SCHOOL LAUNCH · LIFE SCIENCE K–8

Grade 4 Life Science: Classification

A year of true stories about naming and sorting the living world, from Carl Linnaeus and his little book of 1735 and John James Audubon's life-size birds to Richard Owen's new word "Dinosauria" and the men who saved the last American bison, each one followed outdoors with a hand lens, a ruler and a nature notebook until the student can key out a leaf, read a skull's teeth and write a field guide to the creatures in his or her own backyard.

First edition

> *"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)*

Course guide

This course teaches a fourth grader how scientists sort and name living things, and why it matters. It follows eight units through one school year: Carl Linnaeus and his system of kingdoms, classes and two-part names; the five classes of animals with backbones; the animals without them, from spiders and crabs to snails and starfish; birds in depth with John James Audubon's *Birds of America*; mammals in depth, with the teeth that tell what an animal eats and the true story of how the American bison was saved; the plant kingdom from mosses and ferns to conifers and flowers; the great groups of dinosaurs, beginning with Richard Owen, who coined the word "Dinosauria" in 1842; and a final unit in which the student writes and illustrates a field guide to twelve local species.

Every lesson follows the same path. First comes **the story**: a real person at a real place and time, such as Linnaeus sending his students around the world to collect plants, or Audubon painting birds life-size on paper so large it was called double elephant folio. Then **how they figured it out**: what they looked at, what they measured and counted, and what they got wrong at first. Then **the big idea**, explained for a fourth grader. Last, the student **observes and measures** for himself or herself: sorting buttons with a dichotomous key, measuring beaks and wingspans in centimeters (and inches), timing a snail across a ruler, tallying birds at a feeder and pressing leaves for the notebook.

The thread of the year is a single question: **how do we know what group a creature belongs in?** The answer is always the same: look closely, compare carefully, and write down what you see. By spring the student can use a key, read a scientific name, explain why a whale is a mammal and a bat is not a bird, and tell a fern from a moss and a theropod from a sauropod. The optional **Nature Lab** at the end takes those skills outside for a nature walk, a backyard survey, a visit to a zoo, farm or museum and a small specimen collection.

Classification is a way of reading the order God built into His world. Linnaeus himself, a Christian and the son of a pastor, saw his work as cataloguing the Creator's handiwork, and a well-known saying attached to his name runs, "God created, Linnaeus arranged." The course begins where Scripture begins: "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) Each unit asks the student to notice how living things are made after their kinds, with wonderful variety inside each kind, and to give thanks for it.

WHO IT IS FOR

Written for students in grade 4 (about ages 9–10) who read on their own, can measure with a ruler and make a simple tally chart or bar graph. A parent or teacher reads along, goes outside with the student, and supervises every experiment and every walk near water, roads or wild animals. Nothing needs to be bought beyond ordinary household things: a notebook, colored pencils, a metric ruler, a hand lens, zip-top bags, modeling clay, old newspaper and a few heavy books.

HOW TO USE THIS COURSE

The weekly rhythm. The year has 32 lessons in 8 units, one lesson a week. Session 1 (about 45 minutes) is the warm-up, the story and core ideas, the worked examples and the picture study. Session 2 (about 45 minutes) is the experiment, the practice and the nature notebook page. After Unit 8, the optional **Nature Lab** adds four more outdoor lessons; use it in late spring, over the summer or spread through the year whenever the weather is good.

The ★ quarter path. Ten lessons are marked with a star. Together they make a one-quarter course that keeps the core skills: Linnaeus and his ranks, the dichotomous key, the five vertebrate classes, the arthropods, Audubon and the birds, teeth and diet, the plant groups, the dinosaur groups and the finished field guide. Families short on time can teach only the starred lessons and still end with a field guide.

The nature notebook. Use one sturdy sketchbook or composition book for the whole year. Every lesson ends with a dated page: a labeled drawing, a measurement table, a tally, a key or a pressed leaf. Write the common name, the scientific name when you know it, where and when you saw it, and one sentence about what surprised you. Draw what you see, not what you expect to see. These pages become the raw material for the Unit 8 field guide.

Experiments and safety. Each experiment names what is changed (the variable), what is kept the same and what is measured. Measure in metric units, with U.S. customary units in parentheses. Look at spiders, insects and other small animals without handling them, and return every live creature where it was found. Wash hands after outdoor work. Learn to recognize poison ivy and stinging plants before collecting leaves, pick only common plants where you have permission, and never collect wild bird feathers, nests or eggs; in the United States that is against federal law. An adult goes along on every walk near water or roads.

Worked examples and practice. Each lesson has two worked examples that show the thinking step by step, then eight practice items, including one table or graph to read and one experiment to design. Answers are given so a parent can check the work at once. Go over every missed item together; the goal is careful observation, not speed.

Unit reviews and unit projects. Each unit ends with a 10-item, 50-point quiz and a unit project that pulls the unit together, such as a dichotomous key to a family's shoe collection, a vertebrate class poster, a life-size bird drawing, a skull-and-teeth chart or a pressed-plant sheet. Keep the projects in one folder; Unit 8 gathers them into the field guide.

A word about time. The course is written from a Christian view of creation (Genesis 1:1) and the Flood (Genesis 6–9). Deep-time names such as "Jurassic" or "Ice Age" are taught as museum words, so students can read any sign or textbook with understanding. Wherever they come up, especially in the dinosaur unit, a ⏳ *Thinking About Time* box sets out what the sign says, what we actually observe in the bones and rocks, and how Christians read it.

SCOPE AND SEQUENCE

Unit 1: Linnaeus and the Order of Living Things (1–4)

Carl Linnaeus and his Systema Naturae of 1735; the ranks from kingdom to species; two-part scientific names; and using and building a dichotomous key.

Unit 2: Vertebrates: Animals with Backbones (5–8)

The five classes of vertebrates (fish, amphibians, reptiles, birds and mammals); how a backbone is built and why it bends; warm-blooded and cold-blooded animals measured with a thermometer; and a sorting game.

Unit 3: Invertebrates: Animals Without Backbones (9–12)

Spiders and their eight legs; crabs, lobsters and the jointed-leg arthropods; snails and the mollusks; and starfish and the spiny-skinned echinoderms.

Unit 4: Birds in Depth (13–16)

John James Audubon and The Birds of America (1827–1838); how beaks and feet fit what a bird eats and where it lives; a backyard bird count with tallies and a bar graph; and drawing a bird from life.

Unit 5: Mammals in Depth (17–20)

Teeth that tell an animal's diet; marsupials and their pouches; the primates; and the true story of how the American bison was brought back from the edge in the 1880s–1900s.

Unit 6: Plants Classified (21–24)

Mosses and ferns that grow from spores; conifers that bear cones; flowering plants and their seeds; and pressing and labeling plants for the notebook.

Unit 7: Dinosaur Classification (25–28)

Richard Owen names Dinosauria in 1842; the meat-eating theropods; the long-necked sauropods; and the bird-hipped ornithischians, with ⏳ Thinking About Time boxes for the museum words.

Unit 8: Field Guide Project (29–32)

The student chooses twelve local species, gathers field notes, drawings and photos, writes a page for each with its group and scientific name, and presents a finished field guide with its own dichotomous key.

Unit 9: Nature Lab (optional) (Optional)

Four outdoor lessons that put the year's skills to work: a nature journal walk, a backyard survey, a visit to a zoo, farm or museum, and a small, lawful specimen collection.

MATERIALS

- **Nature notebook (a sturdy sketchbook or composition book)**: One for the whole year: labeled drawings, measurement tables, tallies, keys and pressed leaves.
- **A hand lens or magnifying glass**: Used in nearly every unit for leaves, shells, feathers found indoors in craft packs, insects and seeds.
- **A ruler and tape measure marked in centimeters and inches**: For beaks, wingspans, leaves and the snail race. Metric comes first; inches go in parentheses.
- **Colored pencils, a soft pencil and an eraser**: For drawing from life in the notebook and the field guide.
- **A kitchen or outdoor thermometer and a timer**: For the warm-blooded and cold-blooded experiments and for timing observations.
- **Modeling clay, pipe cleaners, empty thread spools or large beads**: For backbone models, beak-and-feet models and dinosaur skeleton sketches in three dimensions.
- **Old newspaper, paper towels and a stack of heavy books**: A homemade plant press for Unit 6 and the Nature Lab.
- **Zip-top bags, small jars and index cards**: For sorting games, keys and short-term looks at small creatures, which are always returned where they were found.
- **A bird feeder, or a window with a view of trees, and binoculars if you have them**: For the backyard bird count in Unit 4. A camera or phone helps with the field guide but is never required.
- **Optional: a regional field guide to birds, trees or wildflowers from the library**: Never required. Helpful for checking names in Units 4, 6 and 8.

GRADING

Grades come from the unit quizzes, the nature notebook and the experiments and unit projects, because classification is learned by looking closely and writing down what you see. An experiment that did not turn out as predicted but is honestly measured and explained earns full credit.

- Unit quizzes (8 quizzes, 50 points each): 30%
- Nature notebook (dated pages, labeled drawings, careful measurements): 25%
- Experiments (prediction, variable and control, measurements, conclusion): 20%
- Unit projects and the Unit 8 field guide: 25%

A 90–100, B 80–89, C 70–79, D 60–69. Below 60: redo the quiz or project with help.

- Grade the process, not just the result. Did the student predict, observe carefully, measure with units, record honestly and explain what the evidence shows?
- A notebook page earns full marks when it has a date, a place, a title, a labeled drawing or table with units, and one sentence about what the student noticed.
- Unit quizzes may be done orally for a student who writes slowly; the parent writes down the answers.

- The Unit 8 field guide counts as the final project. Grade it for accurate names and groups, careful drawings, a working key and a clear presentation.

A NOTE TO PARENTS

You do not need to be a biologist to teach this course. Read the story aloud together, go outside, and ask three questions over and over: “What do you see?”, “How is it like the others, and how is it different?” and “How could we measure that?” Those questions are the heart of classification, and they are the same ones Linnaeus and Audubon asked.

The course teaches the names and groups scientists use, so your child can read any field guide, museum sign or textbook. It is written from a Christian view of creation, and where museum words about deep time appear, especially in the dinosaur unit, a ⏳ Thinking About Time box explains plainly what the sign says, what we actually observe and how Christians read it. Nothing in the course asks you or your child to take a side in present-day public debates.

Be your child’s outdoor partner. Go along on the walks, keep an eye on water, roads and stinging plants, and help return every creature where it was found. Above all, the course hopes to raise a young person who looks closely, names things truly, handles living things with care, and gives thanks to the God who made each one “after his kind.”

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Unit 9: Bonus: Nature Lab (optional)

- 9.1 Nature Journal Walk
- 9.2 Backyard Survey
- 9.3 Zoo, Farm or Museum Visit
- 9.4 Specimen Collection

★ quarter path · ⏳ Thinking About Time box

UNIT 1

Linnaeus

King Solomon was a great naturalist as well as a king: “he spake of trees, from the cedar tree that is in Lebanon even unto the hyssop that springeth out of the wall: he spake also of beasts, and of fowl, and of creeping things, and of fishes” (1 Kings 4:33). More than 2,600 years later, a Swedish pastor’s son named Carl Linnaeus set out to do the same thing in an orderly way. In this unit you will learn how he sorted all of nature into groups inside groups, gave every living thing a short two-part name, and made it possible for scientists everywhere to talk about the same creatures without mix-ups.

You will follow young Linnaeus from his father’s garden to the far north of Lapland and to the printing press in Leiden, where his *Systema Naturae* came out in 1735. You will climb down the seven ranks from kingdom to species with the gray wolf, find out why Linnaeus moved the whales into the mammals, learn to read and write names like *Acer rubrum* and *Canis lupus*, and discover why an English robin and an American robin are not the same bird. Finally you will meet Jean-Baptiste Lamarck and learn to use, write and test a dichotomous key.

Like a real scientist, you will sort specimens, count and graph your results, run fair tests with a control, and measure in centimeters and inches. Most of all, you will notice that the living things God made “after their kind” are full of order, and that is why they can be classified at all.

BEFORE YOU BEGIN

- Can sort a set of objects into groups and explain the rule used
- Can add and subtract numbers to 100 and read a simple table
- Can measure with a ruler in centimeters and inches
- Knows that animals and plants are living things and rocks are not

MASTERY CHECKLIST

- I can tell how Carl Linnaeus published *Systema Naturae* in 1735 and name his three kingdoms.
- I can list the seven ranks from kingdom to species and place the gray wolf in each one.
- I can compare two animals by counting the ranks they share.
- I can write a scientific name correctly and explain why scientists use them instead of common names.
- I can use a dichotomous key to identify a tree from its leaf.
- I can write a dichotomous key for eight objects, test it on other people and improve it.

