears are different. A black bear in its den drops its body temperature only a few degrees, to around 31–35 °C, but its heart can slow from about 40–50 beats a minute to as few as about 8 to 10, with long pauses between breaths. For as long as five to seven months it does not eat, drink, urinate or pass waste. It recycles the waste nitrogen in its blood into new protein, so it loses fat but keeps most of its muscle, and its bones do not weaken as a bedridden person’s would. Mother bears give birth in the den in January or February to tiny cubs weighing under a pound and nurse them until spring. Older books called this “winter sleep, not true hibernation”; many scientists now call it hibernation of a different kind. The words are debated because the animals do not fit our neat boxes.

Frozen solid, then alive. The wood frog, found as far north as Alaska, does what seems impossible. In winter it lies under leaf litter and freezes: up to about two-thirds of the water in its body turns to ice, its heart stops and it stops breathing. As ice begins to form on its skin, its liver floods its cells with glucose, a sugar that acts as a **cryoprotectant**, keeping ice outside the cells where it does less harm. In spring it thaws from the inside out, its heart restarts and it hops off to breed. Reptiles have their own winter rest, called **brumation**, in burrows or the mud of ponds.

Do birds hibernate? For two thousand years, from Aristotle to Gilbert White, many naturalists believed swallows spent the winter asleep in mud or hollow trees, because they vanished every autumn. They were wrong about swallows, which migrate to Africa and South

America. But in December 1946 the naturalist Edmund Jaeger found a common poorwill, a nightjar, tucked motionless in a rock crevice in the Chuckwalla Mountains of California. It was cold and seemed lifeless, yet it was alive. He banded it, and it returned to the same crevice in later winters. The Hopi people had long called this bird by a name meaning “the sleeping one.” The poorwill remains the only bird known to hibernate in this way.

Stewardship and wonder. Every arousal burns fat a hibernator cannot replace before spring. That is why visitors should never enter caves where bats hibernate in winter: waking them can starve them. Since 2006 a fungal disease called white-nose syndrome has killed millions of North American bats by making them wake too often. Closing some caves and cleaning gear between caves are simple acts of the care God commanded when He put man in the garden “to dress it and to keep it” (Genesis 2:15). Job wrote that when God sends the snow, “then the beasts go into dens, and remain in their places.” Their winter rest is part of His design.

PICTURE STUDY



The Hunters in the Snow (Winter), Pieter Bruegel the Elder, 1565 · Oil on oak panel · Kunsthistorisches Museum, Vienna

Wikimedia Commons · Public domain

Bruegel painted this as one of a series of six panels showing the seasons of the year. It shows a hard winter in the Low Countries: weary hunters returning with little to show for their day. The cold is so real you can almost feel it. Under that snow, out of sight, much of the countryside’s animal life is resting.

Look closely

- Count the dogs. Find what the hunters are carrying home. Was it a good day’s hunting?
- Find every bird in the picture. Which birds are still active in winter?

- Look at the bare trees, the frozen ponds and the hillside. Where might frogs, hedgehogs, dormice and bats be spending this winter?

Talk about it

1. Why would winter be a hard season for the hunters and for the animals alike?
2. How did the people in the village survive the winter, and how is that like and unlike the ways animals survive it?

Safety first. The project uses hot tap water. A parent pours it; do not use boiling water, and handle full jars with a towel.

HANDS-ON: SMALL BODIES COOL FAST: A DEN EXPERIMENT

Why do so many hibernators, like ground squirrels, bats and dormice, tend to be small? Small bodies have a lot of surface for their size, so they lose heat quickly. Test that, and test what a den does.

You will need

- Three jars with lids: two small (baby-food size) and one large (quart)
- Hot tap water (about 45–50 °C) and a kitchen or aquarium thermometer
- A box packed with dry leaves, wool or an old sweater (the “den”)
- A cold place (refrigerator, porch in winter or a cooler with ice)
- Timer, graph paper and Field Notebook

Steps

1. Fill all three jars with hot water of the same starting temperature. Record it.
2. Place one small jar and the large jar uncovered in the cold place. Place the second small jar inside the leaf-and-wool den, then put the den in the same cold place.
3. Measure each jar’s temperature every 10 minutes for one hour, opening each jar only long enough to read the thermometer.
4. Graph all three lines (temperature against time) on one chart in three colors.
5. Answer: Which cooled fastest? How much did the den help? What does this tell you about why a small animal needs either a den, a very thick coat or a way to lower its body’s furnace?

Check your work

- My graph has a title, labeled axes with units and a key.
- I compared the small and large jar fairly (same start temperature and place).
- I wrote a conclusion that connects body size, insulation and hibernation.

FIELD NOTEBOOK

1. **Narration.** In one paragraph, compare how three different animals survive winter: a ground squirrel, a black bear and a wood frog. Use at least one number for each. Your parent keeps this page.
2. Draw a cross-section of the ground in winter: snow on top, a bear den under tree roots, a ground squirrel burrow, a wood frog in the leaf litter, a turtle in the mud of a pond.
3. Copy Job 37:6–8 and underline the phrase that describes hibernation.

Did you know? Groundhog Day (February 2) comes from old European weather sayings about badgers and hedgehogs. In real life, male woodchucks in some areas do wake early in February, not to look for shadows, but to visit the burrows of females before spring. Hedgehogs in Britain hibernate in piles of leaves, so gardeners are asked to check leaf heaps before burning them.

Go deeper. Bernd Heinrich, *Winter World: The Ingenuity of Animal Survival* (2003), by a biologist who studies winter animals in the Maine woods; the National Park Service pages on black bears and on white-nose syndrome; the University of Alaska Fairbanks Institute of Arctic Biology pages on arctic ground squirrels; a second video topic: “how wood frogs freeze and thaw.”

Goes deeper in. Life Science (high school), the unit on body systems and metabolism (coming soon); Earth Science, for seasons and weather.

For families. The -2.9°C ground-squirrel measurement was reported by Brian M. Barnes in *Science* (1989). Edmund C. Jaeger reported the hibernating poorwill in *The Condor* (1948, describing the bird found in late December 1946). White-nose syndrome was first documented in New York in 2006. Heart rates and temperatures vary by species and study; typical figures are given. No primary source excerpt appears in this stop because no suitable public-domain text was available from the approved archives; Gilbert White’s letters on swallows (free on Project Gutenberg) are a good related reading for a strong student.

PRACTICE

1. **EASY** How is hibernation different from ordinary sleep?
2. **EASY** What does a wood frog’s liver do when the frog starts to freeze?
3. **MEDIUM** Give two ways a black bear’s winter differs from an arctic ground squirrel’s.
4. **CHALLENGE** A woodchuck’s heart beats 80 times a minute when active and 5 times a minute in hibernation. How many beats does it save in one day of hibernation? How many times fewer is that?
5. **CHALLENGE** A 4-kilogram woodchuck loses 30% of its body mass over a 150-day hibernation. How many grams does it lose in all, and how many per day? If arousals use 80% of the energy, how many of those grams are burned during arousals?

6. **MEDIUM** Why were so many naturalists, including Gilbert White, wrong about swallows, and what discovery in 1946 showed they were not foolish to wonder?

Make it a game • Freeze and Arouse. The leader calls “Winter!” and everyone curls up and stays perfectly still, breathing slowly. Every so often the leader calls “Arousal!” and everyone must stand, shiver hard for five seconds and sit back down. Anyone who moves between calls is out. After the game, discuss: if every arousal costs a hibernator fat, why is it so harmful to wake it on purpose?

Scripture. “For he saith to the snow, Be thou on the earth; likewise to the small rain, and to the great rain of his strength. He sealeth up the hand of every man; that all men may know his work. Then the beasts go into dens, and remain in their places.” (Job 37:6-8, KJV)

Elihu describes winter as God’s command: snow and rain stop men’s outdoor work, and the animals go into their dens and stay put. Hibernation is not an accident of nature; it is the beasts obeying the season their Maker sends.

Practice: answers

1. Sleep is a state of the brain with normal body temperature; hibernation is a whole-body slowdown in which body temperature, heart rate, breathing and metabolism drop far below normal for weeks or months.
2. It floods the cells with glucose (sugar), which acts as a cryoprotectant and protects the cells from freezing damage.
3. Any two: the bear’s temperature drops only a few degrees, while the squirrel’s falls below freezing; the bear gives birth and nurses cubs in the den; the bear recycles its waste and does not urinate or pass waste for months; the squirrel rewarms in regular arousals, the bear does not cool and rewarm in the same way.
4. Active: $80 \times 60 \times 24 = 115,200$ beats a day. Hibernating: $5 \times 60 \times 24 = 7,200$ beats. Saved: 108,000 beats a day; the hibernating heart beats 16 times fewer.
5. 30% of 4,000 g = 1,200 g in all; $1,200 \div 150 = 8$ g per day. Arousals use $80\% \times 1,200$ g = 960 g, leaving only 240 g for all the time spent cold.
6. Swallows vanished every autumn and no one could follow them, so it seemed reasonable they hid and slept nearby; in fact they migrate thousands of miles. In 1946 Edmund Jaeger found a common poorwill hibernating in a rock crevice, proving that at least one bird does hibernate.

6.4 ANIMAL BUILDERS: THE BEAVER AND THE WEAVER BIRD

OBJECTIVES

- Explain how a beaver builds a dam and lodge and how the pond it makes changes the land around it.
- Describe how a village weaver knots a nest and how sociable weavers build shared “apartment” nests.
- Read a naturalist’s primary source description closely and test it with a model.

Warm-up. Take a handful of sticks and try to stop a trickle from a garden hose running down a slope. Then add mud and leaves. Which stopped more water? Every beaver knows the answer.

Video slot. Video coming. Beavers building and repairing a dam and lodge (an inside-the-lodge camera if available); village weaver birds tying their nests; sociable weaver colonies in the Kalahari. Search approved channels (National Park Service, U.S. Fish and Wildlife Service, BBC Earth, Smithsonian Channel, Cornell Lab of Ornithology); preview first.

KEY TERMS

dam

A barrier across a stream that holds back water; a beaver dam is built of sticks, mud and stones.

lodge

A beaver’s dome-shaped home of sticks and mud in or beside the pond, with underwater entrances and a dry room inside.

food cache

A pile of branches a beaver sinks in the pond mud near its lodge in autumn, to eat under the ice all winter.

wetland

Land soaked or covered by shallow water much of the year, such as a marsh or beaver meadow.

colonial nest

One large nest structure shared by many birds, each family with its own chamber, as in the sociable weaver.

CORE IDEAS

The engineer of the stream. The North American beaver is the largest rodent on the continent, often 40 to 60 pounds, and it is one of the few animals that reshapes the land on purpose. Its chisel-like front teeth are orange because their front surface is hardened with

iron, and they never stop growing. A beaver can drop a willow as thick as your wrist in minutes and a large aspen overnight. It then cuts the trunk into lengths, eats the bark, and drags the sticks to the water. What it builds with them is a dam, a pond and a home.

How a dam goes up. The naturalist Enos Mills, who watched beavers in the Colorado Rockies for decades, described the method in *In Beaver World* (1913): poles laid along the current, their upstream ends set higher, small bushy trees with their tops downstream, the whole weighed down with mud and stones (see the primary source). The upstream face is plastered with mud and leaves until it holds water. Most dams are a few yards to a hundred yards long. In 2007 a researcher looking at satellite images found one in Wood Buffalo National Park in northern Canada about 850 meters (more than half a mile) long, built and extended by generations of beavers. Experiments in the twentieth century showed something curious: the sound of running water is a strong trigger. When researchers played recorded trickling from a loudspeaker, beavers piled sticks and mud on the speaker, even where no leak existed.

A house with a moat. The pond the dam creates is the beaver's moat. In it the beaver builds a **lodge**, a mound of sticks and mud that may stand five or six feet above the water, with one or more tunnels opening below the surface. Inside, above the waterline, is a dry chamber where the family sleeps and kits are born. In autumn the beavers plaster the outside with fresh mud, which freezes as hard as concrete; a wolf or coyote can stand on the roof and not dig in. A little gap at the top lets stale air out. Beside the lodge they sink a **food cache** of branches, so all winter they can swim out under the ice, fetch a stick and eat it in the dry room.

A keystone of the land. A beaver pond raises the water table, slows floods, traps silt and keeps streams flowing in dry summers. Ducks, frogs, moose, trout and dragonflies move in. When the beavers leave and the dam breaks, the silted pond becomes a rich, flat "beaver meadow." Early American settlers sought out such meadows for farms. The fur trade, which built the Hudson's Bay Company (chartered 1670) and helped open the continent, trapped beavers out of much of their range by the late 1800s, chiefly to make felt hats. With careful protection and reintroduction, they have come back across most of North America. Today some ranchers and land managers welcome them as free engineers, and others must manage the flooding they cause: stewardship means both.

The knot-tying bird. Across Africa, the male village weaver builds a hanging nest with no hands at all, only a beak and feet. He strips long ribbons from grass or palm leaves, wraps one around a twig, and ties it with real knots, including half-hitches and slip knots. He first builds a ring, stands in it, and weaves outward: a roof, a round egg chamber and a downward entrance tube that keeps out snakes. Then he hangs upside down, flaps his wings and calls. A female inspects the nest, tugging on the weaving. If she rejects it, he often tears it down and starts again. Studies of related weavers show that young males get better with practice: their early nests are untidy, and their later ones neater and faster. The skill is built in, but it is also learned.