OPTIONAL BOOKS AND RESOURCES

- **Integrated Taxonomic Information System (ITIS)** (https://www.itis.gov/): Free, from U.S. government agencies. Type in a common or scientific name and see its full classification from kingdom to species. Best used with a parent for Lessons 1.2 and 1.3.
- **Biodiversity Heritage Library** (https://www.biodiversitylibrary.org/): Free online library of old natural history books. A parent can search for “Systema Naturae” or “Species Plantarum” and page through Linnaeus’s own books, printed in Latin, and find the two-part plant names printed in the margins of *Species Plantarum*.
- **The Linnean Society of London** (https://www.linnean.org/): Free. The society keeps Linnaeus’s own collections of plants, insects and shells, and its website has short articles and pictures about his life and work.

1.1 Carl Linnaeus, Systema Naturae (1735) ★

OBJECTIVES

- Tell the story of Carl Linnaeus and explain why his book *Systema Naturae* (1735) helped scientists everywhere sort living things the same way.
- Name the three kingdoms in Linnaeus's first book and sort real objects into them.
- Explain why scientists need a shared sorting rule, and test that idea with a simple sorting experiment.

Warm-up. Empty a junk drawer or a bag of mixed small things (buttons, coins, pencils, paper clips, rubber bands, bottle caps) onto the table. In three minutes, sort them into groups any way you like. Then ask someone else to sort the same pile without watching you. Did you both make the same groups? Talk about why or why not.

Video. Coming soon. Carl Linnaeus and the beginning of classification for kids (Systema Naturae, three kingdoms, sorting plants by flower parts); search Homeschool Pop (Alternate), SciShow Kids, the Natural History Museum (London), the Linnean Society of London, Smithsonian, and nature footage of the Linnaeus Garden in Uppsala.

KEY TERMS

naturalist
A person who studies living things and nature by watching, collecting, drawing and recording carefully.

classify
To sort things into groups by the features they share.

kingdom
The biggest group in Linnaeus's system. His first book had three: animals, plants and stones.

specimen
One real sample of a living thing (or a rock) kept so it can be studied, such as a pressed leaf or an empty shell.

botany
The study of plants. A person who studies plants is a botanist.

CORE IDEAS

The story. In 1735, in the busy university town of Leiden in the Netherlands, a young Swedish medical student named Carl Linnaeus saw his new work come off the printing press. Its title was *Systema Naturae*, Latin for "The System of Nature." It was only eleven pages long, but they were huge pages, more like wall charts than a book. On them Linnaeus

did something bold. He tried to give every stone, plant and animal then known a place in one orderly chart, so that anyone, anywhere, could find it again.

How they figured it out. Linnaeus was born in 1707 in Råshult, a farming village in southern Sweden. His father, a country pastor, loved flowers and kept a fine garden, and the family name came from a large linden tree that grew on their land. Carl spent so much time with plants that people called him “the little botanist.” At Uppsala University he read every plant book he could find and noticed a problem: each author sorted plants a different way, so a plant that was easy to find in one book was lost in another. In 1732 he traveled through Lapland, the far north of Sweden, on horseback and on foot, collecting and drawing plants and animals and writing careful notes. When he went to the Netherlands in 1735 to finish his medical degree, new friends there were so impressed by his charts that they helped pay to print them.

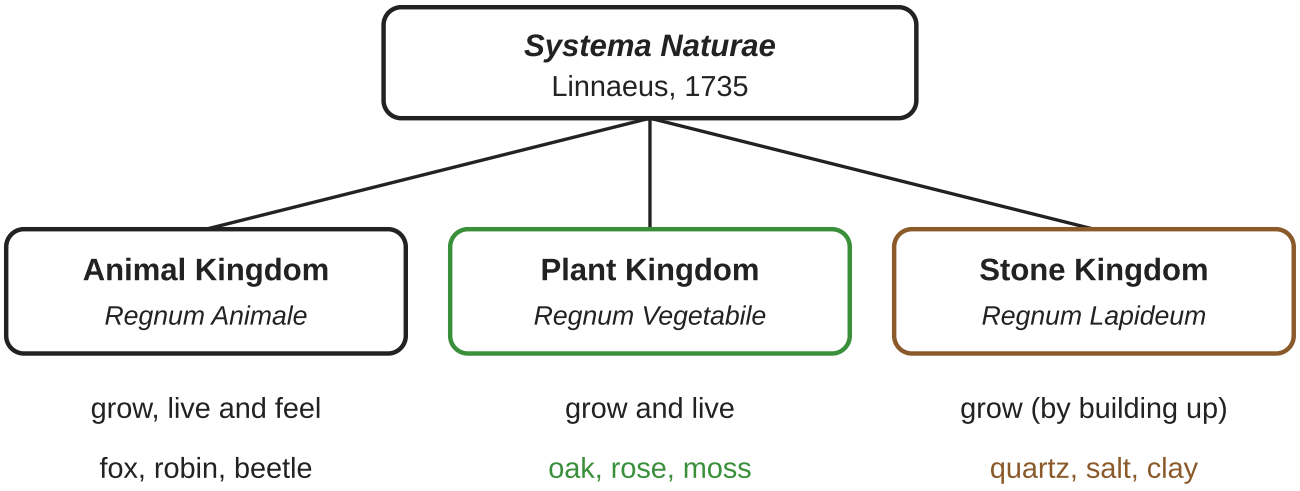
The big idea. To **classify** is to sort things into groups by features they share. Linnaeus began with three great groups he called **kingdoms**: the animal kingdom, the plant kingdom and the stone kingdom (rocks and minerals). He summed them up in a short Latin line: stones grow; plants grow and live; animals grow, live and feel. (By “grow” for stones he meant that crystals build up layer by layer, which is very different from the way a living thing grows.) Inside each kingdom he made smaller groups. He sorted plants mainly by counting the parts inside their flowers: the thread-like stamens and the pistils in the center. His system was not perfect, but it had one great strength. It used features anyone could see and count. A student in Sweden and a doctor in America could look at the same flower, count the same parts and land in the same group.

Try it and see. Gather a pile of natural things: a leaf, a pebble, a pine cone, a clam shell from the kitchen, a seed. First ask Linnaeus’s question: did this come from an animal, from a plant, or from neither? A clam shell goes with the animals, because a living clam built it. A pine cone goes with the plants. A pebble goes with the stones. Then try sorting only the leaves. Will you sort them by shape, by edge or by size? You will quickly find that the feature you choose changes your groups. That is exactly why scientists agree ahead of time on which features to use.

In the world today. Linnaeus kept improving his book all his life. By the tenth edition, printed in 1758 and 1759, it filled two volumes and more than a thousand pages. He became a famous professor at Uppsala, and his students sailed to Asia, Africa, the Americas and the Pacific to collect plants and animals for him. Scientists have learned much more since then. Today they no longer count stones as a kingdom, and they no longer put mushrooms with the plants. Yet they still use his plan of groups inside groups, and the university garden he cared for in Uppsala is still growing.

God’s handiwork. Linnaeus believed he was studying the works of God. Near the start of a later edition of his book he wrote that, looking at creation, he had seen the everlasting, all-knowing God passing by, the way Moses was allowed to see God’s back on the mountain (Exodus 33:23), and he was struck with wonder. A saying often linked to his name puts it in a

few words: God created, Linnaeus arranged. Scientists do not invent the order in nature. They discover the order God has already built into it.



Linnaeus's three kingdoms in Systema Naturae (1735).

PICTURE STUDY



Carl Linnaeus, Alexander Roslin, 1775 · Oil on canvas · Nationalmuseum (Swedish National Portrait Gallery), Gripsholm Castle, Sweden

Alexander Roslin was one of the best portrait painters in Europe. He was born in Sweden but worked for many years in Paris, painting kings, queens and famous thinkers. In 1775 he painted Carl Linnaeus, who was then about 68 years old and the most famous naturalist in the world. This is the portrait people usually picture when they think of Linnaeus.

By this time the king of Sweden had made Linnaeus a knight and then a nobleman, and his book *Systema Naturae* had grown from eleven pages into thick volumes. Look for signs that this is a man people honored, and also for signs of the curious, careful scientist inside.

Look closely

- Look closely at his face. Does he look stern, kind, tired or thoughtful? What makes you think so?
- Look at his clothes and wig. These were the formal clothes of an important man in the 1770s. Can you find any badge or decoration on his coat?
- Notice the background. Is it busy or plain? Why might the painter keep it simple?
- Find where the light falls brightest. What does Roslin want you to look at first?

Talk about it

1. This portrait was painted forty years after *Systema Naturae* first came out. What do you think Linnaeus would say about his life's work if he could talk to you?
2. If someone painted your portrait as a young naturalist, what specimen or tool would you want to hold in the picture?

> **Safety first.** Collect outdoor specimens only with a grown-up. Do not touch plants you do not know, especially poison ivy ("leaves of three, let it be"), and do not touch wild mushrooms. Do not pick up live insects, spiders or other animals. Leave wild birds' feathers, nests and eggs where you find them; in the United States it is against the law to keep them for most wild birds. Wash your hands after handling specimens.

EXPERIMENT: SORT LIKE LINNAEUS

Linnaeus noticed that every author sorted plants differently. In this small experiment you will find out for yourself whether a shared rule helps two people sort the same things the same way. Then you will sort your collection into Linnaeus's three kingdoms.

Question: If two people sort the same 20 objects, will they put them in the same groups? Does it help to give them both the same rule?

You will need

- 20 natural objects, such as leaves, seeds, acorns, pine cones, pebbles, sand, salt crystals, clam or mussel shells from the kitchen, an eggshell from the kitchen, a chicken feather, and a dead insect found indoors on a windowsill
- A helper (a brother, sister or parent)
- 3 paper plates or shoebox lids labeled Animal, Plant and Stone
- Ruler marked in centimeters and inches
- Magnifying glass, if you have one
- Lab notebook and pencil
- A timer

Steps

1. Write the question at the top of a notebook page. Under it write your **prediction**: Will you and your helper sort the objects the same way?
2. Lay out all 20 objects. Measure five of them with your ruler and record each length in centimeters, with inches in parentheses, for example: pine cone 8 cm (3 in).
3. **Round 1, no rule.** Set the timer for 3 minutes. You sort the objects into any groups you like while your helper waits in another room. Write down your groups. Mix the pile, then your helper sorts for 3 minutes while you wait. Write down the helper's groups.
4. Compare. Record how many groups each of you made, and count how many objects ended up in groups that do not match.
5. **Round 2, shared rule.** Give both of you the same rule: "Did it come from an animal, from a plant, or from neither (stone)?" Sort again the same way, one at a time, 3 minutes each, using the three labeled plates.
6. Count again how many objects the two of you placed differently.
7. Make a table in your notebook with columns: Round, Rule given?, Number of groups (me), Number of groups (helper), Objects placed differently.
8. Write your **conclusion** in two sentences: Did the shared rule make your sorting match better? Which object was hardest to place, and why?

Tips

- **What we change:** whether the sorters are given a shared rule. **What we keep the same:** the same 20 objects, the same two people and the same 3-minute time limit. **What we measure:** how many objects were placed differently.
- Things made by a living animal, such as shells, eggshells and feathers, go in the animal kingdom. Things made by a plant, such as seeds, cones and nuts, go in the plant kingdom.
- If you disagree about an object in Round 2, talk it over the way scientists do. What feature would settle it?

Check your work

- I sorted 20 objects into Linnaeus's three kingdoms.
- I recorded my results in a table and measured five objects in centimeters and inches.
- I can explain why a shared rule helps people sort the same way.

NATURE NOTEBOOK

1. Draw one plant specimen from your collection as carefully as you can, life-size. Write its length in centimeters and inches beside it, and label at least two parts.
2. Make a page titled "My Three Kingdoms" with three columns. Draw or list at least four things from your home or yard in each column.
3. Draw a large linden (or any shade) tree and write under it how the Linnaeus family got its name.

From history. Linnaeus sent his best students on long voyages to collect for him, and people called them his “apostles.” One of them, Pehr Kalm, traveled to North America from 1748 to 1751. He visited Philadelphia, met the botanist John Bartram and Benjamin Franklin, and carried hundreds of American plants back to Sweden. Linnaeus honored him by naming the mountain laurel, a flowering shrub of the eastern United States, *Kalmia*.

WORKED EXAMPLES

Example 1. A student finds 12 things: an acorn, a pebble, an empty snail shell, a pine cone, a grain of salt, a dead beetle, a maple leaf, a piece of quartz, a clump of moss, a chicken feather, a clam shell and a dandelion. Sort them into Linnaeus’s three kingdoms and count each group.

(Use the map or drawing “Use the three kingdoms to sort the objects.” shown earlier in this lesson.)

1. Ask of each object: did it come from an animal, from a plant, or from neither?
2. Animal kingdom (made by or part of an animal): snail shell, dead beetle, chicken feather, clam shell. That is 4.
3. Plant kingdom (part of a plant): acorn, pine cone, maple leaf, moss, dandelion. That is 5.
4. Stone kingdom (never alive): pebble, salt, quartz. That is 3.
5. Check the total: 4 + 5 + 3 = 12, which matches the 12 objects.

Answer: Animal: 4 (snail shell, beetle, feather, clam shell). Plant: 5 (acorn, pine cone, maple leaf, moss, dandelion). Stone: 3 (pebble, salt, quartz).

Example 2. Linnaeus was born in 1707. He traveled to Lapland in 1732, printed the first *Systema Naturae* in 1735, and printed the tenth edition in 1758. How many years passed (a) from his birth to the Lapland trip, (b) from the Lapland trip to the first *Systema Naturae*, and (c) from the first edition to the tenth?

1. (a) Subtract the earlier year from the later year: 1732 − 1707 = 25 years.
2. (b) 1735 − 1732 = 3 years.
3. (c) 1758 − 1735 = 23 years.
4. Check: 25 + 3 + 23 = 51, and 1758 − 1707 = 51. The parts add up to the whole.

Answer: (a) 25 years, (b) 3 years, (c) 23 years.

PRACTICE

1. EASY What does *Systema Naturae* mean in English, and in what year and country was it first printed?

2. EASY Name the three kingdoms in Linnaeus’s first book.
3. EASY Put each in Linnaeus’s kingdom: a granite pebble, a sunflower seed, an earthworm, an oyster shell.
4. MEDIUM Where did the Linnaeus family get its name, and what did people call young Carl?
5. MEDIUM A family sorted the specimens they found on a nature walk. Use the table to answer.
   Kingdom | Number of specimens
   Animal | 7
   Plant | 12
   Stone | 5
   (a) How many specimens did they find in all? (b) Which kingdom had the most? (c) How many more plant specimens than stone specimens? (d) What fraction of all the specimens were plants?
6. MEDIUM A pressed maple leaf measures 12 cm across. About how many inches is that? (1 inch = 2.54 cm.)
7. HARD Sam wants to test this question: “Do children sort 20 leaves more alike when they are told to sort by leaf edge (smooth, toothed or wavy) than when they get no rule?” Name (a) what Sam changes, (b) two things Sam must keep the same, (c) what Sam measures, and (d) which round is the control.
8. CHALLENGE In two or three sentences, explain why it was so helpful that Linnaeus sorted plants by features anyone could see and count, such as the number of stamens in a flower.

COMMON MISTAKES

- Thinking Linnaeus discovered all the plants and animals himself. He studied many himself, but he also gathered what other naturalists had found and gave it all one shared order.
- Putting shells, feathers or eggshells in the stone kingdom because they are hard or no longer alive. They were made by living animals, so they belong with the animals.
- Thinking there is only one way to sort anything. Many ways are possible; scientists agree on the same rules so that everyone sorts alike, and they improve those rules as they learn more (for example, mushrooms now have their own kingdom).

Make it a game · Animal, Plant or Stone?. A parent names or holds up a thing: an apple, a wool sock, a marble countertop, a cotton shirt, honey, a pencil. The player has five seconds to call out “Animal!”, “Plant!” or “Stone!” and give the reason (wool comes from a sheep, cotton from a plant, graphite in a pencil is a mineral). One point for the right kingdom, one more for a good reason. Tricky items (a pencil is wood and graphite) earn a bonus point for spotting both. Play to fifteen points.

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. Linnaeus spent his life trying to list God’s many works, and he found them full of wise order. When you sort your collection, you are noticing that same wisdom.

Practice answers

1. “The System of Nature.” It was first printed in 1735 in the Netherlands (in the city of Leiden).
2. The animal kingdom, the plant kingdom and the stone kingdom (rocks and minerals).
3. Granite pebble: stone. Sunflower seed: plant. Earthworm: animal. Oyster shell: animal (a living oyster made it).
4. From a large linden tree that grew on the family’s land. People called Carl “the little botanist” because he loved plants so much.
5. (a) $7 + 12 + 5 = 24$ specimens. (b) The plant kingdom. (c) $12 - 5 = 7$ more. (d) 12 out of 24, which is one half.
6. $12 \div 2.54 \approx 4.7$, so the leaf is about 4.7 inches (almost 5 inches) across.
7. (a) Whether the children get the rule (sort by edge) or no rule. (b) Any two of: the same 20 leaves, the same children, the same time limit, the same place and light. (c) How many leaves the children put in different groups (or how many groups each child makes). (d) The no-rule round is the control, because it shows what happens without the change.
8. Answers will vary. Example: Because anyone could count the same flower parts, a botanist in Sweden and one in America would put the same plant in the same group. That meant scientists could share what they found and find each other’s plants in the book. A feature that depends on someone’s opinion, like “pretty,” would give different answers for different people.

1.2 Kingdom to Species

OBJECTIVES

- List the seven main ranks of classification in order, from kingdom down to species.
- Follow one animal, the gray wolf, through every rank and explain why each group is smaller and its members more alike.
- Compare two animals by counting how many ranks they share, and explain why Linnaeus moved whales into the mammals.

Warm-up. Write your full home address on a card, but in reverse order: start with the country, then the state, then the city, then the street, then the house number, then your own name. Count how many people live at each level (a country holds millions, your house holds only your family). Each line is a smaller group tucked inside a bigger one. Scientists sort living things the same way.

Video. Coming soon. Levels of classification for kids (kingdom, phylum, class, order, family, genus, species; “King Philip Came Over For Good Soup”); search Homeschool Pop (Alternate), SciShow Kids, Smithsonian National Museum of Natural History, the Natural History Museum (London), and nature footage of gray wolves, coyotes and foxes.

KEY TERMS

rank
One level of classification, such as kingdom, class or genus. Each rank is a group inside the rank above it.

kingdom
The largest rank in this lesson. All animals belong to the animal kingdom, Animalia.

genus
A small group of very similar kinds of living things, such as *Canis* (wolves, coyotes and dogs). The plural is genera.

species
The smallest main rank: one kind of living thing whose members can mate and have young that can also grow up and have young.

mammal
An animal with hair or fur that breathes air and whose mother feeds its young with milk. Linnaeus named this class Mammalia in 1758.

CORE IDEAS

The story. In 1758, in Stockholm, Sweden, Linnaeus printed the tenth edition of *Systema Naturae*. In it he sorted the animal kingdom into six large groups he called classes, and he gave one of them a brand-new name: **Mammalia**, from the Latin word for the part of a

mother's body that makes milk. Then he made a surprising move. He took the whales out of the fishes and put them in with the mammals. Whales swim like fish, but Linnaeus looked past their shape. Whales breathe air with lungs, give birth to live young and feed their babies milk, just as cows and bears do.

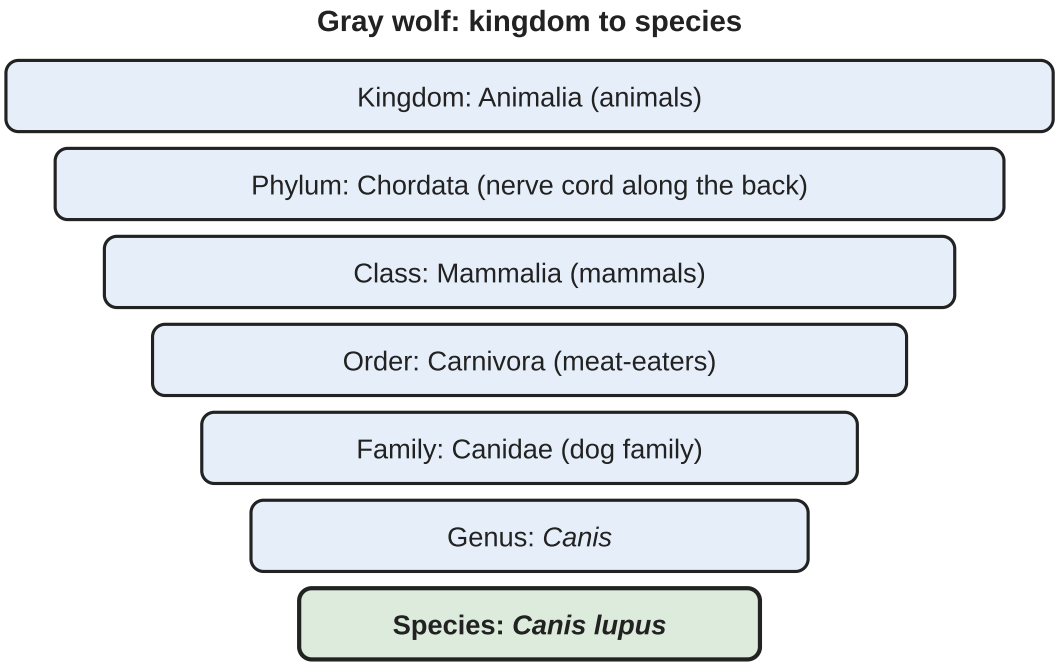
How they figured it out. Linnaeus sorted living things like boxes packed inside boxes. Inside a kingdom were classes, inside each class were orders, inside each order were genera, and inside each genus were species. The higher the rank, the bigger the group and the fewer features its members share. The lower the rank, the smaller the group and the more alike its members are. Scientists after Linnaeus liked this plan so much that they added two more ranks: **phylum**, between kingdom and class, and **family**, between order and genus.

The big idea. Today the seven main ranks, from biggest to smallest, are kingdom, phylum, class, order, family, genus and species. A silly sentence helps you remember the order: "King Philip Came Over For Good Soup." Follow the gray wolf down the ladder. Its kingdom is Animalia (animals). Its phylum is Chordata (animals with a nerve cord along the back). Its class is Mammalia (mammals). Its order is Carnivora (meat-eaters with sharp shearing cheek teeth). Its family is Canidae (the dog family). Its genus is *Canis*. Its species is *Canis lupus*, the gray wolf. At each step, the group gets smaller. More than a million kinds of animals are in Animalia, but only gray wolves are *Canis lupus*.

Try it and see. The more ranks two living things share, the more alike they are. A coyote (*Canis latrans*) shares six ranks with the gray wolf, all the way down to genus. A red fox shares five, down to the dog family. A house cat shares four; it is a mammal and a meat-eater, but it belongs to the cat family. An American robin shares only two: kingdom and phylum. A honeybee shares only the kingdom. An oak tree shares none at all.

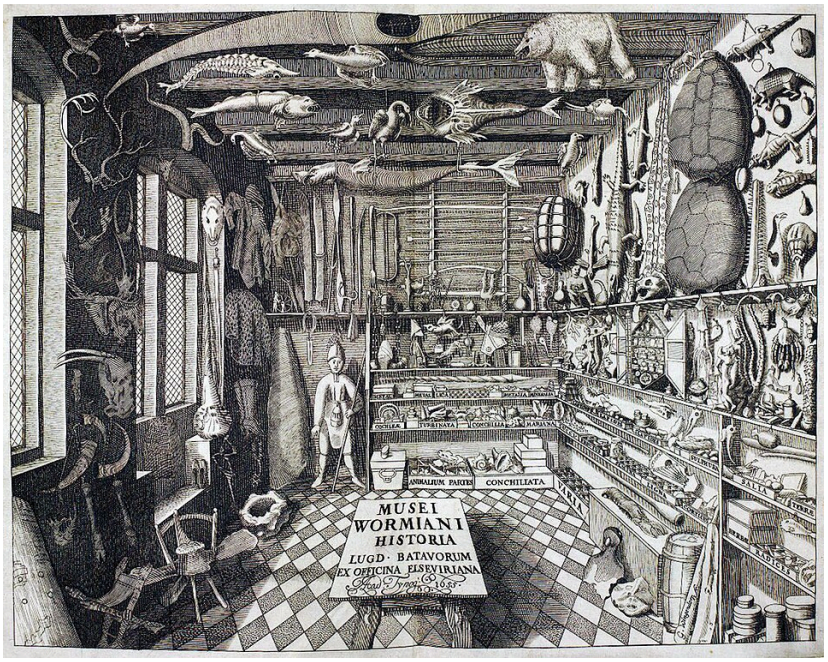
God's handiwork. The Bible says God made each living thing "after his kind" (Genesis 1:25), and we see that living things truly do reproduce after their kind: robins hatch robins, and wolves have wolf pups. A Bible kind is not always the same as a scientist's species, though. Wolves, coyotes and dogs can mate and have pups together, so many Christians who study this think a created kind is often closer to a genus or a family. Within a kind, God built in room for wonderful variety, which is why there are so many breeds of dogs.