The bird apartment house. In the Kalahari of southern Africa, the sociable weaver builds the largest bird nests on earth. Dozens of pairs, sometimes well over a hundred birds, share one thatched structure in a camel-thorn tree or on a telephone pole, each family with its own chamber opening below. Some colonies are used for generations and are thought to be more than a century old; the biggest can weigh close to a ton and occasionally break the branches that hold them. The thick thatch keeps the inner rooms cooler than the desert by day and warmer by night.

Who teacheth them? Proverbs names four small creatures “exceeding wise,” among them the conies, which “make they their houses in the rocks.” A beaver has never seen a blueprint, and a young weaver has never had a lesson from his father. Yet the work is purposeful, adjustable and good. The wisdom in it points beyond the builder to the One who made the builder.

PICTURE STUDY



The “Beaver Map”: Niagara inset from A New and Exact Map of the Dominions of the King of Great Britain on ye Continent of North America, Herman Moll, 1715 · Engraving with hand coloring · Copies in the Library of Congress, Colonial Williamsburg and other collections
Wikimedia Commons · Public domain

The London mapmaker Herman Moll filled a corner of his great map of British North America with Niagara Falls and a colony of busy beavers. It became so famous it is still called “the beaver map.” Beaver fur was one of the richest trades in North America, and the industrious beaver was a symbol of hard work. Moll had never seen a beaver build. His engraving copies an earlier French picture, and it is more fanciful than accurate.

Look closely

- Find the beavers carrying things. How are they carrying them? Is that how real beavers carry sticks and mud?
- Find the dam. Does it look like the dam Enos Mills describes in the primary source?
- Look at Niagara Falls behind them. Would beavers build a dam on a river like the Niagara? Why or why not?

Talk about it

1. Make a list of three things Moll's picture gets wrong and one thing it gets right about beavers.
2. Why might a mapmaker in London in 1715 want to put beavers on a map of the colonies?

HANDS-ON: BUILD A BEAVER DAM MODEL AND TEST MILLS'S METHOD

Enos Mills described exactly how beavers lay the poles of a dam. Build a small stream and two dams, one by his method and one any way you like, and see which holds more water.

You will need

- A long plastic storage bin, a sandbox or a sloped patch of garden soil
- Sand or soil to make a stream channel
- Straight sticks (pencil-thick, 6-12 inches) and small leafy twigs
- Mud (soil mixed with water), small stones and dead leaves
- A watering can or hose on a gentle trickle; a ruler; a timer

Steps

1. Shape a channel about 4 inches wide down the slope.
2. Dam A (Mills's method): lay sticks along the flow on the bottom with upstream ends propped higher, add leafy twigs with tops downstream, weigh down with stones, then plaster the upstream face with mud and leaves.
3. Run a steady trickle for 3 minutes. Measure the depth of the pond behind the dam and note where it leaks.
4. Repair the leaks the way a beaver would. Run water again and measure.
5. Clear the channel and build Dam B with the same amount of material, sticks laid across the stream with no mud. Test it the same way.
6. Record both results and explain why the beaver's method works better (or does not).

Check your work

- I followed the steps in the primary source for Dam A.
- I tested both dams with the same water flow and time.
- I recorded pond depth and leaks for each, and explained the difference.

FIELD NOTEBOOK

1. **Narration.** Write one paragraph describing a beaver colony through one year: building the dam, the lodge, the food cache, winter under the ice and spring. Your parent keeps this page.
2. Draw a cut-away diagram of a beaver lodge. Label: dam, pond, lodge, underwater entrance, dry chamber, air vent, food cache, ice.
3. Draw a village weaver nest hanging from a twig. Label the ring, roof, egg chamber and entrance tube.

Did you know? A beaver's lips close behind its front teeth, so it can gnaw underwater without swallowing water. It has clear eyelids like built-in goggles, ears and nose that close underwater, and a flat, scaly tail it slaps on the water as an alarm. The beaver is the national animal of Canada and appears on its five-cent coin.

Primary source. Enos A. Mills, *In Beaver World* (1913), Chapter 5, "The Beaver Dam"; Project Gutenberg eBook #42282.

The majority of dams are made of slender green poles which are placed lengthwise with the flow for the bottom, and set braced with the end upstream a foot or so higher than the downstream end. With these there are occasionally used small limby trees. The large end of the tree is placed upstream, and the small bushy end downstream. If in a current these sometimes are weighed down with mud or stones. Short, stout sticks and long, slender poles are deftly mingled in the dam as it rises.

Mills spent many years watching beaver colonies near his cabin in the Rocky Mountains of Colorado. Use his description for the project and for practice question 6.

Go deeper. Enos A. Mills, *In Beaver World* (1913; free on Project Gutenberg); Lewis H. Morgan, *The American Beaver and His Works* (1868; free scans on the Internet Archive); Karl von Frisch, *Animal Architecture* (1974); the Cornell Lab of Ornithology's Birds of the World or All About Birds pages on weavers; a second video topic: "sociable weaver colonies."

Goes deeper in. Life Science (high school), the unit on ecosystems and habitats (coming soon); History, for the North American fur trade; Gardening & Animals, for ponds and wetlands.

For families. The 850-meter dam in Wood Buffalo National Park (Alberta) was found on satellite imagery in 2007 and reported by Parks Canada. The running-water experiments are described in the beaver literature from the 1960s-1970s (Wilsson and others). Weaver learning was documented in southern masked weavers (Walsh and colleagues, 2010-2011). Sociable weaver colony weights and ages are estimates. Moll's 1715 beaver vignette was copied from a picture by the French engraver Nicolas de Fer (c. 1698), as

most map historians note. The Hebrew word translated “conies” in Proverbs 30:26 is usually identified today as the rock hyrax.

PRACTICE

1. **EASY** Why does a beaver lodge have its entrances underwater?
2. **EASY** What is a food cache, and when is it used?
3. **MEDIUM** Name three ways a beaver pond helps other creatures or the land.
4. **CHALLENGE** Water pressure increases by about 9.8 kilopascals for every meter of depth. A beaver dam holds back water 1.5 meters deep. What is the pressure at the bottom of the dam compared with 0.5 meters down? Use your answer to explain why beaver dams (and human dams) are much thicker at the base.
5. **CHALLENGE** Experiments showed beavers pile sticks on a loudspeaker playing the sound of running water, even with no leak. What does this tell us about how beavers know where to build, and why is it a good “rule” for a beaver to follow in a real stream?
6. **MEDIUM** According to Enos Mills’s primary source, which way do the large ends of small trees point in a dam, and what holds the poles down in a current?

Make it a game • Weaver’s Knot Race. Give each player a strip of raffia, ribbon or long grass and a pencil held sideways as a twig. On “Go!” each player ties a half-hitch around the twig, then a second half-hitch on top, then a slip knot. Check each other’s knots: can they be pulled loose? Then try it with one hand held behind your back, as close as you can come to being a bird with only a beak.

Scripture. “There be four things which are little upon the earth, but they are exceeding wise: The ants are a people not strong, yet they prepare their meat in the summer; The conies are but a feeble folk, yet make they their houses in the rocks;” (Proverbs 30:24-26, KJV)

Solomon’s point is that small and weak creatures can be wise in what they build and store. Their wisdom is given, not earned in school, and it shames the lazy and the foolish.

Practice: answers

1. So predators such as wolves and coyotes cannot get in, and so the beavers can come and go under the ice in winter.
2. A pile of branches sunk in the pond mud near the lodge in autumn; the beavers eat from it under the ice all winter.
3. Any three: it creates wetland homes for ducks, frogs, fish, moose and insects; it raises the water table; it slows floods; it keeps streams flowing in dry seasons; it traps silt that later becomes a rich meadow.
4. At 1.5 m: $1.5 \times 9.8 \approx 14.7$ kPa. At 0.5 m: $0.5 \times 9.8 = 4.9$ kPa. The bottom feels three times the pressure, so it must be heavier and thicker to resist being pushed over or leaking. A wide base of poles, mud and stones does exactly that.
5. Beavers respond to the sound of flowing water as a built-in trigger rather than reasoning about where a leak is. In a real stream the sound of trickling water nearly always means a

leak or gap in the dam, so following that sound leads them straight to the place that needs repair; it is a simple rule that almost always gives the right answer.

6. The large end points upstream and the bushy end downstream; the poles are weighed down with mud or stones.

6.5 ANIMAL PARTNERS: LIVING TOGETHER

OBJECTIVES

- Define symbiosis and sort partnerships into mutualism, commensalism and parasitism, with examples.
- Read Herodotus's account of the crocodile and the trochilus and judge it against modern observation.
- Interpret real field-study numbers from the oxpecker and honeyguide experiments.

Warm-up. Think of two people you know who are good partners: a farmer and a mechanic, a cook and a gardener, two friends who help each other. What does each give and what does each get? Now guess: can two different kinds of animals have a deal like that?

Video slot. Video coming. Clownfish and sea anemones; a cleaner wrasse cleaning station on a coral reef; oxpeckers on rhinos and buffalo; honeyguides leading Yao honey-hunters in Mozambique; a goby and pistol shrimp sharing a burrow. Search approved channels (BBC Earth, Smithsonian Channel, Monterey Bay Aquarium, University of Cambridge, National Geographic); preview first.

KEY TERMS

symbiosis

Two different kinds of living things living in close association over a long time (from Greek, "living together").

mutualism

A partnership in which both partners benefit, such as clownfish and anemone.

commensalism

A relationship in which one partner benefits and the other is neither helped nor harmed, such as egrets following cattle to catch insects.

parasitism

A relationship in which one partner (the parasite) benefits at the other's (the host's) expense, such as a tick on a deer.

cleaning station

A spot on a reef where small fish or shrimp remove parasites and dead skin from larger fish that come and wait to be cleaned.

honeyguide

An African bird that leads people to wild bees' nests and feeds on the wax left behind.

CORE IDEAS

The oldest report. Around 440 B.C. the Greek traveler Herodotus visited Egypt and wrote down what he saw and was told. Among his stories is one of the most famous animal partnerships in literature: the crocodile, he says, comes out of the river and lies with its mouth open, and a little bird called the trochilus walks inside and eats the leeches clinging to its gums. The crocodile is “benefited” and “does no harm to the trochilus” (see the primary source). For more than two thousand years people repeated the story, and some later writers named the Egyptian plover as the trochilus.

Is it true? Here is honest complexity. Modern naturalists have spent countless hours around Nile crocodiles, and a clear photograph or film of a bird cleaning inside a crocodile’s open mouth has never been confirmed. Sandpipers and plovers do walk near basking crocodiles and pick insects off the mud and sometimes off the crocodiles’ backs. Crocodiles do lie with their jaws open, but mainly to shed heat. So Herodotus may have recorded a real habit, an exaggerated one, or a tale told to visitors. A careful student neither mocks him nor believes him blindly: he is an honest witness to what Egyptians said in his day, and his claim can be tested.

Three kinds of living together. Biologists use the word **symbiosis** for any close, long-lasting association of two different kinds of creatures. In **mutualism** both gain. In **commensalism** one gains and the other is unaffected, as when cattle egrets follow grazing cows to snap up insects the cows stir from the grass. In **parasitism** one gains at the other’s cost, like a tick or tapeworm. The same pair can shift between these categories, as the oxpecker shows below.

Partners of the reef. The orange clownfish lives among the stinging tentacles of a sea anemone. A coat of mucus protects it from the stings that kill other small fish, so the anemone is its fortress. In return the clownfish chases off butterflyfish that nibble anemones, and its waste feeds the anemone. On the same reefs, small cleaner wrasse set up **cleaning stations**. Large fish, even predators such as groupers, line up, hold still and open their mouths and gills while the wrasse eat parasites and dead skin. The big fish could swallow the cleaner in an instant, and they almost never do. It is the reef’s real-life version of Herodotus’s story.

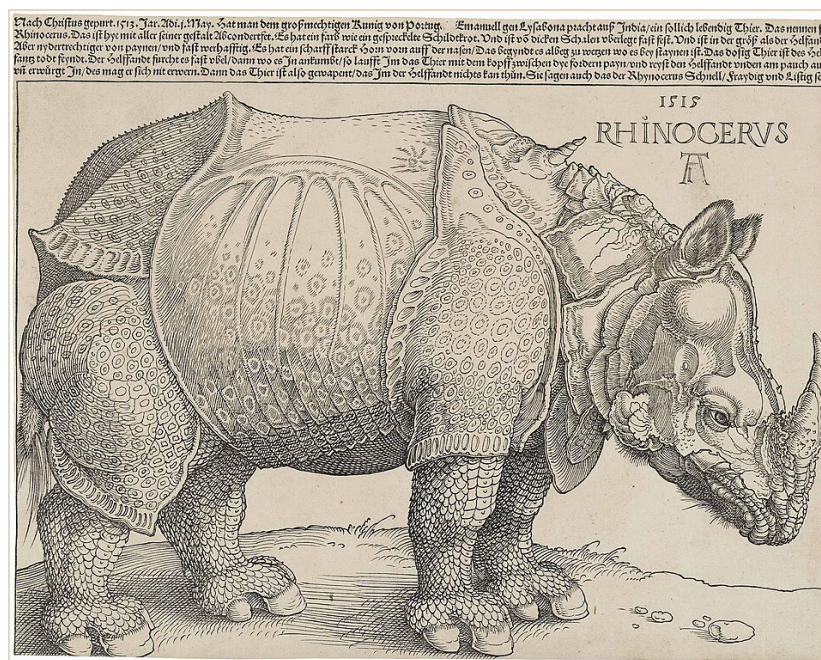
The rhino’s guard. In Swahili the red-billed oxpecker is called *askari wa kifarū*, “the rhino’s guard.” Oxpeckers ride on rhinos, buffalo and giraffes, eating ticks. Black rhinos see poorly. In a study published in 2020, Roan Plotz and Wayne Linklater found that rhinos without oxpeckers noticed researchers approaching on foot only 23 percent of the time, but rhinos carrying oxpeckers, which give an alarm call, noticed every time, and at an average of 61 meters instead of 27. Yet oxpeckers also peck at wounds and drink blood, keeping sores open. So the partnership is mostly mutual, with a parasitic edge. Real creatures rarely fit neat labels.