In the world today. Scientists still use Linnaeus's ranks, but they have learned much more. Instead of three kingdoms, most textbooks today list five or six: animals, plants, fungi (mushrooms and molds), protists (tiny living things such as amoebas) and one or two kingdoms of bacteria. In high school you will meet one more rank, the **domain**, even bigger than a kingdom. The stone kingdom is gone, because rocks are not alive; they are now studied in Earth Science.



The gray wolf's place in each of the seven ranks. Each group is smaller than the one above it.

PICTURE STUDY



Frontispiece of Museum Wormianum (Ole Worm's Cabinet of Curiosities), Engraver for Ole Worm's museum catalog, 1655 · Engraving · Printed in Leiden, the Netherlands; Worm's museum was in Copenhagen, Denmark

Ole Worm was a Danish doctor and professor in Copenhagen who collected thousands of natural objects: shells, bones, horns, stones, plants and stuffed animals. He kept them in a room people called a "cabinet of curiosities." This picture was printed at the front of the

catalog of his museum, which came out in 1655, about eighty years before Linnaeus wrote *Systema Naturae*.

Collectors like Worm loved nature and saved many treasures, but there was not yet one shared system for sorting them. As you look, think about how Linnaeus might have rearranged this room.

Look closely

- Find something hanging from the ceiling. What kind of animal do you think it is?
- Look at the walls. Can you find horns or antlers? Shells? Fish?
- Look at the boxes on the shelves. They have labels. Why would a collector label his boxes?
- Find two things that seem to be grouped together. What do you think they have in common?

Talk about it

1. If you were in charge of this room, how would you sort it? Would you use Linnaeus's three kingdoms?
2. Why is a jumbled collection hard to use, even if every object in it is wonderful?
3. What is one thing you collect? How do you keep it in order?

EXPERIMENT: THE SHRINKING GROUPS CARD SORT

You will make a deck of 24 living-thing cards and sort it down the seven ranks, one rank at a time, until only one card is left. Along the way you will count and record how many cards stay in each group.

Question: As we go from kingdom down to species, what happens to the number of living things in the group, and do the ones that are left look more alike or less alike?

You will need

- 24 index cards and colored pencils (or pictures cut from old magazines and glued on)
- Write or draw one living thing on each card: oak tree, maple tree, sunflower, moss, honeybee, monarch butterfly, earthworm, garden snail, garden spider, starfish, American robin, bald eagle, leopard frog, rainbow trout, box turtle, cow, horse, rabbit, humpback whale, house cat, black bear, gray wolf, coyote, red fox
- 7 sticky notes labeled Kingdom Animalia, Phylum Chordata, Class Mammalia, Order Carnivora, Family Canidae, Genus *Canis*, Species *Canis lupus*
- Lab notebook, pencil and ruler

Steps

1. Write the question in your notebook. Write your **prediction**: Will the groups get bigger or smaller as you go down? Will the animals in them look more alike or less alike?

2. Lay the 24 cards in a row. Put the Kingdom Animalia sticky note at the top of the table. Move every animal card under it and push the plants aside. Count the cards that stayed and record the number.
3. Next, keep only the animals with a nerve cord and backbone (Phylum Chordata). Push the others aside. Count and record.
4. Keep only the mammals (hair or fur, milk for their young). Count and record. Do you have the whale? You should!
5. Keep only the order Carnivora (meat-eaters with shearing cheek teeth). Then keep only the dog family (Canidae). Then the genus *Canis*. Then the species *Canis lupus*. Count and record after each step.
6. Make a table with two columns, Rank and Number of cards, and fill in all seven rows.
7. Make a bar graph from your table. Put the ranks along the bottom and the number of cards up the side, using 1 cm (about 0.4 in) for each card.
8. Write a **conclusion**: What happened to the number of cards at each step? Were the last three cards (wolf, coyote, fox) more alike than the first 20?

Tips

- **What we change:** the rank we sort by. **What we keep the same:** the same deck of 24 cards and the same sorting rules. **What we measure:** the number of cards left in each group.
- If you are unsure about a card, look up its classification with a parent at the Integrated Taxonomic Information System (itis.gov).
- You should end with 20, 14, 9, 5, 3, 2 and 1 cards. If your numbers differ, check which card is out of place.

Check your work

- I can list the seven ranks in order.
- I recorded my counts in a table and drew a bar graph.
- I can explain why the groups get smaller and more alike as we go down the ranks.

NATURE NOTEBOOK

1. Draw a set of seven nesting boxes or circles, one inside the other, and label them kingdom to species for an animal you love (a parent can help you look up its ranks).
2. Draw a whale and a fish side by side. Label three ways the whale is like a cow and not like a fish.
3. Write “King Philip Came Over For Good Soup” in large letters and, under each word, write the rank it stands for.

> **From history.** The rank “family” is older than Linnaeus’s ranks in one way. In 1689 Pierre Magnol, a botany professor in Montpellier, France, grouped plants that looked alike into what he called families, and later scientists made family a regular rank.

> Magnol's name lives on in a flower: the botanist Charles Plumier named the magnolia after him, and Linnaeus kept the name *Magnolia* in his own books.

WORKED EXAMPLES

Example 1. Use the table to count how many ranks each animal shares with the gray wolf. Which animal is grouped most closely with the wolf?

Animal | Kingdom | Phylum | Class | Order | Family | Genus
Gray wolf | Animalia | Chordata | Mammalia | Carnivora | Canidae | *Canis*
Coyote | Animalia | Chordata | Mammalia | Carnivora | Canidae | *Canis*
Red fox | Animalia | Chordata | Mammalia | Carnivora | Canidae | *Vulpes*
House cat | Animalia | Chordata | Mammalia | Carnivora | Felidae | *Felis*
American robin | Animalia | Chordata | Aves | Passeriformes | Turdidae | *Turdus*

(Use the map or drawing "Compare each animal with the gray wolf's ranks." shown earlier in this lesson.)

1. Start at the kingdom column for each animal and move right. Count the matches with the wolf until you reach the first rank that is different.
2. Coyote: Animalia, Chordata, Mammalia, Carnivora, Canidae, *Canis* all match. That is 6 ranks. Only the species is different (*Canis latrans*).
3. Red fox: matches through Canidae, then the genus is *Vulpes*. That is 5 ranks.
4. House cat: matches through Carnivora, then the family is Felidae. That is 4 ranks.
5. American robin: matches Animalia and Chordata, then the class is Aves (birds). That is 2 ranks.
6. The animal with the most shared ranks is grouped most closely.

Answer: Coyote 6, red fox 5, house cat 4, American robin 2. The coyote is grouped most closely with the gray wolf.

Example 2. Ellie sorted the 24-card deck from the project. She recorded: all cards 24, Animalia 20, Chordata 14, Mammalia 9, Carnivora 5, Canidae 3, *Canis* 2, *Canis lupus* 1. How many cards did she remove at each step, and what pattern do you see?

1. All cards to Animalia: 24 − 20 = 4 removed (the 4 plants).
2. Animalia to Chordata: 20 − 14 = 6 removed (bee, butterfly, earthworm, snail, spider, starfish).
3. Chordata to Mammalia: 14 − 9 = 5 removed (robin, eagle, frog, trout, turtle).
4. Mammalia to Carnivora: 9 − 5 = 4 removed (cow, horse, rabbit, whale).
5. Carnivora to Canidae: 5 − 3 = 2 removed (cat, bear). Canidae to *Canis*: 3 − 2 = 1 removed (fox). *Canis* to *Canis lupus*: 2 − 1 = 1 removed (coyote).
6. Check: 4 + 6 + 5 + 4 + 2 + 1 + 1 = 23 removed, and 24 − 23 = 1 card left.

Answer: She removed 4, 6, 5, 4, 2, 1 and 1 cards. The group gets smaller at every rank, until only the gray wolf is left.

PRACTICE

1. EASY List the seven ranks in order from the biggest group to the smallest.
2. EASY Which rank holds the fewest kinds of living things: class, genus or kingdom?
3. EASY What class name did Linnaeus make up in 1758, and what is it named after?
4. MEDIUM Give three reasons Linnaeus moved whales out of the fishes and into the mammals.
5. MEDIUM Use the table.
   Animal | Order | Family | Genus
   Black bear | Carnivora | Ursidae | *Ursus*
   Brown bear | Carnivora | Ursidae | *Ursus*
   Raccoon | Carnivora | Procyonidae | *Procyon*
   All three are in kingdom Animalia, phylum Chordata and class Mammalia. (a) How many ranks do the black bear and brown bear share? (b) How many do the black bear and raccoon share? (c) Which two are grouped most closely?
6. MEDIUM True or false: two animals in the same family must also be in the same order. Explain.
7. HARD Pill bugs (roly-polies) are not insects; they are cousins of crabs and breathe with gill-like parts that must stay moist. Jack predicts pill bugs will choose damp places. He puts 10 pill bugs in a shoebox with damp paper towel on one half and dry paper towel on the other half, and counts them after 10 minutes. (a) What is he changing? (b) Name two things he should keep the same. (c) What is he measuring? (d) What would be a good control?
8. CHALLENGE Wolves, coyotes and dogs can mate and have pups together, but a wolf and a fox cannot. In two or three sentences, explain what this suggests about how big a created “kind” in Genesis might be compared to a species.

COMMON MISTAKES

- Thinking a whale is a fish because it lives in water and has a fish-like shape. Whales breathe air, have live babies and feed them milk, so they are mammals.
- Mixing up the order of the ranks and thinking species is the biggest group. Kingdom is the biggest; species is the smallest. Remember “King Philip Came Over For Good Soup.”
- Thinking the ranks are written on the animals themselves. The creatures are real and made by God; the ranks are names people use to sort them, and scientists sometimes move an animal to a new group when they learn more about it.

Make it a game · King Philip’s Ladder. Write the seven ranks on seven sheets of paper and lay them on the floor like a ladder, kingdom at the top. A parent calls out an animal from the card deck. The player starts on Kingdom and steps down one sheet for each rank that animal shares with the gray wolf, saying the name of each rank aloud (coyote goes down six steps; robin only two). Land on the right step for a point. Then switch, and the player calls out animals for the parent.

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)

Linnaeus’s ranks are a way of noticing how God made living things: alike in some ways, different in others, and each reproducing after its kind. God looked at what He made and called it good.

Practice answers

1. Kingdom, phylum, class, order, family, genus, species.
2. Genus. (Of the three, kingdom is the biggest and genus the smallest.)
3. Mammalia (mammals). It is named after the part of a mother’s body that makes milk for her young.
4. Whales breathe air with lungs, they give birth to live young, and the mothers feed their babies milk. (Also: whales are warm-blooded.)
5. (a) 6 ranks (kingdom through genus). (b) 4 ranks (kingdom through order). (c) The black bear and the brown bear.
6. True. Each family fits entirely inside one order, the way a room fits inside one house, so animals in the same family always share the same order (and class, phylum and kingdom).
7. (a) Whether the paper towel is damp or dry. (b) Any two of: the same light on both sides, the same temperature, the same kind of paper towel, the same number of pill bugs, the same waiting time. (c) How many pill bugs are on each side after 10 minutes. (d) A control box with dry paper on both halves (to see how the pill bugs spread out when there is no difference). He should also return the pill bugs to where he found them.
8. Answers will vary. Example: Wolves, coyotes and dogs are different species, but because they can have pups together they may belong to one created kind. That suggests a Bible kind can

be bigger than a single species, perhaps closer to a genus or a family. Animals still reproduce after their kind, with lots of variety inside the kind.

1.3 Two-Part Names

OBJECTIVES

- Explain how Linnaeus replaced long phrase names with short two-part names, first for plants (1753) and then for animals (1758).
- Write a scientific name correctly: genus with a capital letter, species word in small letters, both in italics or underlined.
- Explain why scientists use scientific names instead of common names, using the two very different birds called “robin” as an example.

Warm-up. Ask three people in your family what they call a soft drink, a long sandwich on a roll, and a small bug that rolls into a ball. (You may hear “soda,” “pop” or “coke”; “sub,” “hoagie” or “hero”; “pill bug” or “roly-poly.”) Write down every answer. If names change from house to house and town to town, how could scientists around the world be sure they are talking about the same living thing?

Video. Coming soon. Binomial nomenclature for kids (how Linnaeus gave every living thing a two-part scientific name, genus and species, and how to write it); search Homeschool Pop (Alternate), SciShow Kids, the Linnean Society of London, the Natural History Museum (London), Smithsonian, and nature footage of the American robin and the European robin.

KEY TERMS

scientific name
The two-part Latin name scientists use for one species everywhere in the world, such as *Canis lupus* for the gray wolf.

binomial nomenclature
Linnaeus’s system of naming each species with two words. “Binomial” means “two names,” and “nomenclature” means “a system of naming.”

genus
The first part of a scientific name. It names the small group the species belongs to and always starts with a capital letter.

species word
The second part of a scientific name. It is written in small letters and often describes the living thing, such as *alba* (white) or *borealis* (northern).

common name
The everyday name people use for a living thing in their own language, such as “red maple.” Common names can differ from place to place.

CORE IDEAS

The story. In 1753, in Stockholm, Linnaeus published a great two-volume book called *Species Plantarum*, "The Kinds of Plants." It described every plant he knew. In those days, each plant had a long Latin name that was really a short description. Catnip, for example, was *Nepeta floribus interrupte spicatis pedunculatis*, which means "catnip with flowers in a broken, stalked spike." Names like that were hard to remember and kept getting longer as new plants were found. So in the margin beside each long name, Linnaeus printed a short nickname of just two words. Catnip became simply *Nepeta cataria*. Five years later, in the tenth edition of *Systema Naturae* (1758), he gave the animals two-part names too.

How they figured it out. Linnaeus saw that the first word could name the genus, the small group of very similar kinds, and the second word could point to one species inside it. All the maples share the genus *Acer*. The red maple is *Acer rubrum*, and the sugar maple is *Acer saccharum*. All the oaks share the genus *Quercus*; the white oak is *Quercus alba*. Two words were enough to give every species its own name, and the names were easy to say, write and remember. Botanists and zoologists everywhere quickly began to use them.

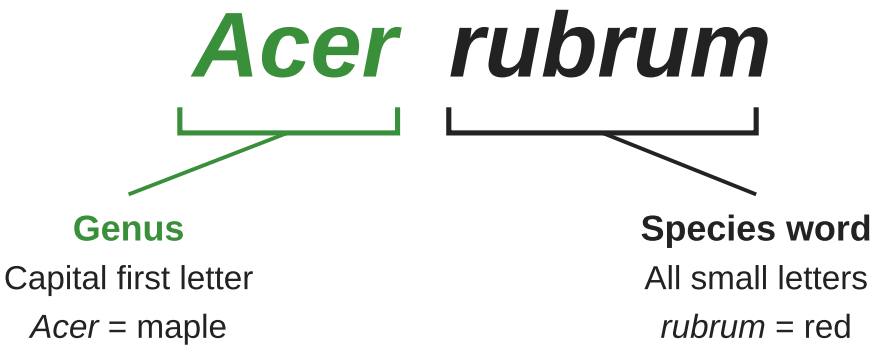
The big idea. Every species has one scientific name, used the same way in every country, and no two animals share the same one. There are simple rules for writing it. The genus comes first and starts with a capital letter. The species word comes second and is all small letters, even when it comes from a place or a person. In print the whole name is in *italics*; when you write by hand, you underline it. After you have written the full name once, you may shorten the genus to its first letter: *Canis lupus* becomes *C. lupus*.

Try it and see. Common names can fool you. In England a "robin" is a small round bird with an orange face and breast, *Erithacus rubecula*. When English settlers came to America, they saw a much larger bird with a reddish breast and called it a robin too, but it is really a thrush, *Turdus migratorius*. Two birds, one common name, two scientific names. Scientific names also hold little clues. Learn a few Latin words, such as *alba* (white), *rubra* or *rubrum* (red), *nigra* (black) and *borealis* (northern), and you can read many names like a secret code.

In the world today. Scientists still follow Linnaeus's rules. They treat his *Species Plantarum* (1753) as the starting point for plant names and his tenth edition (1758) as the starting point for animal names. When a scientist finds a new species today, she or he must give it a two-part name in Latin form and publish a description so others can check it. Some names honor people. A friend of Linnaeus named a little twinflower of the northern forests *Linnaea borealis* after him, and Linnaeus named the black-eyed Susan *Rudbeckia* after his teacher Olof Rudbeck the Younger and Rudbeck's father, both Uppsala professors.

God's handiwork. Naming living things is one of the oldest jobs God gave to people. Before there was any science book, God brought the animals to Adam "to see what he would call them" (Genesis 2:19). Linnaeus even gave our own species a name: *Homo sapiens*, "wise man." The Bible tells us something greater than any name: people are made in the image of God (Genesis 1:27). Every time a scientist names a species carefully, she or he is still doing

the work God gave Adam: looking closely, telling one kind from another and calling each by its name.



Whole name: *Acer rubrum*, the red maple.
Italics in print; underline it when you write by hand.

The two parts of a scientific name, using the red maple.

PICTURE STUDY



Carl Linnaeus in Lapland Dress, Martin Hoffman, 1737 · Oil on canvas · Rijksmuseum Boerhaave, Leiden, the Netherlands

In 1732 young Linnaeus traveled through Lapland, the far north of Sweden, where the Sami people live and herd reindeer. He brought back plants, notes and a set of Sami clothes. A few years later he posed for this portrait wearing them. He was about 30 years old.

In his hand he holds a sprig of his favorite plant, the twinflower, a tiny plant of the northern forests with two pink bell-shaped flowers hanging from each forked stalk. His friend Jan Frederik Gronovius named it *Linnaea* in his honor, and today its full scientific name is *Linnaea borealis*, "the northern Linnaea."

Look closely

- Find the twinflower in his hand. How many flowers can you see on the sprig?
- Look at his clothes. What do you think they are made of? How would they help someone live in a very cold land?
- Look at his face. How old does he look here compared with the Roslin portrait from Lesson 1.1?
- Find any tools or objects besides the flower. Why might a naturalist want to be painted with them?

Talk about it

1. Why do you think Linnaeus chose to be painted in his travel clothes instead of his best city clothes?
2. If a plant or animal were named after you, what would you want it to be, and why?

EXPERIMENT: THE NAME CARD MEMORY TEST

Scientific names can look hard at first. In this experiment you will find out whether knowing what a name *means* helps you remember it.

Question: Do I remember scientific names better when I learn what the Latin words mean?

You will need

- 10 index cards and a pencil or fine marker
- A timer
- Lab notebook
- The ten names below (a parent can help you check spellings at itis.gov)

Steps

1. Write your **prediction**: Will you remember more of the names you learn with meanings, or the names you learn without meanings, or the same number?
2. Make **Group A** cards (with meanings). On the front write the common name; on the back write the scientific name, underlined, and its meaning: red maple, *Acer rubrum* (red maple); white oak, *Quercus alba* (white oak); black walnut, *Juglans nigra* (black walnut); American black bear, *Ursus americanus* (American bear); honeybee, *Apis mellifera* (honey-carrying bee).
3. Make **Group B** cards (no meanings). Front: common name. Back: scientific name only, underlined: sunflower, *Helianthus annuus*; gray wolf, *Canis lupus*; American robin, *Turdus migratorius*; house cat, *Felis catus*; dandelion, *Taraxacum officinale*.

4. Set the timer for 5 minutes and study Group A. Then set it for 5 minutes and study Group B. Use the same time for each group.
5. Wait until the next day. Then have a parent read each common name aloud while you write the scientific name. Do not look at the cards.
6. Score yourself: 1 point for each name with the genus and species word both correct. Record your scores in a table: Group, Studied with meanings?, Names correct (out of 5).
7. Write a **conclusion**: Which group did you remember better? Was your prediction right? Now learn the Group B meanings: *Helianthus annuus* means “sunflower that lives one year,” *Canis lupus* means “dog wolf,” *Turdus migratorius* means “migrating thrush,” *Felis catus* means “cat cat,” and *officinale* means “from the medicine shop,” because dandelion was once sold as a medicine.

Tips

- **What we change:** whether the meanings are learned with the names. **What we keep the same:** the number of names (5 in each group), the study time (5 minutes each) and the wait before the test (one day). **What we measure:** how many names are written correctly.
- Group B is the control: it shows how well you remember names without the change.
- To make the test fairer, have a brother or sister do it too, but with the groups switched.

Check your work

- I wrote ten scientific names correctly, with capital genus, small species word and underlining.
- I recorded my test scores in a table.
- I can explain whether learning meanings helped me remember the names.

NATURE NOTEBOOK

1. Draw the American robin and the European robin side by side (use a field guide or a picture a parent finds). Label each with its common name and its scientific name, underlined.
2. Make a “Latin code” page: write *alba*, *rubra*, *nigra*, *borealis*, *americanus* and *annuus* with their meanings, and add any new ones you find.
3. Draw a twinflower with its two hanging bells and write *Linnaea borealis* beneath it, with one sentence about why it carries Linnaeus’s name.

> **From history.** Linnaeus was born Carl Linnaeus, and he signed his Latin books *Carolus Linnaeus*. In 1761 the king of Sweden made him a nobleman, and he took a new name, Carl von Linné. That is why you will see both names in old books and on Swedish signs. The house where he lived in Uppsala and his country home at Hammarby can still be visited.

WORKED EXAMPLES

Example 1. Here are four trees: red maple, *Acer rubrum*; white oak, *Quercus alba*; sugar maple, *Acer saccharum*; northern red oak, *Quercus rubra*. (a) Which trees are in the same genus? (b) Two of the names have species words that mean "red." Are those two trees in the same genus?

(Use the map or drawing "The first word is the genus; the second is the species word." shown earlier in this lesson.)

1. The genus is the first word. Sort by the first word.
2. *Acer*: red maple and sugar maple. They are both maples.
3. *Quercus*: white oak and northern red oak. They are both oaks.
4. The species words *rubrum* and *rubra* both mean "red." They belong to *Acer rubrum* and *Quercus rubra*.
5. Those two names have different first words, so they are in different genera. A species word may be used again in another genus, but the full two-part name is never repeated.

Answer: (a) Red maple and sugar maple (*Acer*); white oak and northern red oak (*Quercus*). (b) No. *Acer rubrum* is a maple and *Quercus rubra* is an oak; only the species word "red" is shared.

Example 2. A student wrote these names in a report. Find and fix every mistake: (a) canis Lupus (b) Felis Catus (c) ursus americanus (d) In the second sentence of the report, she wrote Canis lupus again in full. How could she shorten it?

1. Rule 1: the genus begins with a capital letter. Rule 2: the species word is all small letters. Rule 3: the whole name is in italics in print, or underlined by hand.
2. (a) *canis* needs a capital C, and *Lupus* needs a small l: *Canis lupus*.
3. (b) *Felis* is correct, but *Catus* needs a small c: *Felis catus*.
4. (c) The genus needs a capital U: *Ursus americanus*. The species word stays small even though it comes from the name of a place.
5. (d) After the full name has been written once, shorten the genus to its first letter with a period: *C. lupus*.

Answer: (a) *Canis lupus* (b) *Felis catus* (c) *Ursus americanus*, all in italics or underlined. (d) *C. lupus*.

PRACTICE

1. EASY What are the two parts of a scientific name, and which one is capitalized?
2. EASY Which is written correctly? (a) helianthus Annuus (b) *Helianthus annuus* (c) *Helianthus Annuus*

3. EASY In what book and year did Linnaeus give two-part names to all the plants? In what book and year did he do it for animals?
4. MEDIUM A girl in England and a boy in Ohio both say, “I saw a robin today.” Are they talking about the same bird? How would scientific names clear this up?
5. MEDIUM Use the code table to translate each name.
   Latin word | Meaning
   Juglans | walnut
   Quercus | oak
   Ursus | bear
   nigra | black
   alba | white
   americanus | American
   (a) *Juglans nigra* (b) *Quercus alba* (c) *Ursus americanus*
6. MEDIUM You have already written *Turdus migratorius* once in your report. How should you write it the second time?
7. HARD In the Name Card Memory Test, (a) what is changed between Group A and Group B, (b) name two things that must be kept the same, (c) what is measured, and (d) which group is the control? (e) Why would the test be unfair if Group A got 10 minutes of study and Group B got only 2?
8. CHALLENGE A scientist in Japan calls a house cat *neko*, and a scientist in Brazil calls it *gato*. In two or three sentences, explain how they can be sure they are writing about the same animal, and why Linnaeus’s idea of using Latin helped.