A partnership with people. In northern Mozambique, honey-hunters of the Yao people walk through the bush making a special trilling call, “brrr-hm.” A small bird, the greater

honeyguide, answers and flies ahead from tree to tree until it reaches a wild bees' nest. The hunters smoke out the bees, take the honey, and leave the wax, which the honeyguide eats. In 2016 Claire Spottiswoode and her colleagues tested the call. Compared with other sounds, the "brrr-hm" raised the chance of being guided from 33 to 66 percent and the chance of being shown a nest from 16 to 54 percent. The birds know the call and choose to answer it.

Two are better than one. Partnerships fill creation: bees and flowers, the fungus and alga that together form lichen, the yucca plant and the small moth that pollinates it and nowhere else. Solomon wrote, "Two are better than one; because they have a good reward for their labour." Partnership among creatures is a picture of the help and fellowship God built into His world, and of the help people are meant to give one another.

PICTURE STUDY



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

In 1515 an Indian rhinoceros was sent as a gift from Sultan Muzaffar II of Gujarat to King Manuel I of Portugal. It was the first living rhino in Europe in more than a thousand years. Albrecht Dürer, in Nuremberg, never saw it. He worked from a letter and a sketch sent from Lisbon, and his woodcut became the picture of the rhinoceros for more than two hundred years. The real animal drowned in a shipwreck in 1516 on its way to the pope.

Look closely

- Find the small twisted horn on the shoulders. Real rhinos do not have it; it is sometimes called "Dürer's hornlet."
- Look at the skin. What did Dürer think the folds of a rhino's skin were?

- Find the scaly legs. What creature might Dürer have been thinking of?

Talk about it

1. Dürer's rhino carries no oxpeckers. Where on this rhino would they ride and feed, and what would they be looking for?
2. Dürer drew from a description rather than the real animal. How is that like and unlike Herodotus reporting the trochilus?

HANDS-ON: PARTNERSHIP FIELD SURVEY

Partnerships are all around you. Spend a half hour finding and recording three of them: lichens, flowers and their pollinators, and one more.

You will need

- A magnifying glass or hand lens
- A watch or timer
- Field Notebook and colored pencils
- A yard, park, field edge or garden in bloom

Steps

1. Lichens: find lichen on a tree trunk, rock or old fence. Look at it through the lens. Sketch it and label it "fungus + alga partnership." Note whether it is crusty, leafy or shrubby.
2. Pollinators: choose one patch of flowers. For 10 minutes, tally every visitor by kind (honeybee, bumblebee, fly, butterfly, other). Note what the insect takes (nectar, pollen) and what it gives (it carries pollen to the next flower).
3. One more partnership: look for ants tending aphids on a stem, birds following a mower or livestock, or galls on leaves (a parasite). Sketch and label it.
4. Classify each of your three partnerships as mutualism, commensalism or parasitism, and give your reasons.
5. Make a bar graph of your pollinator tally.

Check your work

- I found and sketched three partnerships.
- I classified each one and explained my choice.
- My pollinator tally and bar graph are labeled and dated.

FIELD NOTEBOOK

1. **Narration.** Write one paragraph explaining the three kinds of symbiosis, with an example of each from this stop, and say why the oxpecker does not fit neatly into one box. Your parent keeps this page.

2. Draw a cleaning station: a large fish with mouth and gills open and two small cleaner wrasse at work. Add a caption.
3. Draw a Venn diagram: “What the honeyguide gets,” “What the Yao honey-hunter gets,” and in the middle, “What they share.”

Did you know? A goby fish and a nearly blind pistol shrimp share a burrow on the sandy seafloor. The shrimp digs and keeps the burrow clean; the goby stands guard at the entrance. The shrimp keeps one antenna touching the goby’s tail, and when the goby flicks its tail in alarm, both dive into the burrow.

Primary source. *Herodotus, The Histories, Book II, section 68, translated by G. C. Macaulay (1890); Project Gutenberg eBook #2131, “An Account of Egypt.”*

Since he has his living in the water he keeps his mouth all full within of leeches; and whereas all other birds and beasts fly from him, the trochilus is a creature which is at peace with him, seeing that from her he receives benefit; for the crocodile having come out of the water to the land and then having opened his mouth (this he is wont to do generally towards the West Wind), the trochilus upon that enters into his mouth and swallows down the leeches, and he being benefited is pleased and does no harm to the trochilus.

Herodotus wrote about 2,450 years ago. Read slowly: the sentence has several parts. Practice question 6 asks you to sort his claims.

Go deeper. Herodotus, *An Account of Egypt* (Book II of the *Histories*, Macaulay translation; free on Project Gutenberg); the University of Cambridge news release and video on the honeyguide study (2016); Monterey Bay Aquarium and Smithsonian Ocean pages on clownfish and cleaner fish; a second video topic: “goby and pistol shrimp.”

Goes deeper in. Life Science (high school), the unit on ecology and relationships among living things (coming soon); History, ancient Greece and Egypt, for Herodotus; Gardening & Animals, for pollinators.

For families. Oxpecker figures are from Plotz and Linklater, *Current Biology* (2020). Honeyguide figures are from Spottiswoode, Begg and Begg, *Science* (July 22, 2016). Identification of Herodotus’s trochilus with the Egyptian plover is a later suggestion; no confirmed modern record shows a bird cleaning inside a crocodile’s mouth, and the stop says so. Dürer’s woodcut history (the 1515 gift to Manuel I and the 1516 shipwreck) is standard in the British Museum’s and National Gallery’s catalog notes. Herodotus is a pre-Christian writer whose work includes Egyptian religious customs; this excerpt contains none.

PRACTICE

1. **EASY** Classify each: (a) clownfish and anemone; (b) cattle egret and cow; (c) tick and deer.
2. **EASY** How does a clownfish avoid being stung by its anemone?
3. **MEDIUM** Why do scientists call the oxpecker-rhino relationship “mostly mutual, with a parasitic edge”?
4. **CHALLENGE** In the oxpecker study, rhinos with oxpeckers detected people at 61 meters on average, rhinos without at 27 meters. By what percent did the oxpeckers increase the warning distance? If a person walks at 1.4 meters per second, how many extra seconds of warning does the rhino gain?
5. **CHALLENGE** In the honeyguide study, the “brrr-hm” call led to a bees’ nest 54 percent of the time, and control sounds 16 percent. Out of 50 outings, how many more nests would a hunter expect to find by using the call? How many times more likely is success?
6. **MEDIUM** In Herodotus’s primary source, find (a) one claim that modern observation supports, and (b) one claim that has not been confirmed.

Make it a game • Partner Match. Write 12 creatures on cards, six pairs: clownfish/anemone, oxpecker/rhino, honeyguide/honey-hunter, goby/pistol shrimp, bee/flower, cleaner wrasse/grouper. Shuffle and lay them face down. Players take turns flipping two. A match counts only if the player can say what each partner gives the other. Most pairs wins.

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; for he hath not another to help him up.” (Ecclesiastes 4:9-10, KJV)

Solomon is writing about people, but creation shows the same truth: partners can do what neither can do alone. God did not make a world of lonely creatures but one full of help and fellowship.

Practice: answers

1. (a) mutualism; (b) commensalism; (c) parasitism.
2. A protective coat of mucus on its skin keeps the anemone’s stinging cells from firing.
3. The oxpecker eats ticks and warns the rhino of danger (both benefit), but it also pecks wounds and drinks blood, keeping sores open, which harms the rhino.
4. Increase: $61 - 27 = 34$ m; $34 \div 27 \approx 1.26$, so about a 126 percent increase (more than double). Extra time: $34 \div 1.4 \approx 24$ seconds of extra warning.
5. With the call: $0.54 \times 50 = 27$ nests. Without: $0.16 \times 50 = 8$ nests. That is 19 more nests. $54 \div 16 \approx 3.4$, so success is about 3.4 times as likely.
6. (a) Supported (any one): crocodiles come out on land and lie with their mouths open; other animals avoid crocodiles; small birds do feed near basking crocodiles. (b) Not confirmed: that

the trochilus enters the crocodile's mouth and eats the leeches there (or that the crocodile's mouth is full of leeches).

6.6 ANIMAL TOOLS: THE SEA OTTER'S ROCK

OBJECTIVES

- Describe how sea otters use rocks as tools and how fur, appetite and tool use fit together in their lives.
- Explain how sea otters protect kelp forests by eating sea urchins, and tell the story of their near loss and recovery.
- Compare animal tool use with human toolmaking and explain from Scripture why people are different in kind.

Warm-up. Try to open a walnut with only your hands. Now find a smooth stone and a flat rock outdoors and try again (with a parent nearby). How many tries did it take each way? A sea otter solves this problem every day while floating on its back in cold water.

Video slot. Video coming. Sea otters cracking shellfish with rocks on their chests, otters wrapped in kelp, and a mother otter with a pup; Shark Bay dolphins carrying sponges; New Caledonian crows using hooked tools. Search approved channels (Monterey Bay Aquarium sea otter cams, U.S. Fish and Wildlife Service, BBC Earth, Smithsonian Channel, University of Oxford); preview first.

KEY TERMS

tool use

Using an object that is not part of the body to accomplish a task, such as a rock to break a shell.

anvil

A hard surface on which something is struck; a sea otter uses a rock on its chest or a boulder on shore.

keystone species

A creature whose activity holds a whole community together, so that removing it changes everything around it, like the keystone of an arch.

kelp forest

An underwater forest of giant brown seaweed growing in cool, shallow coastal waters.

urchin barren

A stretch of seafloor where sea urchins have eaten the kelp away, leaving bare rock.

underfur

The dense, soft inner layer of fur that traps air; a sea otter has the thickest of any animal.

CORE IDEAS

A floating workbench. Along the coasts of California, Alaska and the North Pacific, a sea otter dives to the bottom, gathers a clam, a mussel or a crab, and tucks it into a loose pouch

of skin under its forearm. Often it brings up a flat stone as well. Back at the surface it rolls onto its back, sets the stone on its chest as an **anvil**, and pounds the shell against it until it cracks. Sometimes it holds the stone in its paws and hammers the shellfish instead, or knocks an abalone loose from the seafloor with repeated blows. Many otters keep a favorite rock in the pouch from dive to dive.

Why it needs the rock. The sea otter is the heaviest member of the weasel family (males often 30 kilograms or more) but one of the smallest marine mammals, and it has no blubber. In water as cold as 5 °C it stays warm two ways. First, it has the densest fur of any animal, by most estimates up to about a million hairs per square inch, more than most people have on their whole head. Air trapped in that **underfur** keeps the cold water off its skin, which is why otters spend hours grooming. Second, it burns food at about three times the rate of a land mammal its size and eats roughly a quarter of its body weight every day. An otter that cannot crack hard shells quickly will soon be cold and hungry. The rock is its answer.

Learned and individual. Not every otter uses tools equally. Pups learn by watching their mothers, who carry them on their chests for months. Otters that eat mostly hard snails and mussels use rocks far more than those eating soft urchins. Some individuals specialize in one food and one technique for life. On shore, favorite boulders used as anvils for many years become worn with dents and stained with shell; in 2019 researchers in California showed such rocks can be studied the way archaeologists study ancient human sites.

Guardians of the kelp. Sea otters love sea urchins, and sea urchins eat kelp. Where otters are present, urchins stay few and hidden, and the kelp grows tall enough to form forests that shelter hundreds of kinds of fish and invertebrates. Where otters are missing, urchins multiply and chew through the kelp's anchoring holdfasts until whole forests become **urchin barrens** of bare rock. In the 1970s James Estes and John Palmisano compared Aleutian islands with and without otters and found exactly this difference. The sea otter is a classic **keystone species**: remove it and the arch falls.

Lost and found. When Vitus Bering's Russian expedition was shipwrecked in 1741, the naturalist Georg Wilhelm Steller described the sea otters on the island, and the crew carried their pelts home. Sea otter fur became one of the most valuable in the world, especially in China. For 170 years Russian, British and American hunters pursued them, until a population once thought to number in the hundreds of thousands fell to perhaps one or two thousand. In 1911 the United States, Great Britain (for Canada), Russia and Japan signed the North Pacific Fur Seal Convention, which also banned hunting sea otters at sea. California's otters were thought gone, but in 1938 a small group was seen near Bixby Creek on the Big Sur coast. With protection they have grown to around three thousand there, and many more in Alaska. It is a story of greed and of good stewardship.

Other toolmakers. In 1960 Jane Goodall watched a chimpanzee in Tanzania strip a grass stem and use it to fish termites from a mound. New Caledonian crows shape twigs and leaves into hooks. Egyptian vultures throw stones at ostrich eggs. Some bottlenose dolphins in Shark Bay, Australia, wear sea sponges on their snouts to protect them while probing the

seafloor. Researchers in Indonesia filmed octopuses carrying coconut shell halves to use as portable shelters.

Different in kind. These are real skills, and they should amaze us. But notice how narrow each one is: one tool, one task, much the same in every generation. No otter has improved its rock into a hammer, and none has taught the trick to a crow. Human tools build on one another across centuries, from the plow to the printing press, because people reason, speak, write and plan. Elihu asked who it is that “teacheth us more than the beasts of the earth.” Man is made in the image of God, and our toolmaking is part of the work of exercising dominion and caring for the earth.