COMMON MISTAKES

- Capitalizing the species word, as in “Canis Lupus.” Only the genus gets a capital letter, even when the species word comes from a place or a person’s name.
- Using only the second word as the name, as in “lupus.” The species word is never used alone; it always goes with its genus.
- Thinking common names are wrong. Common names are good and useful in everyday life; scientific names are added so that people everywhere can be exact.

Make it a game · Name Builder. Write genus words on blue cards (*Acer*, *Quercus*, *Canis*, *Ursus*, *Felis*, *Juglans*) and species words on white cards (*rubrum*, *alba*, *lupus*, *americanus*, *catus*, *nigra*). Shuffle each pile. A parent calls out a common name, such as “white oak” or “gray wolf,” and the player races to build the right two-card name and lay it down in the right order. One point for the right pair, one more for saying which card needs the capital letter. Then make up a silly name from a wrong pair (*Ursus rubrum*, the “red bear”) and draw it.

Scripture. “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.” (Genesis 2:19, KJV)

To name an animal well, Adam had to look at it closely. Scientists who name species today are still doing that first job: observing carefully and giving each kind a name.

Practice answers

1. The genus and the species word. Only the genus starts with a capital letter.
2. (b) *Helianthus annuus*: capital genus, small species word, in italics.
3. Plants: *Species Plantarum*, 1753. Animals: the tenth edition of *Systema Naturae*, 1758.
4. No. The English robin is a small bird, *Erithacus rubecula*; the American robin is a larger thrush, *Turdus migratorius*. If they used the scientific names, each would know exactly which bird the other meant.
5. (a) black walnut (b) white oak (c) American bear (the American black bear).
6. *T. migratorius* (the genus shortened to its capital first letter and a period, still in italics or underlined).
7. (a) Whether the meanings of the names are learned. (b) Any two of: 5 names in each group, the same study time, the same one-day wait, the same person tested the same way. (c) How many names are written correctly. (d) Group B (no meanings). (e) Because then you could not tell whether a better score came from knowing the meanings or just from studying longer; two things would be changing at once.
8. Answers will vary. Example: They both use the scientific name *Felis catus*, which is the same in every country. In Linnaeus's day, scholars all over Europe read and wrote Latin, so a Latin name belonged to no single country and everyone could use it. Today that one shared name still lets scientists who speak different languages know they mean the same species.

1.4 Dichotomous Keys ★

OBJECTIVES

- Explain what a dichotomous key is and use one, step by step, to identify a tree from its leaf.
- Write good couplets that use clear features you can see, measure or count.
- Build a dichotomous key for eight real objects, test it on other people and improve it.

Warm-up. Play a quick round of "Twenty Questions." A parent thinks of an animal. You may ask only yes-or-no questions ("Does it have fur?" "Does it live in water?"). Count how many questions it takes to guess. Which questions cut down the choices the most? You have just used the idea behind a dichotomous key.

Video. Coming soon. How to use and make a dichotomous key for kids (identifying leaves, trees and animals by yes-or-no choices); search Homeschool Pop (Alternate), SciShow Kids, Science Max, the Arbor Day Foundation, the U.S. Forest Service, state extension services, and nature footage of tree leaves.

KEY TERMS

dichotomous key
A tool for identifying a living thing by making a series of choices between two statements. "Dichotomous" comes from Greek words meaning "cut in two."

couplet
One step in a key: a pair of opposite statements, such as "leaves are needles" or "leaves are flat and wide." Only one can be true.

feature
Something about a living thing you can see, count or measure, such as leaf shape, number of legs or kind of edge. Scientists also call it a trait or a characteristic.

identify
To find out the name of a living thing by looking carefully at its features.

field guide
A book or chart that helps people identify plants, animals or rocks outdoors, often with pictures and keys.

CORE IDEAS

The story. In 1778, the year Linnaeus died, a young French botanist named Jean-Baptiste Lamarck published a three-volume book about the wild plants of France, called *Flore françoise*. Lamarck wanted ordinary people, not only experts, to be able to name the plants they found. So he gave them a new kind of guide. Instead of paging through hundreds of descriptions, a reader answered one simple question at a time, always choosing between just

two answers, until only one plant was left. His readers loved it, and soon this way of identifying living things spread to books everywhere.

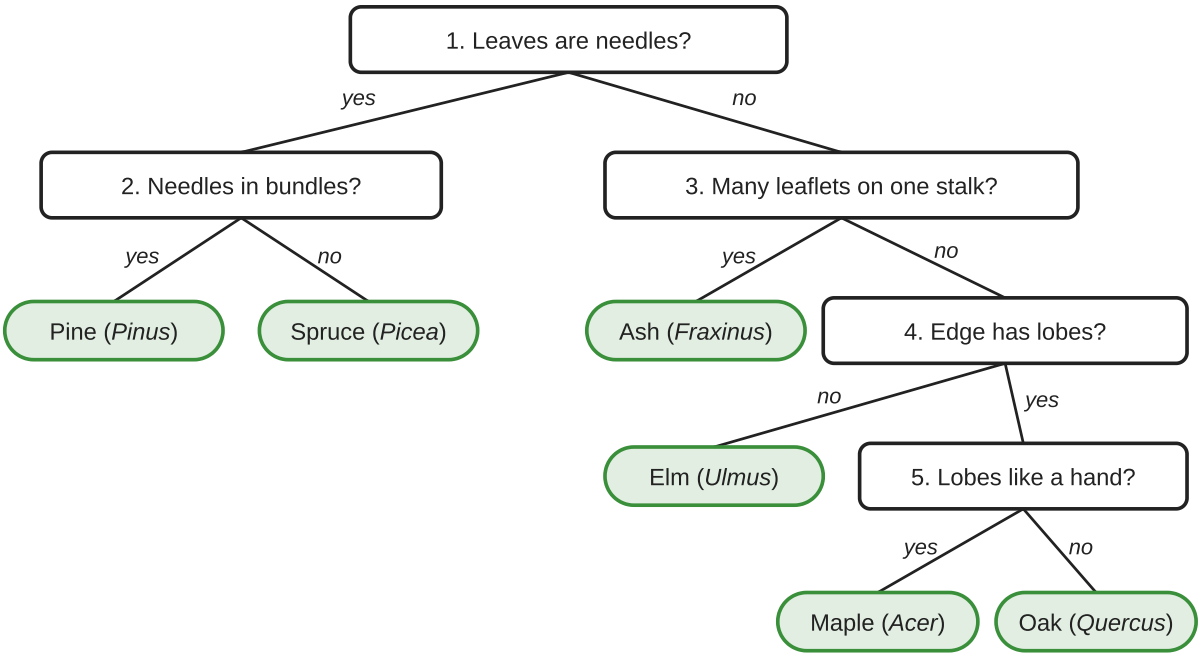
How they figured it out. Linnaeus had already shown how to sort plants into groups. Lamarck turned the sorting around. A sorting chart starts with one name and splits it into groups; a key starts with a mystery plant in your hand and leads you down to its name. Each step of a key is a **couplet**: two statements that cannot both be true, such as “leaves are needles” and “leaves are flat and wide.” You choose the one that fits, and it tells you either the name of the plant or the number of the next couplet to read.

The big idea. A good key uses **features** that are clear and stay the same: the shape of a leaf, whether the edge has teeth or lobes, the number of legs, whether there are wings. It avoids features that change or depend on opinion, such as “big,” “pretty” or “green,” since leaves change color in the fall and a young tree is small. When size matters, a good key measures it: “leaf longer than 10 cm (4 in).” Look at the tree key in the figure. Start at couplet 1 and choose: needles, or flat leaves? Keep choosing until you reach a name. Every path ends at exactly one kind of tree.

Try it and see. You can make a key for almost anything: leaves from your yard, pasta shapes in the kitchen, buttons in a jar. Here is a neat fact you can check. Every couplet splits one group into two, so to separate any number of things you always need one fewer couplet than the number of things. Six trees need five couplets; eight leaves need seven. When you finish your key, test it. Hand it to someone who does not know the answers and watch where they get stuck. A real scientist fixes the couplet that confused them.

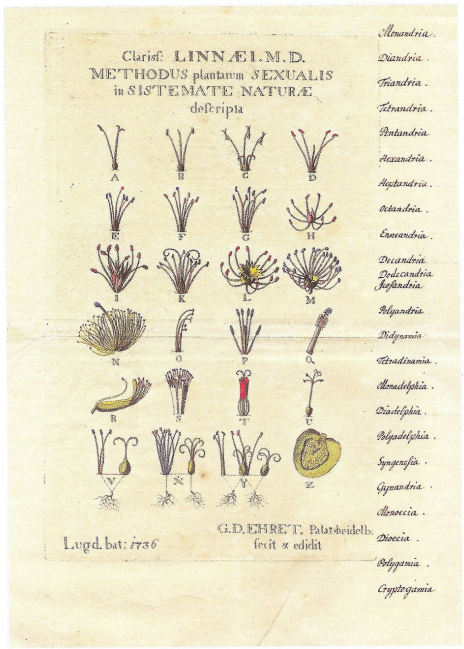
In the world today. Field guides, park rangers, farmers checking for weeds and scientists sorting insects in a museum all still use keys. Many phone apps and websites that identify plants and birds still ask a chain of questions in the same way. Keys only work for the group they were written for, though. A tree-leaf key cannot identify a beetle. That is why there are keys for trees, wildflowers, birds, insects, shells and even rocks.

God’s handiwork. A key works only because the living things God made are orderly. Every white oak has the same kind of leaf; every spider has eight legs. If creatures changed their features at random, no key could ever be written. Job told his friends to “ask now the beasts, and they shall teach thee” (Job 12:7). When you use a key, you are asking a leaf careful questions and letting it answer.



A dichotomous key for the leaves of six common trees. Five couplets separate six trees.

PICTURE STUDY



Methodus Plantarum Sexualis (Linnaeus's Plant Classes), Georg Dionysius Ehret, 1736 · Engraving (some copies hand-colored) · First printed in Leiden, the Netherlands

Georg Dionysius Ehret was a German gardener's son who became one of the finest painters of plants who ever lived. In 1736, in Holland, he met Linnaeus and drew this chart to show Linnaeus's plan for sorting plants. Each little drawing stands for one of Linnaeus's plant classes, sorted mainly by how many stamens the flower has and how they are arranged.

This chart is not a dichotomous key, but it does the same job in pictures: it shows a reader exactly which features to look at. With a flower in one hand and this chart in the other, a student could count the stamens and find the right class.

Look closely

- Find a flower drawing with only one stamen. Now find one with many stamens.
- Look at how the drawings are arranged in rows. Why might Ehret have put them in order like this?
- Pick three drawings and count the stamens in each. Did you get a different number each time?
- Ehret drew only the important parts, not the whole plant. Why would that make the chart easier to use?

Talk about it

1. How is this chart like a dichotomous key? How is it different?
2. If you made a chart like this for the leaves in your yard, which feature would you draw for each one?

> **Safety first.** Collect leaves only with a grown-up and only from trees and shrubs you know are safe. Do not touch poison ivy or poison oak (“leaves of three, let it be”) or poison sumac, and do not handle wild mushrooms. Pick up fallen leaves when you can, ask permission before taking leaves from someone else’s yard, and wash your hands when you finish.

EXPERIMENT: MY OWN DICHOTOMOUS KEY

You will collect eight different leaves (or, in winter, eight different kinds of dried pasta, beans or buttons), write a dichotomous key for them, and test it on your family. Then you will improve it like a real scientist.

Question: Can other people use my key to name all eight objects correctly? Which couplet causes the most mistakes?

You will need

- 8 different leaves (or 8 different kitchen objects)
- 8 small sticky notes and a marker
- Ruler marked in centimeters and inches
- Magnifying glass, if you have one
- Lab notebook, pencil and a large sheet of paper
- 2 or 3 testers (family members)

Steps

1. Lay out your eight objects. Give each one a name and write it on a sticky note under it (for example: red maple, white oak, or elbow macaroni, bow tie).
2. Look closely and list the features you can see, count or measure: shape, edge (smooth, toothed or lobed), needles or flat, length in centimeters and inches, number of points.
3. Write **couplet 1**: a feature that splits your eight objects into two groups. Example: “1a. Leaf has lobes … go to 2. 1b. Leaf has no lobes … go to 5.”
4. Keep splitting each group in two with a new couplet until every object has its own name at the end of a path. Count your couplets. You should have 7.
5. Copy the finished key neatly onto the large sheet, as a list of numbered couplets or as a branching chart like the figure.
6. **Test it.** Take the sticky notes off and mix up the objects. Give each tester your key and one object at a time. Do not help! Record each answer.
7. Make a table: Tester, Number named correctly (out of 8), Couplet where they got stuck.
8. Rewrite the couplet that caused the most trouble. Test it again with one person and record whether it worked better.
9. Write a **conclusion**: Did your key work? What did you change, and why?

Tips

- **What we change:** the wording of the confusing couplet (in the second test). **What we keep the same:** the same eight objects and no help from you. **What we measure:** how many objects each tester names correctly.
- Use opposites in each couplet: “edge has teeth” and “edge is smooth,” not “edge has teeth” and “leaf is long.”
- Avoid color and “big or small.” If size matters, measure it: “leaf longer than 10 cm (4 in).”

Check your work

- My key has 7 couplets for 8 objects, and every path ends with one name.
- I tested my key on other people and recorded the results in a table.
- I improved at least one couplet and explained why.

NATURE NOTEBOOK

1. Trace or draw one leaf from each tree in the figure key (pine, spruce, ash, elm, maple, oak) from real leaves or a field guide. Label each with its genus, underlined.
2. Draw a branching key that separates four animals in your home or neighborhood (for example a dog, a cat, a robin and an ant). How many couplets did you need?
3. Write three bad couplets and three good ones. Beside each bad one, explain what is wrong with it.

> **From history.** In 1934 a young bird painter named Roger Tory Peterson published *A Field Guide to the Birds*. Instead of long descriptions, he drew similar birds side by side and drew small arrows pointing to the few “field marks” that tell them apart, such as a

wing bar or an eye ring. It is not a dichotomous key, but it uses the same wise idea: look for the one clear feature that separates one kind from another. His little book sold out quickly and changed the way millions of people learned to watch birds.

WORKED EXAMPLES

Example 1. Use the tree key in the figure. A leaf is flat and wide. It is one single blade, not made of leaflets. Its edge has deep lobes, and the lobes are lined up along a center vein like the sides of a feather, not spread out like the fingers of a hand. What tree is it?

(Use the map or drawing "Follow the path from couplet 1 to a name." shown earlier in this lesson.)

1. Couplet 1: Are the leaves needles? No, the leaf is flat and wide. Go to couplet 3.
2. Couplet 3: Many leaflets on one stalk? No, it is a single blade. Go to couplet 4.
3. Couplet 4: Does the edge have lobes? Yes. Go to couplet 5.
4. Couplet 5: Are the lobes spread like a hand? No, they are lined up along a center vein.
5. The path ends at oak.

Answer: Oak (genus *Quercus*). The path was 1 → 3 → 4 → 5 → oak.

Example 2. The tree key separates 6 trees with 5 couplets. How many couplets would a key need to separate (a) 8 leaves, (b) 12 species of birds, (c) 2 kinds of beetles?

1. Each couplet splits one group into two, which adds one more group. Starting with 1 group, you need 1 split to get 2 groups, 2 splits to get 3 groups, and so on.
2. So the number of couplets is always one less than the number of things: couplets = things − 1.
3. Check with the figure: 6 − 1 = 5 couplets. It matches.
4. (a) 8 − 1 = 7. (b) 12 − 1 = 11. (c) 2 − 1 = 1.

Answer: (a) 7 couplets (b) 11 couplets (c) 1 couplet.

PRACTICE

1. EASY What does "dichotomous" mean, and why is it a good name for this kind of key?
2. EASY What is a couplet in a dichotomous key?
3. EASY Use the tree key in the figure. A tree has needles that grow in bundles of five. What tree is it?
4. MEDIUM Use the tree key. A leaf is flat, has one single blade, and its edge has small teeth but no lobes. What tree is it? Give the path.
5. MEDIUM Max wrote this couplet: "1a. Leaf is big. 1b. Leaf is green." Give two reasons it is a poor couplet, and write a better one.

6. MEDIUM Grace tested her 8-leaf key on three people.
   Tester | Leaves named correctly (out of 8) | Got stuck at
   Dad | 8 | none
   Sister | 6 | couplet 4
   Grandma | 7 | couplet 4
   (a) How many leaves were named correctly in all? (b) How many tries were there in all? (c) Which couplet should Grace rewrite, and why?
7. HARD Grace wonders: “Do people name leaves more correctly when my key has small drawings beside each couplet?” Plan a fair test. (a) What will she change? (b) Name two things she must keep the same. (c) What will she measure? (d) What is the control?
8. CHALLENGE Leo’s friend says, “Your tree key is broken. I used it on a ladybug and it said ‘elm.’” In two or three sentences, explain what went wrong and what this teaches about keys.

COMMON MISTAKES

- Using features that change or depend on opinion, such as color, “big” or “pretty.” Leaves change color in the fall, and young trees are small. Use shape, edges, counts or measurements.
- Writing a couplet whose two choices are not opposites, such as “leaf has teeth” and “leaf is long.” A leaf could be both, so the reader would not know which way to go.
- Thinking a key can name any living thing. A key only works for the group it was written for, so a tree key cannot identify a beetle.

> **Make it a game · Two Doors.** Lay out ten small objects from around the house. One player secretly picks one. The other player may ask only “two-door” questions that split the objects into two groups (“Is it made of metal or not?”, “Is it longer than 5 cm (2 in) or not?”). After each answer, push the objects that are ruled out to the side. Count how many questions it takes to find the secret object. The best players need only four (ten objects split in half each time leaves 5, then 3, then 2, then 1). Take turns and try to beat your record.

> **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)

A key is a way of asking a living thing careful questions. When you look closely at a leaf’s edge or count a beetle’s legs, the creature itself “tells” you what it is, because God made it orderly and true to its kind.

Practice answers

1. It means “cut in two.” Every step of the key gives you a choice between just two statements.
2. A pair of opposite statements at one step of the key. You choose the one that fits, and it tells you the name or the next couplet to go to.

3. Pine (*Pinus*). The path is 1 (needles, yes) → 2 (in bundles, yes) → pine.
4. Elm (*Ulmus*). Path: 1 (not needles) → 3 (not leaflets) → 4 (no lobes) → elm.
5. The two statements are not opposites (a leaf can be big and green), and “big” and “green” are not clear features: size depends on opinion and on the age of the tree, and color changes in the fall. Better: “1a. Leaf longer than 10 cm (4 in). 1b. Leaf 10 cm (4 in) or shorter.” (Or any pair of clear opposites, such as “edge has teeth” and “edge is smooth.”)
6. (a) 8 + 6 + 7 = 21. (b) 3 testers × 8 leaves = 24 tries (so 3 mistakes). (c) Couplet 4, because both people who made mistakes got stuck there.
7. (a) Whether the key has drawings or no drawings. (b) Any two of: the same 8 leaves, the same wording of the couplets, testers of about the same age who have not seen the key before, the same amount of time, no help from Grace. (c) How many leaves each tester names correctly out of 8. (d) The key without drawings (the words-only key).
8. Answers will vary. Example: The key was not broken; it was written only for the leaves of six trees, so it cannot identify a ladybug or anything else outside that group. Every key works only for the things it was made for. To identify a ladybug you need an insect key.

Unit 1 review

Answer each question. Show your work for counting questions and use complete sentences for explanations. Use the tree key from Lesson 1.4 for question 9. The test is worth 50 points.

1. (5 pts) What book did Carl Linnaeus publish in 1735, in what country was it printed, and what was he trying to do in it?
2. (5 pts) Sort these into Linnaeus’s three kingdoms: clam shell, acorn, quartz, beetle, moss, salt.
3. (5 pts) List the seven ranks of classification from the biggest group to the smallest. Then write a memory sentence for them.
4. (5 pts) The gray wolf is Animalia, Chordata, Mammalia, Carnivora, Canidae, *Canis*. The coyote is Animalia, Chordata, Mammalia, Carnivora, Canidae, *Canis*. The house cat is Animalia, Chordata, Mammalia, Carnivora, Felidae, *Felis*. How many of these six ranks does the wolf share with the coyote? With the cat? Which is grouped more closely with the wolf?
5. (5 pts) A whale lives in the sea and has a shape like a fish. Why did Linnaeus put whales in the class Mammalia?
6. (5 pts) A student wrote “ursus Americanus” for the American black bear. Rewrite it correctly and name the rules you used.
7. (5 pts) Explain, using the two birds called “robin,” why scientists use scientific names.
8. (5 pts) *Juglans nigra* is the black walnut and *Quercus nigra* is a kind of oak. Are they in the same genus? What does *nigra* mean, and why can two different trees both use it?
9. (5 pts) Use the tree key from Lesson 1.4. A leaf is flat and wide and is made of many small leaflets on one stalk. What tree is it? Write the path through the key.
10. (5 pts) (a) How many couplets does a dichotomous key need to separate 10 kinds of shells? (b) Why is “1a. Shell is pretty. 1b. Shell is plain.” a poor couplet? Write a better one.

Unit project: my backyard system of nature

Make your own small *Systema Naturae* for your home and yard. On a large poster or in a bound notebook, sort at least 20 specimens or drawings into kingdoms (animals, plants, fungi and Linnaeus’s old stone kingdom for your rocks). Choose three living things and show each one’s seven ranks from kingdom to species, with its scientific name written correctly. Add name cards for ten species with their Latin meanings, and finish with a dichotomous key for eight leaves or objects from your collection, with the results table from your family test.

End with a short paragraph explaining why sorting and naming living things is useful, and what it shows you about the order God built into His creation.

- **Accuracy**: Specimens are in the right kingdoms, the three rank ladders are correct, and every scientific name is written with a capital genus, a small species word and underlining or italics.

- **Key and testing**: The dichotomous key has one fewer couplet than the number of objects, uses clear opposite features, and includes a results table and one improvement.
- **Records**: Measurements are in centimeters with inches in parentheses, and counts, tables and graphs are complete and labeled.
- **Care and explanation**: Drawings are careful and labeled, the work is neat and easy to read, and the paragraph clearly explains why classification is useful.

Answer key

1. *Systema Naturae* ("The System of Nature"), printed in Leiden in the Netherlands. He tried to sort every known stone, plant and animal into one orderly system of groups so anyone could find each one.
2. Animal: clam shell, beetle. Plant: acorn, moss. Stone: quartz, salt.
3. Kingdom, phylum, class, order, family, genus, species. Example sentence: "King Philip Came Over For Good Soup."
4. Wolf and coyote share 6 ranks; wolf and cat share 4 ranks. The coyote is grouped more closely with the wolf.
5. Whales breathe air with lungs, give birth to live young and feed their babies milk (and are warm-blooded), like other mammals.
6. *Ursus americanus*. The genus starts with a capital letter, the species word is all small letters (even though it comes from a place name), and the whole name is in italics in print or underlined by hand.
7. In England "robin" means a small bird, *Erithacus rubecula*; in America it means a larger thrush, *Turdus migratorius*. A common name can mean different living things in different places, but each species has only one scientific name used everywhere, so scientists know exactly which one is meant.
8. No: *Juglans* and *Quercus* are different genera. *Nigra* means black. A species word can be used again in a different genus, because the full two-part name is still different.
9. Ash (*Fraxinus*). Path: couplet 1 (not needles) → couplet 3 (many leaflets, yes) → ash.
10. (a) 10 − 1 = 9 couplets. (b) "Pretty" and "plain" are opinions, so different people would choose differently. Better: "1a. Shell is coiled in a spiral. 1b. Shell is made of two halves." (Any clear pair of opposite features you can see, count or measure earns full credit.)

UNIT 2

Vertebrates

In Unit 1 you learned how Linnaeus sorted living things from kingdom down to species. Now you will climb inside one great branch of the animal kingdom: the **vertebrates**, the animals with a backbone. You will meet Jean-Baptiste Lamarck, who drew the line between animals with and without backbones in Paris in the 1790s, and learn the five classes every naturalist knows: fish, amphibians, reptiles, birds and mammals.

You will also look inside the backbone itself with Andreas Vesalius, who drew the human skeleton bone by bone in 1543, and build bendy model spines. You will follow two scientists into the California desert to take the temperature of lizards and learn what “warm-blooded” and “cold-blooded” really mean. Finally you will meet the platypus, the furry, duck-billed, egg-laying puzzle that made scientists look twice, and build a sorting game that uses a dichotomous key to classify any vertebrate.