PICTURE STUDY



Sea Otter, Plate 137 of The Viviparous Quadrupeds of North America, John James Audubon and John Woodhouse Audubon (lithograph by J. T. Bowen), 1845–1848 (Imperial folio edition) · Hand-colored lithograph · From *The Viviparous Quadrupeds of North America* by Audubon and the Rev. John Bachman; this copy is in the New York Public Library
Wikimedia Commons · CC BY 2.0

After finishing *The Birds of America*, John James Audubon set out to picture every mammal of North America with his friend the Lutheran minister and naturalist John Bachman. Audubon’s eyesight failed before the work was done, and his son John Woodhouse Audubon painted many of the later plates, including animals of the Pacific coast that the family could study mainly from preserved skins.

Look closely

- Study the fur. How did the artist show how thick and soft it is?
- Find the forepaws holding the fish and the broad hind feet. Which are built for holding and which for swimming?

- Look at the head and whiskers. What might whiskers help an otter do on a dark seafloor?

Talk about it

1. The artists probably never watched a living sea otter eat. Sea otters feed mostly on sea urchins, crabs and shellfish rather than large fish. What does this picture show well, and what would a modern photograph of a live otter add?
2. Why might a fur trader of the 1840s and a naturalist of the 1840s look at this same picture very differently?

Safety first. For the project, wear safety glasses, kneel or sit with the anvil stone on the ground (not on your lap), keep the fingers of your holding hand on the sides of the nut, and strike gently. A parent supervises.

HANDS-ON: HAMMER AND ANVIL: AN OTTER TRIAL

Test the sea otter's two methods, anvil and hammer, on hard-shelled nuts, and keep careful records like a field scientist.

You will need

- 10 walnuts or hazelnuts in the shell
- One flat, fist-sized stone (anvil) and one smooth, rounded stone that fits your hand (hammer)
- Safety glasses
- Field Notebook and a pencil

Steps

1. Make a data table with columns: nut number, method, number of strikes to crack, was the kernel crushed (yes/no).
2. Method A (anvil): hold a nut in your fingertips and strike it down onto the flat stone. Count the strikes until it cracks. Do this for five nuts.
3. Method B (hammer): set the nut on the flat stone and strike it with the hammer stone. Count the strikes. Do this for five nuts.
4. Find the average number of strikes for each method and how many kernels were crushed.
5. Write a conclusion: which method was faster? Which was gentler on the food? Why might a sea otter choose different methods for a mussel, a clam and an abalone?

Check your work

- I wore safety glasses and followed the safety rules.
- My table has ten rows of data and two averages.
- My conclusion connects my results to how sea otters choose a method.

FIELD NOTEBOOK

1. **Narration.** Write one paragraph telling the story of the sea otter from Steller's first description in 1741 to the rediscovery at Big Sur in 1938, and explain why the return of otters matters for kelp forests. Your parent keeps this page.
2. Draw two side-by-side panels: a kelp forest with otters, kelp and fish; and an urchin barren with bare rock and many urchins. Add arrows showing who eats whom.
3. Draw a sea otter floating on its back with a rock on its chest. Label the anvil, the forearm pouch, the underfur and the webbed hind feet.

Did you know? Sea otters sometimes wrap themselves in strands of kelp before sleeping so they do not drift away, and groups resting together, called rafts, may hold paws. A newborn pup's fur is so fluffy and full of air that it cannot sink; its mother can leave it bobbing like a cork while she dives for food.

Go deeper. Monterey Bay Aquarium sea otter program pages and live cams; the U.S. Fish and Wildlife Service page on the southern sea otter; Jane Goodall, *In the Shadow of Man* (1971), for her first observations of chimpanzee tool use; a second video topic: "New Caledonian crows making hooks."

Goes deeper in. Life Science (high school), the unit on marine ecosystems and food webs (coming soon); History, for the North Pacific fur trade and Russian America; Geography, the Pacific coast of North America.

For families. Fur density, food intake and population figures vary by source; "up to about a million hairs per square inch" and "roughly a quarter of body weight" are commonly cited estimates. The pre-trade population and the 1911 low are estimates. The Aleutian comparison is Estes and Palmisano, *Science* (1974). The otter-anvil archaeology study is Haslam and colleagues, *Scientific Reports* (2019). The coconut octopus report is Finn, Tregenza and Norman (2009). The Audubon plate date is given for the Imperial folio as a range; the exact issue date of plate 137 was not confirmed. No primary source excerpt is included: Steller's 1751 description is public domain in Latin, but an English text was not available from the approved archives. Dr. Goodall's views on origins are not part of this stop.

PRACTICE

1. **EASY** Name two ways a sea otter uses a rock.
2. **EASY** With no blubber, how does a sea otter stay warm?
3. **MEDIUM** Explain in a chain of three or four steps what happens to a kelp forest when sea otters disappear.
4. **CHALLENGE** A 30-kilogram sea otter eats 25 percent of its body weight each day. How many kilograms of food is that? If it ate only sea urchins with 100 grams of edible food each, how many urchins a day, and how many in a year?

5. **CHALLENGE** Suppose the sea otters of the North Pacific fell from about 200,000 to about 2,000. What percent of the population was lost? If a recovering population grows 5 percent a year, about how many years would it take 2,000 otters to double? (Hint: use the “rule of 70”: years to double $\approx 70 \div$ growth rate.)
6. **MEDIUM** Give two differences between a sea otter’s tool use and human toolmaking.

Make it a game • Otter Relay. Played on a lawn. Each team has a “seafloor” (a basket of pinecones or beanbags) at one end and a “raft” (a blanket) at the other. Each player must lie on the blanket on their back, then go to the seafloor and bring back one item tucked under one arm, with a small ball (the rock) held on the other side, without dropping either. First team to collect ten items wins. Afterward, talk about why the otter’s forearm pouch is such a good design.

Scripture. “But none saith, Where is God my maker, who giveth songs in the night; Who teacheth us more than the beasts of the earth, and maketh us wiser than the fowls of heaven?” (Job 35:10-11, KJV)

Elihu says that God gives creatures wisdom, and gives people more. An otter’s rock is a marvel; a human workshop is a greater one. Both should make us ask, “Where is God my maker?” and thank Him.

Practice: answers

1. As an anvil on its chest to pound shellfish against, and as a hammer to strike shells or knock abalone off the seafloor (also: carried in its forearm pouch for later).
2. Its extremely dense underfur traps air next to the skin, and it burns food very fast, eating about a quarter of its body weight a day.
3. No otters eat urchins → urchins multiply and come out to feed openly → they chew through kelp holdfasts → the kelp forest collapses into an urchin barren, and the fish and other creatures that lived in the kelp lose their home.
4. $0.25 \times 30 = 7.5$ kg a day. $7,500 \text{ g} \div 100 \text{ g} = 75$ urchins a day. $75 \times 365 = 27,375$ urchins a year.
5. Lost: $198,000 \div 200,000 = 0.99$, or 99 percent. Doubling time $\approx 70 \div 5 = 14$ years.
6. Any two: the otter uses one kind of tool for one kind of task, while people make countless tools for countless purposes; the otter does not improve its tool over generations, while human tools build on earlier inventions; people reason, speak and write to pass on and plan new tools; people make tools to make other tools.

6.7 LONG JOURNEYS: TERNS, GODWITS, SWIFTS AND WHALES

OBJECTIVES

- Describe four record-setting migrations with distances and times.
- Explain four ways migrating animals find their way: sun, stars, the earth's magnetism and landmarks or smell.
- Use Gilbert White's 1767 observation to show how a good question can wait centuries for an answer.

Warm-up. On a globe, find Alaska and then Tasmania, the island south of Australia. Stretch a piece of string between them along the shortest path. Now imagine flying that whole distance without landing, eating, drinking or sleeping on the ground. In October 2022 a five-month-old bird did it.

Video slot. Video coming. Arctic tern and bar-tailed godwit migrations (tracking maps), common swifts that stay in the air for months, and gray whales migrating along the Pacific coast. Search approved channels (Cornell Lab of Ornithology, U.S. Fish and Wildlife Service, NOAA Fisheries, BBC Earth, Smithsonian Migratory Bird Center); preview first.

KEY TERMS

migration

A regular, seasonal journey between two places, such as a breeding ground and a wintering ground, and back.

navigation

Finding and following a route to a goal, including knowing where you are and which way to go.

sun compass

Using the sun's position, corrected by an inner clock for the time of day, to hold a direction.

magnetic sense

The ability to detect the earth's magnetic field and use it as a compass or map.

geolocator

A tiny tag that records light levels so scientists can later calculate where a bird was each day.

stopover

A place where a migrating animal rests and refuels on its journey.

CORE IDEAS

A parson's puzzle. On August 4, 1767, the Rev. Gilbert White wrote from the village of Selborne in southern England to his friend Thomas Pennant. Why, he asked, did the swift “leave us before the middle of August invariably,” when swallows and house martins, which seemed to live the same life, stayed until October? (See the primary source.) White did not know where any of these birds went. Some thought they slept in mud all winter (Stop F3). Others guessed Africa. Not until the twentieth century did bird banding prove that Britain's swifts winter in Africa south of the Sahara. And in 2016 a team in Sweden, using tiny data loggers, showed that common swifts can stay in the air for ten months without landing at all, feeding, drinking and apparently even sleeping on the wing. White's question was a good one; it simply needed tools he did not have.

The longest commute. The Arctic tern nests around the Arctic in the northern summer and spends the southern summer near Antarctica, enjoying more daylight than any other creature. In 2010 researchers fitted terns from Greenland and Iceland with **geolocators** weighing less than a paperclip. The birds did not fly straight; they followed winds in an S-shape down the Atlantic, and the average round trip measured about 70,900 kilometers (44,000 miles) a year. A tern can live 30 years, so over a lifetime it may fly about the distance to the moon and back three times.

The nonstop champion. The bar-tailed godwit, a long-billed shorebird, nests in Alaska and winters in New Zealand and Australia. Before leaving it eats until fat makes up about half its weight, while its stomach and gut shrink to save weight; it will not eat again until it lands. In 2022 a juvenile tagged as B6 left Alaska on October 13 and landed in Tasmania on October 24: about 13,560 kilometers (8,435 miles) in 11 days, without stopping. It had never made the trip before, and no adult showed it the way.

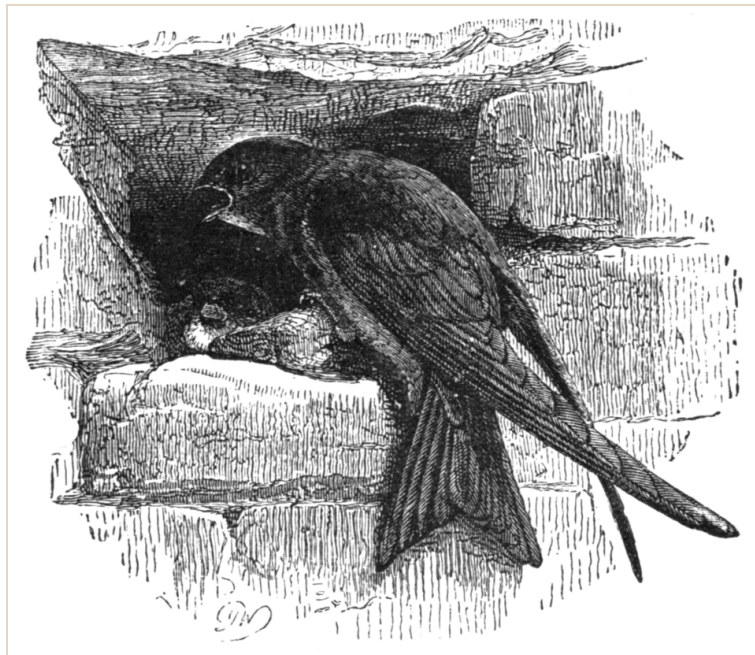
Giants on the move. Gray whales travel along the Pacific coast of North America between their summer feeding grounds in the Bering and Chukchi Seas and the warm lagoons of Baja California, Mexico, where calves are born: a round trip of roughly 16,000 to 20,000 kilometers each year. Humpback whales, leatherback sea turtles, caribou, salmon (Trail D) and monarch butterflies (Trail E) also make great journeys. Some are made by the same individuals year after year; the monarch's is completed over several generations, none of which has made it before.

How do they find the way? Experiments have found several built-in systems. In the 1950s Gustav Kramer showed that caged starlings oriented by the sun, correcting for the time of day with an internal clock: a **sun compass**. In the 1960s Stephen Emlen placed indigo buntings in a planetarium and found they steered by the stars, learning as young birds which point the night sky turns around (near the North Star). In 1972 Wolfgang and Roswitha Wiltschko showed that European robins use a **magnetic sense**, reading the angle of the earth's magnetic field lines. Birds also use coastlines, mountains and, in seabirds such as shearwaters, smell. Most migrants seem to combine several systems and check one against another.

Honest complexity. Much remains unknown. Scientists still debate how the magnetic sense works: one idea involves light-sensitive proteins in birds' eyes, another tiny particles of magnetic iron. No one fully understands how a young godwit or cuckoo on its first trip "knows" where it is going without being led. The usual answer is that the route is inherited, but saying "inherited" names the mystery rather than explaining it. The more scientists learn, the more precise and remarkable the design turns out to be.

Appointed times. The prophet Jeremiah watched the migrating storks, turtledoves, cranes and swallows that still pass over Israel by the hundreds of thousands every spring and fall. "The stork in the heaven knoweth her appointed times," he wrote, "but my people know not the judgment of the LORD." The birds keep the schedule God gave them without fail. His rebuke is that people, who can reason and read His word, often do not keep theirs. Migration is a wonder of design, and it is also a sermon on faithfulness.

PICTURE STUDY



The Common Swift, from an 1879 edition of The Natural History of Selborne, Unknown wood engraver (signed with a small monogram), 1879 · Wood engraving · From Gilbert White, The Natural History of Selborne, and the Naturalist's Calendar (London, 1879 edition)
Wikimedia Commons · Public domain

Gilbert White watched the swifts that nested in the walls and under the eaves of Selborne for years, and his letters describe them more carefully than anyone had before. A century later, publishers in Victorian England were still printing his book, now with pictures like this one, cut into the hard end-grain of boxwood in the way Thomas Bewick had made famous. The engraver signed it only with a small monogram.

Look closely

- Look at the wings. Compare their length with the body. What does that shape suggest about how the bird lives?
- Find where the swift is clinging and the second bird inside the hole. Swifts have tiny feet and can barely walk. Why would a nest hole high in a wall suit them?
- Notice how the engraver shows dark feathers and rough stone with only black lines and white paper. Find the finest lines you can.

Talk about it

1. Knowing that a swift may stay airborne for ten months, explain how its shape fits that life.
2. White described swifts in words, and this engraver drew one. What can a careful drawing teach that a written description cannot?

HANDS-ON: MEASURE A MIGRATION ON THE GLOBE

Use a globe and string to measure real migration routes, then convert them to kilometers and compare them with trips people make.

You will need

- A globe (at least 12 inches across) and a piece of string
- A ruler or tape measure
- A calculator and Field Notebook
- Optional: an atlas or online map with a distance tool, to check your answers

Steps

1. Find the globe's scale: stretch the string around the equator, measure it, and divide 40,075 km (the earth's distance around) by that length. That tells you how many kilometers each centimeter of string equals.
2. Measure with the string, then convert: (a) Alaska to Tasmania (the godwit), (b) Greenland to the edge of Antarctica (one way for the tern), (c) Baja California to the Bering Strait (the gray whale).
3. Compare your godwit measurement with the 13,560 km the tagged bird actually flew. Why might the bird's route be longer than the shortest string path?
4. Calculate the godwit's average speed: distance $\div$ (11 days $\times$ 24 hours).
5. On an outline map, draw all three routes in different colors with a key.

Check your work

- I showed how I found the scale of my globe.
- I measured and converted three routes and calculated one average speed.
- My map has three colored routes, a title and a key.

FIELD NOTEBOOK

1. **Narration.** Write one paragraph on how scientists learned where Gilbert White's swifts went, from his 1767 letter to the 2016 discovery that swifts can stay airborne for ten months. Your parent keeps this page.
2. Make a chart of four ways animals navigate (sun, stars, magnetism, landmarks or smell). For each, name the scientist or experiment and one animal.
3. Begin a "first and last" list for your own area: write the date you first see swallows, geese or another migrant this year, and the date you last see them in fall.

Did you know? Israel lies on one of the great bird flyways of the world, a land bridge between Europe, Asia and Africa. Hundreds of thousands of white storks and common cranes, and great numbers of birds of prey, pass over it each spring and autumn, just as Jeremiah saw. The Hula Valley in northern Israel is a famous place to watch them.

Primary source. *Gilbert White, The Natural History of Selborne, Letter X to Thomas Pennant (August 4, 1767); Project Gutenberg eBook #1408.*

How strange is it that the swift, which seems to live exactly the same life with the swallow and house-martin, should leave us before the middle of August invariably! while the latter stay often till the middle of October; and once I saw numbers of house-martins on the seventh of November.

White kept careful records of the first and last dates he saw each bird every year. Practice question 6 asks what his records could and could not tell him.

Go deeper. Scott Weidensaul, *Living on the Wind: Across the Hemisphere with Migratory Birds* (1999); Gilbert White, *The Natural History of Selborne* (free on Project Gutenberg); the Cornell Lab of Ornithology's BirdCast migration forecasts and eBird; NOAA Fisheries page on gray whales; a second video topic: "indigo buntings in the planetarium" or "how birds sense magnetism."

Goes deeper in. Geography (high school), map scale and great-circle routes (coming soon); Life Science, the unit on animal behavior; Earth Science, for the earth's magnetic field.

For families. Arctic tern figures are from Egevang and colleagues, *Proceedings of the National Academy of Sciences* (2010). The godwit record (bird B6, October 13–24, 2022, about 13,560 km) was reported by the tracking team and confirmed by Guinness World Records. The ten-month swift flights are Hedenström and colleagues, *Current Biology* (2016). Gray whale distances vary by route and source. The Wiltschkos' robin study appeared in *Science* (1972); Kramer's sun-compass studies date from the early 1950s; Emlen's planetarium studies from the late 1960s and 1970. In Jeremiah 8:7 "the turtle" means the turtledove. Bewick's plate is identified from the 1797 first volume; check the edition when using a library copy.

PRACTICE

1. **EASY** Which bird makes the longest yearly migration, and about how far?
2. **EASY** In Jeremiah 8:7, which four birds “know their appointed times”?
3. **MEDIUM** Describe the experiments that showed birds can use (a) the stars and (b) the earth’s magnetism.
4. **CHALLENGE** The godwit B6 flew about 13,560 km in 11 days without stopping. What was its average speed in kilometers per hour? How many 1,000-km legs would a small plane with a 1,000-km range need to make the same trip?
5. **CHALLENGE** An Arctic tern flies about 70,900 km a year and lives 30 years. How far does it fly in a lifetime? The moon is about 384,400 km away. How many round trips to the moon is that?
6. **MEDIUM** Read White’s primary source. What could his dated observations tell him, and what could they not tell him?

Make it a game · Sun Compass. Outdoors on a sunny day, each player uses only the sun and a watch to point toward south (in the Northern Hemisphere, around noon the sun is roughly due south). Mark each guess with a stick. Then check with a real compass. Whose stick was closest? Talk about why a bird’s sun compass needs an inner clock.

Scripture. “Yea, the stork in the heaven knoweth her appointed times; and the turtle and the crane and the swallow observe the time of their coming; but my people know not the judgment of the LORD.” (Jeremiah 8:7, KJV)

The migrating birds obey the times God set for them. Jeremiah holds them up as a rebuke to God’s people, who knew His law and did not keep it. Watching faithful birds should make us more faithful.

Practice: answers

1. The Arctic tern, about 70,900 km (44,000 miles) a year on average for the tracked birds.
2. The stork, the turtle (turtledove), the crane and the swallow.
3. (a) Stephen Emlen put indigo buntings in a planetarium; when he changed the star pattern, the birds changed direction, showing they steer by the stars. (b) The Wiltschkos placed European robins in cages with changed magnetic fields; the birds changed the direction they tried to fly, showing a magnetic compass.
4. $11 \text{ days} \times 24 = 264 \text{ hours}$. $13,560 \div 264 \approx 51 \text{ km/h}$, day and night for 11 days. The plane would need 14 legs (13.56 rounded up), meaning 13 refueling stops; the godwit made none.
5. $70,900 \times 30 = 2,127,000 \text{ km}$. One round trip is 768,800 km. $2,127,000 \div 768,800 \approx 2.8$, almost three round trips to the moon.
6. They could tell him when each kind of bird arrived and left, and that swifts always left earlier than swallows and martins. They could not tell him where the birds went, how they got there, or why the swift left early; that needed banding, tracking devices and later research.

6.8 ANIMALS THAT HELPED PEOPLE: THE 1925 SERUM RUN TO NOME

OBJECTIVES

- Tell the story of the 1925 serum run accurately, with its route, dates, distances and key mushers and dogs.
- Explain what made sled dogs suited to the work, and the role of training and care.
- Separate the popular legend (Balto alone saved Nome) from the fuller record (twenty teams, and Togo's longest leg).

Warm-up. Put on a heavy coat, hat and mittens, step outside on a cold day (or stand in front of an open freezer) and try to tie your shoe with your mittens on. Now imagine doing it in the dark, at fifty degrees below zero, in a wind, holding a dog team that wants to run.

Video slot. Video coming. The 1925 serum run to Nome: historic photographs of Leonhard Seppala, Togo, Gunnar Kaasen and Balto; Alaska sled dogs; the Iditarod Trail. Search approved channels (National Park Service, Smithsonian Channel, Cleveland Museum of Natural History, Alaska Public Media, The History Guy); preview first.

KEY TERMS

diphtheria

A dangerous bacterial disease that forms a thick coating in the throat and can close the airway; it struck children hardest before vaccines were common.

antitoxin (serum)

A medicine made from the blood of immunized horses that neutralizes the diphtheria poison; in 1925 it was called "serum."

musher

The driver of a dog sled, from the French *marche*, "go."

lead dog

The dog at the front of the team that hears the musher's commands, finds the trail and sets the pace.

relay

A race or journey in which one team hands off the load to the next at set points, so fresh teams carry it farther and faster.

CORE IDEAS

A town cut off. In January 1925, Nome, Alaska, was a former gold-rush town of about 1,400 people on the shore of the frozen Bering Sea. Its only doctor, Curtis Welch, began seeing

children with sore throats and a gray membrane that could choke them: **diphtheria**. His supply of **antitoxin** was small and out of date, and a new shipment had not arrived before the port froze. Ships could not reach Nome until spring. The town's only airplanes were open-cockpit machines taken apart for the winter. On January 22 Welch sent an urgent telegram: an epidemic was almost certain without help. The town closed its schools, churches and theaters.

The plan. About 300,000 units of antitoxin were found at the railroad hospital in Anchorage, enough to begin treatment. The package, about 20 pounds, was wrapped in quilts and canvas and sent by train some 298 miles north to the end of the line at Nenana. From there to Nome lay 674 miles along the old mail trail, through forest, across the Yukon River country and over the sea ice of Norton Sound. The mail usually took 25 days. Territorial officials chose a **relay** of the best dog drivers, most of them mail carriers. Many were Athabaskan and Iñupiaq men who knew every mile of the country. At 11 p.m. on January 27, "Wild Bill" Shannon left Nenana with the serum in temperatures near 50 degrees below zero.

Twenty teams. Over the next five and a half days, twenty **mushers** and roughly 150 dogs passed the package hand to hand. Some legs were run at night in temperatures that dropped past -60°F ; drivers stopped in roadhouses to warm the serum by the stove so it would not freeze and spoil. Meanwhile, Leonhard Seppala, Nome's most famous musher, had raced east from Nome to meet the serum, planning to carry it back himself. He met Henry Ivanoff near Shaktoolik on January 31, took the package, turned his team around, and, to save a day, drove straight across the open ice of Norton Sound in a rising gale, with ice cracking behind him. His lead dog was **Togo**, twelve years old. Seppala's team covered about 260 miles in all, and its 91-mile leg with the serum was by far the longest of the relay.

The last leg. Charlie Olson carried the serum on to Bluff, where Gunnar Kaasen waited with a team led by a black dog named **Balto**. Kaasen set out into a blizzard so fierce he could not see his dogs. Balto held the trail. When Kaasen reached Point Safety, the next musher was asleep, expecting the storm to delay things, and Kaasen pushed on rather than lose time. He drove into Nome at about 5:30 a.m. on February 2, 1925. The whole relay had taken about $127\frac{1}{2}$ hours. A second, larger shipment followed by relay later in February. The official death count was small, though Dr. Welch believed some cases among Native families were never recorded.

Fame and fairness. Because Balto ran the final leg, newspapers made him a national hero. A bronze statue of him was unveiled in New York's Central Park in December 1925, with Kaasen present, and it still stands. Seppala felt keenly that Togo, who had run the hardest and longest stretch, was forgotten. Both facts are true: Balto led bravely through a blinding storm, and Togo carried the heaviest share. The fuller story honors all twenty teams. After the run, Balto ended up in a sideshow in Los Angeles until schoolchildren and citizens of Cleveland raised money to buy him and his teammates in 1927; his preserved body is at the Cleveland Museum of Natural History. Togo's is at the Iditarod Trail headquarters in Wasilla, Alaska.

Built and trained for cold. Seppala's dogs were Siberian huskies, small and fast compared with the heavy freight dogs Alaskans had used. A sled dog has a double coat (a dense, woolly undercoat and long guard hairs), furred feet, small furred ears, and a bushy tail it curls over its nose to sleep in the snow. Working sled dogs can burn many thousands of calories a day. But design is only half the story. The teams of 1925 were strong because of years of patient training, good food, booties on sore feet and drivers who knew their dogs one by one.

A righteous man regardeth his beast. The serum run is remembered as an animal story, but it is equally a story of people who took responsibility for a town's children and of dogs whose strength and loyalty were the fruit of good care. Proverbs says, "A righteous man regardeth the life of his beast." The dogs who ran to Nome were cared for, and in turn they carried life to a town. The Iditarod race, first run in 1973, still follows much of the old trail.

PICTURE STUDY



Gunnar Kaasen with his lead dog Balto, Unknown photographer, 1925 · Black-and-white photograph · Many prints survive; examples are held by the Library of Congress and the Cleveland Museum of Natural History
Wikimedia Commons · Public domain

Photographs like this one were taken soon after the serum arrived and were printed in newspapers across the country. They helped make Balto the most famous dog in America in 1925. Look at the picture as a historian: it records real people and a real dog, but it was also made to tell a story to the public.

Look closely

- Study Kaasen's clothing. What materials can you identify, and why would they suit the Arctic?
- Study the dog. Find the thick coat, the ears and the chest. How big is Balto compared with the man?

- Who is missing from this picture? Think of the other nineteen mushers and the rest of Kaasen's team.

Talk about it

1. How might one famous photograph shape what millions of people believed about who "saved Nome"?
2. If you could add one more photograph to the record, what would it show?

Safety first. In the relay game, play on level ground away from streets, and the "blizzard" runner walks (not runs) with eyes half open and a partner guiding. If you ever meet a working sled dog team, approach and handle the dogs only with the musher's permission and with the owner present.

HANDS-ON: MAP THE RELAY AND PLAN A TEAM

Turn the serum run into a timeline map, then think like a musher choosing and caring for a team.

You will need

- An outline map of Alaska (printed or traced from an atlas)
- Colored pencils, a ruler and Field Notebook
- Optional: a library copy of *The Cruellest Miles* or the Iditarod Trail's historical map to check place names

Steps

1. Mark Anchorage, Nenana, the Yukon River, Nulato, Unalakleet, Shaktoolik, Norton Sound, Golovin, Bluff and Nome.
2. Draw the train route (Anchorage to Nenana, about 298 miles) in one color and the dog relay (Nenana to Nome, 674 miles) in another.
3. Label these known legs with musher and miles: Shannon, Nenana to Tolovana (about 52); Seppala, Shaktoolik to Golovin (about 91); Olson, Golovin to Bluff (about 25); Kaasen, Bluff to Nome (about 53).
4. Make a timeline from January 20 (first diagnosis) to February 2 (serum arrives) with at least six dated events.
5. Write a short plan: if you were a musher in 1925, what would you check on each dog before a 50-mile run, and what would you carry for the dogs?

Check your work

- My map shows both routes in different colors with a key and at least ten places.
- My timeline has six dated events in the right order.
- My team plan names at least four specific things I would check or carry for the dogs.

FIELD NOTEBOOK

1. **Narration.** Write one paragraph telling the serum run as a fair historian would, giving credit to Balto, to Togo and to the other teams. Include at least three numbers. Your parent keeps this page.
2. Draw a sled dog and label its cold-weather design: double coat, furred feet, small ears, tail over the nose.
3. Copy Proverbs 12:10 and write one sentence about how a musher “regardeth the life of his beast.”

Did you know? The Balto statue in Central Park, by the sculptor Frederick George Richard Roth, has been rubbed shiny by generations of children climbing on it. Its plaque reads in part: “Endurance · Fidelity · Intelligence.” The 1925 run also sped up a change: within a few years, airplanes began to carry mail and medicine across Alaska.

Go deeper. Gay Salisbury and Laney Salisbury, *The Cruellest Miles: The Heroic Story of Dogs and Men in a Race Against an Epidemic* (2003), a careful modern history; the Cleveland Museum of Natural History’s page on Balto; the National Park Service and Bureau of Land Management pages on the Iditarod National Historic Trail; a second video topic: “Leonhard Seppala and Togo.”

Goes deeper in. History (high school), the American 1920s and the history of Alaska (coming soon); Geography, Alaska and the Bering Sea; Gardening & Animals, for working dogs and their care.

For families. Dates, distances and names follow the standard accounts (Salisbury and Salisbury, 2003; the Iditarod Trail Committee; National Park Service): train from Anchorage to Nenana, relay of 20 mushers over 674 miles from January 27 to February 2, 1925, about 127½ hours. Individual leg mileages differ slightly among sources. The number of diphtheria deaths in Nome is uncertain; official figures were small and Dr. Welch suspected unreported cases. No primary source excerpt is included because the 1925 newspaper reports and Seppala’s own account were not available in exact text from the approved archives; a parent can search the Library of Congress’s Chronicling America for February 1925 newspapers to read the original coverage together. This stop does not discuss later vaccination debates; it states plainly that the medicine saved lives.

PRACTICE

1. **EASY** Why couldn’t the antitoxin simply be sent to Nome by ship or plane?
2. **EASY** Who was Togo, and why did Seppala think he deserved more credit?
3. **MEDIUM** Name four features that suit a husky for Arctic work.
4. **CHALLENGE** The relay covered 674 miles in about 127.5 hours. What was the average speed? The mail normally took 25 days. How many times faster was the relay?
5. **CHALLENGE** Seppala’s team ran about 170 miles out from Nome to meet the serum and then about 91 miles with it. If a single team could travel 50 miles a day at most, how

many days would one team have needed to carry the serum all 674 miles? Use your answer to explain why a relay was chosen.

6. **MEDIUM** A popular saying is “Balto saved Nome.” Write a more accurate one-sentence version.

Make it a game • Serum Relay. Set up a course in a yard with four stations. Wrap a small box (the serum) in a towel. Each runner carries it to the next station and hands it off; the receiver must say “Serum safe!” before running. Each station has a challenge: put on mittens and zip a coat, carry the box across a “sea ice” rope without stepping off, or go around a tree twice in a “blizzard” with eyes half closed and a partner guiding. Time the whole relay, then try to beat it.

Scripture. “A righteous man regardeth the life of his beast: but the tender mercies of the wicked are cruel.” (Proverbs 12:10, KJV)

To “regard” the life of an animal is to care for it wisely. The best mushers knew their dogs by name, fed and rested them well and protected their feet. That care made the run to Nome possible.

Practice: answers

1. The sea around Nome was frozen, so no ship could reach it until spring, and the only airplanes were open-cockpit machines taken apart for the winter, too risky in such cold.
2. Togo was Leonhard Seppala’s twelve-year-old lead dog. He led the team on the longest and most dangerous leg, including the crossing of Norton Sound ice, about 260 miles in all, but the fame went to Balto, who ran the last leg.
3. Any four: a dense double coat; furred feet; small, furred ears; a bushy tail to curl over its nose; endurance and the ability to burn great amounts of food energy; a strong desire to pull and run.
4. $674 \div 127.5 \approx 5.3$ miles per hour, including all stops. 25 days = 600 hours; $600 \div 127.5 \approx 4.7$, so the relay was nearly five times faster than the normal mail.
5. $674 \div 50 \approx 13.5$ days, so about 14 days. A relay of fresh teams kept moving day and night and finished in about $5\frac{1}{2}$ days. Fresh dogs and drivers at each stage meant no team had to rest long enough to slow the serum.
6. Sample: “Twenty mushers and about 150 dogs, including Togo on the longest leg and Balto on the last, relayed the serum 674 miles to Nome in five and a half days.” (Any version crediting the whole relay is correct.)

6.9 DESIGN COPIED BY ENGINEERS

OBJECTIVES

- Explain how the Wright brothers learned wing warping from watching birds, using Wilbur Wright's own words.
- Describe four inventions copied from creatures (Velcro, the Shinkansen nose, termite-mound cooling, whale-flipper blades) and the principle borrowed in each.
- Explain why engineers copy principles rather than shapes, and where a famous example turned out to be more complicated than first told.

Warm-up. Take a long, narrow cardboard box (an empty foil or plastic-wrap box with the ends open works well). Hold it at both ends and twist: one end's front edge goes up while the other end's goes down. In 1899 Wilbur Wright did exactly this with an empty bicycle inner-tube box, and it solved one of the great problems of flight.

Video slot. Video coming. The Wright brothers and wing warping (Smithsonian National Air and Space Museum); the 500 Series Shinkansen and the kingfisher; Velcro and burdock burrs under a microscope; humpback whale flipper tubercles and wind-turbine blades. Search approved channels (Smithsonian National Air and Space Museum, Library of Congress, National Park Service Wright Brothers National Memorial, NASA, BBC Earth); preview first.

KEY TERMS

biomimetics

Engineering that copies principles found in living things; the word was coined in the 1950s by the American engineer Otto Schmitt.

lateral balance

Keeping an aircraft or bird level from side to side; control of roll.

wing warping

The Wrights' method of twisting the wingtips in opposite directions to roll an airplane, learned from watching soaring birds; the ancestor of modern ailerons.

drag

The force of air or water that resists a moving object.

passive cooling

Keeping a building cool by its shape, materials and airflow, without air conditioners.

tubercle

A rounded bump; humpback whales have a row of them along the front edge of each flipper.

CORE IDEAS

Two brothers and a buzzard. Wilbur and Orville Wright ran a bicycle shop in Dayton, Ohio. In 1899 Wilbur wrote to the Smithsonian Institution asking for everything it had on flight. Earlier experimenters such as the German engineer Otto Lilienthal, who made about two thousand glider flights before he was killed in a crash in 1896, had shown that wings could lift a man. The unsolved problem was control, above all **lateral balance**: how to keep from tipping sideways. Wilbur watched turkey vultures and other soaring birds and concluded, as he told engineers in Chicago in 1901, that a bird regains its balance by twisting the tips of its wings, so that one side lifts more than the other. That idea, and the cardboard box he twisted in the shop, became **wing warping**.

Watching is not enough. In the same 1901 talk Wilbur warned that the bird's skill "is not apparent to our sight" and that one cannot learn to fly by sitting on a fence watching the birds (see the primary source). So the brothers tested. They flew kites and gliders on the dunes at Kitty Hawk, North Carolina, from 1900 to 1902, built their own wind tunnel to measure hundreds of wing shapes, and designed their own propellers and light engine. On December 17, 1903, Orville made the first controlled, powered, sustained flight: 12 seconds, about 120 feet, into a freezing wind of more than 20 miles an hour. Wilbur's fourth flight that day lasted 59 seconds and covered 852 feet. They copied the bird's principle, not its feathers: their airplane never flapped.

Burrs and a dog. In 1941 the Swiss engineer George de Mestral came home from a walk in the Alps with his dog and found both covered in burdock burrs. Under a microscope he saw that each burr was covered in tiny hooks that caught in loops of fur and cloth. After years of experiments with weaving, especially with nylon, he patented hook-and-loop fastening in the 1950s and named it Velcro, from the French *velours* (velvet) and *crochet* (hook). The burr's hooks are designed to carry the plant's seeds to new ground; de Mestral's carry shoes, jackets and spacesuits.

The bird-watching engineer. Japan's bullet trains had a problem in the 1990s: when a train entered a narrow tunnel at high speed, it pushed a wall of air ahead of it that burst from the far end with a boom heard hundreds of meters away. Eiji Nakatsu, an engineer for JR West and a member of a wild-bird society, thought of the kingfisher, which dives from air into water with hardly a splash. Wind tests showed that a long nose shaped like a kingfisher's beak cut the pressure wave. The 500 Series Shinkansen, in service from 1997, ran about 10 percent faster on about 15 percent less electricity. Nakatsu's team also studied owl feathers, whose serrated edges muffle sound, to quiet the arm that collects power from the overhead wire.

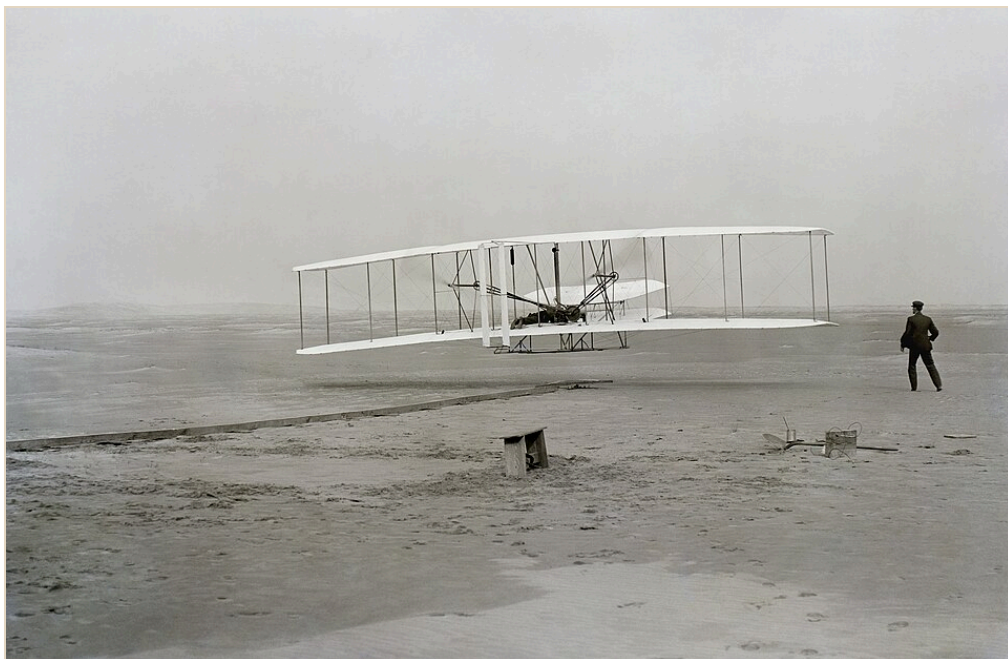
Flippers, feet and mounds. A humpback whale's flippers have a row of **tubercles** along the front edge. Wind-tunnel tests by Frank Fish and his colleagues in 2004 showed that such bumps help a fin keep its grip on the water at steep angles, and the idea has been tried in fans and turbine blades. Geckos cling to glass by millions of microscopic hairs that use weak attractive forces between molecules; engineers have built gecko-like grippers for robots and

spacecraft. In Harare, Zimbabwe, the architect Mick Pearce designed the Eastgate Centre (1996) to stay cool without full air conditioning, inspired by the mounds of African termites.

Honest complexity. The termite story turned out to be more complicated than first told. Later research by the physiologist J. Scott Turner and others found that real termite mounds do not work as simple chimneys drawing cool air up through the nest, as the popular story said; air moves in them in a more complex, tidal way driven by daily changes in temperature. The Eastgate Centre does work, chiefly through thick walls that store heat and fans that flush cool night air through the building. The lesson is the same one Wilbur Wright taught: a design idea from creation must be tested, not just admired.

“In wisdom hast thou made them all.” Engineers copy creatures because creatures are well made. The Wrights studied the buzzard for years and still needed a wind tunnel to catch up with it. The psalmist, looking at the earth and sea full of living things, said, “O LORD, how manifold are thy works! in wisdom hast thou made them all.” When an engineer borrows from a kingfisher or a burr, he is learning, whether he knows it or not, from the wisdom of the Maker.

PICTURE STUDY



First Flight, December 17, 1903, Photograph taken by John T. Daniels with Orville Wright's camera, 1903 · Glass-plate negative (black-and-white photograph) · Library of Congress, Washington, D.C. (Wright Brothers negatives)

Wikimedia Commons · Public domain

Orville Wright set up his camera on a tripod, aimed it at the end of the launching rail and asked John T. Daniels of the nearby lifesaving station to squeeze the bulb if the machine took off. Daniels had never used a camera. He caught the airplane just after it left the rail at about 10:35 a.m., with Orville at the controls and Wilbur running at the wingtip. It is one of the most famous photographs ever taken.

Look closely

- Find Orville lying on the lower wing and Wilbur on the ground. Why is Wilbur running beside the wing?
- Look at the shape of the wings. Can you see any twist at the tips?
- Find the wooden rail on the sand and the bench and tools beside it. What do they tell you about the launch?

Talk about it

1. The Flyer is only a few feet off the ground. Why is this photograph still considered the start of the age of flight?
2. What did the Wrights take from birds, and what did they have to invent themselves?

Safety first. If you cut cardboard for the project, a parent should handle any craft knife; use scissors and cut away from your body.

HANDS-ON: WING WARPING: MAKE A GLIDER THAT ROLLS

Build a simple glider whose wingtips can be twisted, and see for yourself how warping one tip up and the other down makes the glider roll and turn, just as Wilbur saw in the buzzard.

You will need

- A sheet of stiff paper or a manila folder
- Scissors, tape and two paper clips
- A drinking straw or a strip of thin card for the body
- A long hallway or a calm outdoor space
- Field Notebook

Steps

1. Cut a wing about 9 inches long and 2 inches wide, with the corners rounded. Cut a smaller tail about 4 inches by 1½ inches.
2. Tape the wing near the front of the straw and the tail at the back. Clip paper clips on the nose until the glider glides smoothly when gently launched.
3. Fly it straight five times and note its path.
4. Now gently twist the wing: bend the back edge of the left tip slightly up and the back edge of the right tip slightly down. Fly it five times. Which way does it roll and turn?
5. Reverse the twist and fly five more times. Record all fifteen flights in a table.
6. Write a conclusion explaining wing warping in your own words, using the words “lift,” “roll” and “lateral balance.”

Check your work

- My glider flew straight before warping.
- I recorded three sets of five flights in a table.

- My conclusion explains why twisting the tips in opposite directions makes the glider roll.

FIELD NOTEBOOK

1. **Narration.** Write one paragraph on how the Wright brothers learned from birds, using at least one phrase from Wilbur Wright's 1901 speech and explaining why he said watching was not enough. Your parent keeps this page.
2. Make a two-column chart, "Creature" and "Invention," with five rows from this stop. In a third column write the principle borrowed (for example, "hooks catch loops").
3. Sketch a kingfisher's head in profile and the nose of a 500 Series Shinkansen beside it.

Did you know? Around 1505 Leonardo da Vinci filled a small notebook, now called the *Codex on the Flight of Birds* and kept in the Royal Library of Turin, with drawings of birds turning in the wind and notes on how they balance. He designed flying machines that flapped like birds. None could have flown, but he was asking the right question four hundred years before the Wrights.

Primary source. Wilbur Wright, *"Some Aeronautical Experiments,"* an address to the Western Society of Engineers, Chicago, September 18, 1901; printed in *The Early History of the Airplane*, Project Gutenberg eBook #25420.

The person who merely watches the flight of a bird gathers the impression that the bird has nothing to think of but the flapping of its wings. As a matter of fact, this is a very small part of its mental labour. Even to mention all the things the bird must constantly keep in mind in order to fly securely through the air would take a very considerable treatise. ... The bird has learned this art of equilibrium, and learned it so thoroughly that its skill is not apparent to our sight. We only learn to appreciate it when we try to imitate it.

The ellipsis (...) marks a few sentences left out about a falling piece of paper. Practice question 6 uses this source.

Go deeper. Orville and Wilbur Wright, *The Early History of the Airplane* (free on Project Gutenberg); David McCullough, *The Wright Brothers* (2015); the Smithsonian National Air and Space Museum's pages on the 1903 Wright Flyer, which hangs in Washington; Otto Lilienthal, *Birdflight as the Basis of Aviation* (1889; English translation 1911); a second video topic: "gecko feet and gecko grippers."

Goes deeper in. History (high school), invention and industry in America around 1900 (coming soon); Life Science, for structure and function in animals; Small Business & Economics, for how an invention becomes a product (the Wrights' bicycle shop and de Mestral's Velcro company).

For families. Flight details (12 seconds and 120 feet for the first flight; 59 seconds and 852 feet for the fourth) follow the Smithsonian and the National Park Service. Wilbur's speech was given September 18, 1901, and printed in the *Journal of the Western Society of Engineers* that December; the excerpt is copied from the Project Gutenberg text, which uses the spelling "labour." Velcro's patent dates (Swiss filing 1951, grant 1955) are commonly cited. Shinkansen figures are from JR West accounts of Nakatsu's work. The humpback flipper study is Miklosovic, Murray, Howle and Fish, *Physics of Fluids* (2004). The revised understanding of termite mounds comes from J. Scott Turner's work in the 2000s and later studies; the stop presents it as a correction of a popular story, not a settled final word.

PRACTICE

1. **EASY** What problem of flight did wing warping solve?
2. **EASY** What creature inspired Velcro, and what part of it did de Mestral copy?
3. **MEDIUM** What problem did the kingfisher's beak help Japanese engineers solve, and what were the results?
4. **CHALLENGE** Orville's first flight covered about 120 feet in 12 seconds over the ground, into a headwind of about 24 miles per hour. What was the ground speed in feet per second and in miles per hour? About how fast was the Flyer moving through the air? (1 mile per hour $\approx$ 1.47 feet per second.)
5. **CHALLENGE** The popular story said termite mounds cool themselves like chimneys and that the Eastgate Centre copied that. Later research found real mounds work differently. Does that mean the Eastgate Centre failed, or that the inspiration was worthless? Explain carefully.
6. **MEDIUM** In the primary source, what does Wilbur Wright say about the bird's skill, and how does that explain why the Wrights built gliders and a wind tunnel instead of only watching birds?

Make it a game • Creature or Contraption?. One player names an invention (airplane, Velcro, bullet-train nose, sonar, wetsuit, snowshoes, barbed wire, a hypodermic needle, a camera lens). The others race to name a creature that has the same idea (bird, burdock, kingfisher, bat, sea otter fur, hare's feet, rose thorns, mosquito, eye). A point for each match explained correctly; a bonus point for the principle ("hooks catch loops").

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. Engineers searching creation for ideas are mining the "riches" the psalmist praised: wisdom built into creatures by the One who made them.

Practice: answers

1. Lateral balance: keeping the airplane level from side to side and rolling it under control to turn.

2. The burdock plant (its burrs). He copied the tiny hooks that catch in loops of fur or cloth.
3. The boom caused when a fast train entered a tunnel and pushed a wave of air ahead of it. A long, kingfisher-shaped nose reduced the pressure wave; the 500 Series ran about 10 percent faster on about 15 percent less electricity.
4. Ground speed: $120 \div 12 = 10$ feet per second; $10 \div 1.47 \approx 6.8$ miles per hour. Airspeed $\approx$ ground speed + headwind $\approx 6.8 + 24 \approx 31$ miles per hour. The headwind is why it moved so slowly over the sand while flying fast enough to stay up.
5. Neither. The Eastgate Centre works, through thick heat-storing walls and fans that flush cool night air through the building. The termite mound gave a useful idea (passive cooling through a building's shape and airflow), but the simple "chimney" explanation of the mound was wrong. Inspiration can lead to a good design even when the first explanation of the creature is incomplete; both the creature and the building must be tested, and the story should be corrected.
6. He says flapping is a very small part of the bird's work, that its art of balance is so thorough "its skill is not apparent to our sight," and that we only appreciate it when we try to imitate it. So watching could give them ideas, but they had to test and practice with real gliders and measurements to learn what the bird does.

6.10 ADAM NAMES THE ANIMALS

OBJECTIVES

- Read Genesis 2:18–20 closely and explain what Adam’s naming of the animals shows about man’s calling and about God’s purpose.
- Explain how John Ray and Carl Linnaeus built the modern system of naming and classifying living things, including binomial names.
- Build a dichotomous key and use scientific names correctly.

Warm-up. Without looking anything up, write down names for five animals you know that describe what the animal does or looks like (for example, “woodpecker”). Then invent a good descriptive name for an animal you saw this week. What did you have to notice about it first?

Video slot. Video coming. Carl Linnaeus and the naming of living things; how a new species is described and named; museum collections of type specimens. Search approved channels (Natural History Museum London, Smithsonian National Museum of Natural History, The Linnean Society of London, Uppsala University); preview first.

KEY TERMS

taxonomy

The science of naming, describing and classifying living things.

binomial name

A two-part scientific name, genus and species, such as *Castor canadensis* for the North American beaver; the genus is capitalized and both words are italicized.

genus

A group of closely related species; the first word of a scientific name.

kind

The word used in Genesis 1 (Hebrew *min*) for the groups of creatures God made to reproduce “after his kind”; most Christian scholars think a kind is usually broader than a species.

dichotomous key

A tool for identifying a living thing by a series of two-choice questions.

type specimen

The particular preserved specimen to which a species name is officially tied, kept in a museum.

CORE IDEAS

The first naturalist. Genesis 2 tells that the LORD God formed “every beast of the field, and every fowl of the air” and “brought them unto Adam to see what he would call them: and

whatsoever Adam called every living creature, that was the name thereof” (see the primary source). Notice who acts first. God makes the creatures and brings them; Adam names them. God does not hand Adam a list. He invites him into real work and accepts his choices. In Genesis 1:28 God had given man dominion over the fish, the birds and every living thing; here we see that dominion exercised for the first time, not by force but by careful attention. To name a creature well, you must look at it closely.

Naming and a helper. The passage has a second purpose. Verse 18 begins, “It is not good that the man should be alone,” and verse 20 ends, “but for Adam there was not found an help meet for him.” As the animals passed before him, Adam could see that each had its own kind and its own mate, and that none of them was like him. The naming taught Adam his own need, and God answered it by making the woman. Man is set over the animals as their caretaker, and he is not one of them.

How many names? Christians have long asked how Adam could name the animals in part of one day. Several observations help. The text lists cattle, birds and beasts of the field; it does not mention fish, insects or creeping things. And the “kinds” of Genesis 1 are probably broader than modern species: lions, tigers and house cats, for example, may all belong to one cat kind. Creationist researchers estimate that land-animal and bird kinds number in the low thousands. Practice question 4 asks you to work out what that would mean. The exact number is not given, and honest readers hold estimates loosely.

John Ray and the species. For centuries after Adam, naturalists described animals with long Latin phrases. The English naturalist John Ray (1627–1705), a devout Christian, tried to bring order. He gave one of the first practical definitions of a species: creatures that come from the same kind of parents and produce offspring like themselves. In 1691 he published *The Wisdom of God Manifested in the Works of the Creation*, arguing that the careful study of animals and plants is a way of honoring their Maker. His book was read for more than a century.

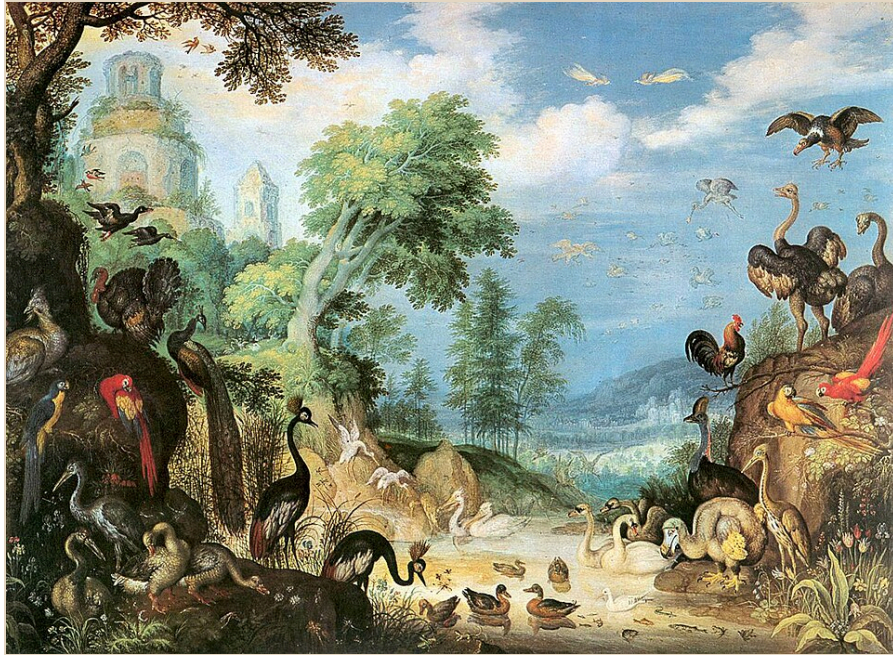
Linnaeus orders the names. The Swedish botanist Carl Linnaeus (1707–1778), the son of a Lutheran pastor, published the first edition of his *Systema Naturae* in 1735: only eleven large pages. He grouped living things into kingdoms, classes, orders, genera and species, and he made popular a simple, two-word **binomial name** for every species. The tenth edition (1758) used binomial names for about 4,400 animals, and it is still the official starting point of animal names today. *Ursus arctos* is the brown bear (Latin *ursus* and Greek *arktos* both mean “bear”). Linnaeus used Latin because scholars in every European country could read it and because a dead language does not drift in meaning. A saying often attributed to him sums up his view: “God created; Linnaeus arranged.”

Naming never ends. Today about two million living species have been formally described, roughly three-quarters of them animals, most of those insects. Scientists still name some fifteen to twenty thousand new species every year, many of them beetles, wasps and deep-sea creatures. Each new name must follow international rules, be published with a description, and be tied to a **type specimen** stored in a museum. The modern system has also met honest difficulties: scientists disagree about where one species ends and another

begins, and names are sometimes revised when new evidence appears. That is the normal work of careful people refining their descriptions.

Names and care. A child who knows the names of the birds at the feeder notices when one goes missing. A farmer who can name the weeds in his field can manage them. Naming is the beginning of stewardship. Every field notebook page you have made on this trail, every labeled sketch of a beaver lodge or a kelp forest, continues the work God first gave Adam: to look closely at His creatures, to call them by fitting names and to care for them well.

PICTURE STUDY



Landscape with Birds, Roelant Savery, 1628 · Oil on panel · Kunsthistorisches Museum, Vienna
Wikimedia Commons · Public domain

Roelant Savery, a Flemish painter who worked for the Holy Roman Emperor Rudolf II in Prague, studied the animals in the emperor's menagerie and painted them gathered together in paradise-like landscapes. Here birds from every continent stand side by side, including a dodo from the island of Mauritius, a bird that has been extinct since the late 1600s. Savery's paintings are among the best records of what the dodo looked like.

Look closely

- Count how many different kinds of birds you can find. Can you name ten of them?
- Find the dodo. Describe it in a way that would let someone who had never seen one recognize it.
- Find birds from different continents: Africa, South America, Asia, Australia or the islands. Could they ever really stand together like this?

Talk about it

1. Savery gathered creatures from all over the world into one scene. How is this like the scene in Genesis 2:19, and how is it different?
2. The dodo was named, painted and then lost within about eighty years of its discovery. What does that teach about naming and stewardship?

HANDS-ON: NAME, KEY AND CLASSIFY: A BACKYARD TAXONOMY

Do the work of Adam and Linnaeus on a small scale: observe eight creatures, give them descriptive names, build a key to tell them apart, and then learn their real scientific names.

You will need

- Field Notebook and colored pencils
- A hand lens
- Access to a field guide or a reliable online guide (Cornell's All About Birds, a state wildlife agency site or iNaturalist with a parent)
- Eight creatures you can observe: birds at a feeder, insects in a garden, or animals pictured in this trail

Steps

1. Observe and sketch each of the eight creatures. Under each sketch, list at least four features (size, color, legs, wings, beak, how it moves).
2. Give each one your own two-word descriptive name, like a binomial: a group word and a describing word (for example, "Gray-hammerer" for a nuthatch).
3. Build a dichotomous key: start with one yes-or-no question that splits your eight into two groups ("Has feathers?"), then keep splitting until each creature stands alone. Write it as numbered pairs of choices.
4. Test your key on a family member: give them a picture of one creature and see if your key leads them to the right name.
5. Look up the real common and scientific name of each creature and write it correctly (genus capitalized, both words underlined or in italics).
6. Compare: which of your names were most like the real ones? What features did the real names notice?

Check your work

- I sketched eight creatures with at least four features each.
- My key works: someone else used it to identify at least one creature correctly.
- I wrote eight scientific names in the correct form.

FIELD NOTEBOOK

1. **Narration.** Write one paragraph explaining what Genesis 2:18-20 teaches about Adam's work, about his relationship to the animals and about why God brought the

animals to him. Then add two sentences on how Ray and Linnaeus continued the work of naming. Your parent keeps this page.

2. Draw a classification ladder for the North American beaver: Kingdom Animalia, Class Mammalia, Order Rodentia, Family Castoridae, Genus *Castor*, Species *Castor canadensis*. Illustrate each rung with a different animal that belongs there.
3. Make a title page for your Trail F Field Notebook with the ten stops listed and Genesis 2:19 copied at the bottom.

Did you know? Scientists sometimes have fun with names. There is a fossil named *Arthurdactylus conandoylensis* after the author of *The Lost World*, and a wasp genus named *Heerz* with the species *Heerz tooya*. The rules allow almost any Latin-shaped name, as long as it has not been used before for an animal.

Primary source. *Genesis 2:18-20, King James Version (1611).*

And the LORD God said, It is not good that the man should be alone; I will make him an help meet for him. And out of the ground the LORD God formed every beast of the field, and every fowl of the air; and brought them unto Adam to see what he would call them: and whatsoever Adam called every living creature, that was the name thereof. And Adam gave names to all cattle, and to the fowl of the air, and to every beast of the field; but for Adam there was not found an help meet for him.

Read it as a historical account, slowly, noticing who does each action. “Help meet” means a helper suited to him. Practice questions 1, 2 and 6 use this passage.

Go deeper. John Ray, *The Wisdom of God Manifested in the Works of the Creation* (1691; free scans on the Internet Archive and the Biodiversity Heritage Library); Carl Linnaeus, *Systema Naturae*, 10th edition (1758; viewable on the Biodiversity Heritage Library); the Linnean Society of London’s pages on Linnaeus; the Natural History Museum (London) page “How are species named?”; a second video topic: “how a new species is described.”

Goes deeper in. Life Science (high school), the unit on classification of living things (coming soon); Literature, for reading Genesis closely as narrative; Art, for Savery and the animal painters of the 1600s.

For families. Genesis 2:18-20 is quoted from the KJV. The count of described species (about two million, with roughly 15,000-20,000 added a year) follows the Catalogue of Life and the International Institute for Species Exploration and changes yearly. The 4,400 animals in *Systema Naturae* (1758) is the usual approximate figure. “Deus creavit, Linnaeus disposuit” is widely attributed to Linnaeus but its exact origin is uncertain, so it is labeled as “often attributed.” Estimates of the number of created kinds come from creationist baraminology research and are presented as estimates. Savery’s *Landscape with Birds* (1628) is in the Kunsthistorisches Museum; the dodo is generally dated as extinct by about 1662-1690. The Eve narrative is mentioned only as the text gives it.

PRACTICE

1. **EASY** According to Genesis 2:19, who brought the animals to Adam, and why?
2. **EASY** Which groups of animals does Genesis 2:20 say Adam named?
3. **MEDIUM** Write the scientific name of the North American beaver correctly, and explain what each part means.
4. **CHALLENGE** Suppose Adam named 2,500 kinds of birds and land animals in 8 hours. How many names per minute is that? About how many seconds per name? Does that seem possible for a man with an unfallen mind who had only to look and name?
5. **CHALLENGE** Linnaeus's 1758 *Systema Naturae* named about 4,400 animals. Today about 1.5 million animal species are described. How many times more is that? If 15,000 new animal species are named each year, how many years would it take to add another 4,400?
6. **MEDIUM** Reading the primary source (Genesis 2:18–20), give two things the naming of the animals accomplished.

Make it a game • Twenty Questions, Linnaeus Style. One player thinks of an animal from anywhere on this trail. The others may ask only yes-or-no questions that follow the classification ladder, from big groups to small: “Is it an animal with a backbone? A mammal? A rodent? Does it live in water?” Count how many questions it takes to name the animal correctly, scientific name for a bonus point. The fewest questions wins.

Scripture. “Thou madest him to have dominion over the works of thy hands; thou hast put all things under his feet: All sheep and oxen, yea, and the beasts of the field; The fowl of the air, and the fish of the sea, and whatsoever passeth through the paths of the seas.” (Psalm 8:6–8, KJV)

David marvels that God set man over the creatures. Adam's naming in Genesis 2:19 was the first act of that dominion, and every careful naturalist since has continued it. Dominion is a trust: to know, name and keep what belongs to God.

Practice: answers

1. The LORD God brought them, “to see what he would call them.”
2. All cattle, the fowl of the air and every beast of the field. (Fish and creeping things are not mentioned.)
3. *Castor canadensis* (genus capitalized, both words italicized or underlined). *Castor* is the genus (the beaver group, from the Greek and Latin word for beaver); *canadensis* is the species name, meaning “of Canada.”
4. 8 hours = 480 minutes. $2,500 \div 480 \approx 5.2$ names per minute, or about 11.5 seconds per name ($60 \div 5.2$). It is quick but possible: naming at a glance, without writing descriptions, is far easier than scientific description. (Any reasoned answer is acceptable for the last part.)
5. $1,500,000 \div 4,400 \approx 341$ times as many. $4,400 \div 15,000 \approx 0.29$ years, about 3½ months; scientists now name as many animals in a few months as Linnaeus did in his great tenth edition.

6. Any two: Adam exercised the dominion God gave him by studying and naming the creatures; God honored Adam's choices ("that was the name thereof"); Adam learned that no animal was a fitting helper for him, which prepared for the creation of the woman; it showed man as caretaker over the animals, distinct from them.

TRAIL 6 BADGE QUIZZES

The badge quizzes are optional. The student answers in writing, in full sentences, and shows the arithmetic for any calculation. Four right out of five earns each badge. Badges and the certificate are earned by completing the stops and the Field Notebook, not by scores.

Badge quiz 1 (Stops 1–5)

1. A bat hears the echo of its call 20 milliseconds (0.020 s) after calling. Using 343 m/s for the speed of sound, how far away is the insect?
2. Explain Thayer's law of countershading, and name one claim of Thayer's that went beyond the evidence.
3. Name two ways a hibernating arctic ground squirrel differs from a denning black bear.
4. Why are beaver dams built thicker at the base, and what triggers beavers to repair them?
5. Is the oxpecker-rhino relationship mutualism, commensalism or parasitism? Explain with evidence.

Badge quiz 2 (Stops 6–10)

6. Explain how sea otters protect kelp forests.
7. Name three ways migrating birds find their way, with the experiment or scientist that showed each.
8. Give the start, end, distance and approximate time of the 1925 serum relay, and name the dogs who led the longest leg and the last leg.
9. What did Wilbur Wright learn from watching soaring birds, and why did he say watching was not enough?
10. What does Genesis 2:19–20 show about man's calling, and what did Linnaeus add to the work of naming?

TRAIL CERTIFICATE: MY AMAZING ANIMALS FIELD NOTEBOOK AND TRAIL F CERTIFICATE

Gather the Field Notebook pages from this trail into one bound or stapled booklet with a cover: "Animals Doing Amazing Things: Expert Field Notebook," your name and the dates you started and finished. Use the title page you made in Stop F10.

Include all ten narration paragraphs (the parent keeps the originals or clean copies), at least five project data tables or graphs, and one page of primary-source notes for each stop that had one.

Add a final one-page essay: choose the ability from this trail that most amazed you and explain how it works, what scientists still do not know about it, and what it teaches about the Creator.

When the booklet is complete, a parent reviews it with the rubric below and signs the Trail F certificate.

- **Completeness:** All ten stops are represented, each with a dated narration paragraph and at least one diagram, table or sketch.
- **Accuracy and numbers:** Facts, dates and calculations are correct; units are shown; arithmetic is written out.
- **Use of sources:** Primary sources are quoted exactly and named; the student distinguishes what a writer observed from what he could not know.
- **Reasoning and care:** The final essay explains a mechanism clearly, names an honest open question and connects the study to Scripture; pages are neat and labeled.

Answer key

1. Round trip = $343 \times 0.020 \approx 6.9$ m, so the insect is about 3.4 m away (half the round trip).
2. Animals darker on top and lighter below cancel the shading sunlight gives a solid body, so they look flat and blend in. He went too far in claiming that all coloring is for concealment, for example that flamingos are pink to match the sunset or that peacocks are hidden by their tails.
3. Any two: the squirrel's body falls below freezing (about -2.9 °C) while the bear's drops only a few degrees; the squirrel rewarms in periodic arousals; the bear gives birth and nurses cubs in the den; the bear goes months without urinating or passing waste, recycling its nitrogen.
4. Water pressure increases with depth, so the bottom must resist the most force. Beavers respond to the sound of running water, which nearly always means a leak.
5. Mostly mutualism with a parasitic edge: oxpeckers eat ticks and their alarm calls helped rhinos detect people (from 23 to 100 percent of approaches, at 61 m instead of 27 m), but they also peck wounds and drink blood.
6. Sea otters eat sea urchins. Without otters, urchins multiply and eat the kelp's holdfasts, turning forests into urchin barrens; with otters, urchins stay few and the kelp forest and its many creatures thrive. The otter is a keystone species.
7. Sun compass (Kramer's starlings, 1950s); star compass (Emlen's indigo buntings in a planetarium, 1960s); magnetic sense (the Wiltschkos' robins, 1972). Landmarks and smell (shearwaters) are also acceptable.
8. Nenana to Nome, 674 miles, about $127\frac{1}{2}$ hours (January 27 to February 2, 1925). Togo led Seppala's team on the longest leg; Balto led Kaasen's team on the last leg.
9. That birds keep lateral balance by twisting their wingtips (which led to wing warping). He said the bird's skill "is not apparent to our sight" and is only appreciated when we try to imitate it, so the brothers had to build and fly gliders and test wings in a wind tunnel.
10. God brought the animals to Adam to see what he would call them and accepted his names: man exercises dominion by studying and naming the creatures as their caretaker, and he learns that none of them is a fitting helper for him. Linnaeus organized names into a system of kingdoms, classes, orders, genera and species and popularized two-part (binomial) Latin names, with the 1758 tenth edition as the starting point for animal names.