All through the unit you will work like a scientist: observing, measuring in grams, centimeters and degrees, recording data in tables, and running fair tests where only one thing changes. And you will find that Job was right: “ask now the beasts, and they shall teach thee” (Job 12:7).

BEFORE YOU BEGIN

- Can name the ranks from kingdom to species and explain what a class is (Lesson 1.2)
- Can use a simple two-choice dichotomous key (Lesson 1.4)
- Can read a thermometer in degrees Celsius and measure with a ruler in centimeters
- Can add, subtract and multiply whole numbers and read a simple data table

MASTERY CHECKLIST

- I can explain the difference between a vertebrate and an invertebrate and name the five classes of vertebrates.
- I can tell each class by its body covering, how it breathes and how its young begin.
- I can name the parts of a backbone (vertebrae, discs, spinal cord) and build a model that shows how it bends.
- I can explain warm-blooded and cold-blooded and read a table or graph of body temperatures.
- I can use a dichotomous key to classify tricky animals such as bats, whales, penguins, salamanders and the platypus.
- I can plan a fair test by naming what I change, what I keep the same and what I measure.

OPTIONAL BOOKS AND RESOURCES

- **Smithsonian National Museum of Natural History** (https://naturalhistory.si.edu/): Free. Browse the museum's online exhibits and virtual tours, including its hall of bones, where skeletons of many vertebrates stand side by side for comparing backbones (Lesson 2.2).
- **Smithsonian's National Zoo and Conservation Biology Institute** (https://nationalzoo.si.edu/): Free. Animal fact pages for fish, amphibians, reptiles, birds and mammals, plus live animal cameras. Watch a reptile bask under its heat lamp for Lesson 2.3.
- **San Diego Zoo Wildlife Alliance: Animals and Plants** (https://animals.sandiegozoo.org/): Free. Short, readable pages on hundreds of animals, including the platypus, bats and caecilians. Useful for writing the trait backs of your sorting cards (Lesson 2.4).

2.1 The Five Classes of Vertebrates ★

OBJECTIVES

- Explain the difference between a vertebrate and an invertebrate and tell how Jean-Baptiste Lamarck drew that line in the 1790s.
- Name the five classes of vertebrates (fish, amphibians, reptiles, birds, mammals) and give the body covering, breathing and young of each.
- Classify an unfamiliar vertebrate by its traits instead of by where it lives, and test with a sponge model why amphibians need damp places.

Warm-up. Reach behind you and slowly run your fingers down the middle of your back. Count the hard bumps you can feel. Those bumps are parts of your backbone. Now write down eight animals you know (a dog, a worm, a robin, a spider, and so on). Put a check next to each one you think has a backbone like yours. Keep the list; you will check it at the end of the lesson.

Video. Coming soon. Vertebrate classes for kids (fish, amphibians, reptiles, birds and mammals compared): search Smithsonian National Museum of Natural History, SciShow Kids, Homeschool Pop (Alternate), Moody Science classics, and nature footage of frogs, lizards, birds and mammals.

KEY TERMS

vertebrate
An animal with a backbone made of small bones called vertebrae. Fish, amphibians, reptiles, birds and mammals are vertebrates.

invertebrate
An animal without a backbone, such as a spider, crab, snail, worm or starfish.

class
A large group of living things that share important traits. In Linnaeus’s ladder, a class sits below phylum and above order.

trait
A feature of a living thing that you can observe or test, such as feathers, fur, scales or the way it breathes.

gills
Feathery body parts that take oxygen out of water. Fish breathe with gills all their lives; young amphibians breathe with gills too.

scales
Small, hard plates that cover the skin of most fish and all reptiles.

CORE IDEAS

The story. In 1793 a new museum of natural history opened in Paris, in the old royal garden of plants. A botanist named Jean-Baptiste Lamarck, then almost fifty years old, was handed a job that no one else wanted. He was put in charge of the “insects and worms.” In those days that one label covered nearly every animal that was not a mammal, bird, fish, reptile or frog: spiders, crabs, snails, clams, starfish, worms, jellyfish and thousands more, all in one enormous jumble. As Lamarck sorted them, he saw that the deepest dividing line in the whole animal kingdom was simple to say: some animals have a backbone and some do not. In his lectures in the 1790s he called the second group the animals “without vertebrae.” We still call them **invertebrates**, and the animals with a backbone are **vertebrates**.

How they figured it out. The animals with backbones had already been sorted into a few large groups called **classes**. In 1758 Carl Linnaeus, whom you met in Unit 1, named the class *Mammalia*, from the Latin word for the milk glands that mothers use to feed their young. In that same book he moved the whales out of the fish and into the mammals, because whales breathe air with lungs and nurse their calves with milk. Linnaeus had put frogs, snakes and turtles together in one class. In the early 1800s other naturalists noticed that frogs, toads and salamanders begin life in water with gills and have soft, damp skin, so they gave them a class of their own: the **amphibians**. The name means “double life,” one life in water and one on land. That gave the five classes most field guides still use: fish, amphibians, reptiles, birds and mammals. (Scientists now split fish into a few classes, such as sharks and bony fish, but all have fins and gills, so we keep them together.)

The big idea. Every vertebrate has a backbone, a skull that protects the brain, and a skeleton inside its body. To tell the five classes apart, a naturalist asks three questions: What covers the body? How does it breathe? How do its young begin? **Fish** live in water, swim with fins, are usually covered with scales, and breathe with **gills** their whole lives. **Amphibians**, such as frogs, toads and salamanders, have moist skin with no scales. Most hatch from jelly-coated eggs in water, breathe with gills when young, and breathe with lungs and through their skin as adults. **Reptiles**, such as snakes, lizards, turtles and crocodiles, have dry skin covered with scales and breathe with lungs, and most lay leathery eggs on land. **Birds** have feathers, beaks and wings, breathe with lungs and lay hard-shelled eggs. **Mammals** have hair or fur, breathe with lungs, and the mothers feed their young with milk.

Try it and see. Why do frogs and salamanders stay near ponds, streams and damp leaves, while a lizard can run across a hot desert? Their skin tells the story. An amphibian’s thin, moist skin lets water pass through easily, so it dries out fast in dry air. A reptile’s dry scales help hold water in. In this lesson’s project you will test this with two damp sponges, one bare like a frog and one wrapped like a lizard, and weigh them to see which loses more water. As you sort, remember to judge an animal by its **traits**, not by where it lives. A whale lives in the sea but is a mammal, and a penguin swims but is a bird.

God’s handiwork. On the fifth day of creation, Genesis tells us, God made “great whales,” the creatures of the waters and “every winged fowl after his kind.” On the sixth day He made the beasts, the cattle and every thing that creepeth upon the earth. Lamarck’s line between

backbone and no backbone runs right through that list. Vertebrates are only about one kind of animal in every twenty, yet they include the blue whale, the largest animal known, and tiny ones like the bee hummingbird, which weighs less than a U.S. penny. Sorting them is one way we notice the order and the variety God built into His world.

Five classes of vertebrates

Class	Fish	Amphibians	Reptiles	Birds	Mammals
Covering	scales, fins	moist skin	dry scales	feathers	hair or fur
Breathes with	gills	gills, then lungs	lungs	lungs	lungs
Young	most lay eggs in water	jelly eggs in water	most lay leathery eggs	hard-shelled eggs	mothers feed babies milk

The five classes of vertebrates. Ask three questions: What covers it? How does it breathe? How do its young begin?

PICTURE STUDY



Young Hare, Albrecht Dürer, 1502 · Watercolor and gouache on paper · Albertina, Vienna, Austria

Albrecht Dürer was a painter and printmaker from Nuremberg, Germany. In 1502 he painted this hare so carefully that you can almost count the hairs. He worked the way a naturalist works: by looking hard at a real animal and recording exactly what he saw.

A hare is a mammal. As you look, hunt for the traits that tell you so, and notice which mammal traits a picture cannot show.

Look closely

- Follow the direction the fur grows on the back, the sides and the legs. Does it all point the same way?
- Find the whiskers and the long ears. How might each one help a hare stay safe?
- Look closely at the eye. Some viewers see the reflection of a window in it. Can you?
- Find Dürer’s monogram, a large A with a D under it, and the date 1502 near the bottom.

Talk about it

1. Which mammal trait can you see in the painting? Which mammal traits can you not see?
2. Why might a naturalist still make a careful drawing today, even though we have cameras?

EXPERIMENT: DAMP SKIN OR DRY SKIN? THE SPONGE TEST

Question: Does a dry, scaly covering keep water in better than bare, moist skin? You will use two sponges as model animals. The bare sponge is the “frog.” The sponge wrapped in plastic is the “lizard,” whose scales help hold in water. You will weigh both to measure how much water each one loses.

You will need

- Two kitchen sponges of the same size and kind
- Water and a bowl
- Plastic wrap
- A kitchen scale that reads in grams
- A plate or tray
- Notebook, pencil and a clock

Steps

1. Write your prediction: Which sponge will lose more water in one day, the bare “frog” or the wrapped “lizard”? Why?
2. Soak both sponges in the bowl of water. Squeeze each one gently until it stops dripping.
3. Wrap one sponge loosely in plastic wrap, leaving one small end open so it can breathe a little, like the openings in an animal’s body. Leave the other sponge bare.
4. Weigh each sponge (the wrapped one with its wrap on) and record its mass in grams. This is your starting mass.
5. Set both sponges side by side on the plate in the same warm, dry spot, such as a table near a sunny window.
6. Weigh both again after 2 hours, after 4 hours and the next morning. Keep the wrap on the lizard sponge each time you weigh it.
7. Make a table with columns: Time, Frog sponge (g), Lizard sponge (g). Then subtract to find how many grams each sponge lost.

8. Write two sentences: Which sponge lost more water? What does that tell you about why frogs live near water and lizards can live in deserts?

Tips

- What we change: the covering (bare or wrapped). What we keep the same: sponge size, amount of water, place, and time. What we measure: mass in grams.
- If you have no scale, squeeze each sponge over a measuring cup at the end and compare how much water comes out.

Check your work

- I made a prediction before I started.
- I kept everything the same except the covering.
- I recorded masses in a table and found how much each sponge lost.
- I can explain why an amphibian’s moist skin keeps it near water.

NATURE NOTEBOOK

1. Draw a five-column page titled “Five Classes.” Under each class, draw one animal from your own area and label its covering.
2. Look again at your warm-up list. Circle every invertebrate in a different color. Were your checks correct?
3. Draw a frog and a lizard side by side. Label three ways their skin, feet or eggs are different.

> **From history.** Linnaeus wrote *Systema Naturae* many times over his life, and it grew from a few large pages in 1735 to thick volumes. In the early editions he listed whales among the fish. By the tenth edition in 1758 he had looked at the evidence again: whales breathe air, have warm blood and nurse their young. So he moved them into his new class Mammalia. A good scientist is willing to change his mind when the evidence calls for it.

WORKED EXAMPLES

Example 1. A whale lives in the ocean and has a smooth tail with flukes. Is it a fish? Use the three questions to classify it.

1. What covers it? Smooth skin with a few stiff hairs, often around the mouth. It has no fish scales.
2. How does it breathe? It comes to the surface and breathes air through a blowhole into lungs. It has no gills.
3. How do its young begin? The calf is born alive, and the mother feeds it milk.
4. Hair and milk are mammal traits; lungs fit too. Where it lives (water) does not decide its class.

Answer: A whale is a mammal, not a fish. This is why Linnaeus moved whales into the class Mammalia in 1758.

Example 2. Here are rounded counts of known kinds (species) in each class: Fish about 35,000; Amphibians about 8,000; Reptiles about 12,000; Birds about 11,000; Mammals about 6,500. Which class has the most kinds? How many kinds are in the other four classes together, and how does that compare with the fish?

1. Look down the list for the biggest number: fish, about 35,000.
2. Add the other four: 8,000 + 12,000 = 20,000.
3. 20,000 + 11,000 = 31,000.
4. 31,000 + 6,500 = 37,500.
5. Compare: 37,500 is only a little more than 35,000.

Answer: Fish have the most kinds. The other four classes together have about 37,500 kinds, so fish are almost as many as all the other vertebrates put together, about half of all known vertebrate kinds.

PRACTICE

1. EASY What is a vertebrate? Name two vertebrates and two invertebrates.
2. EASY Match each covering to its class: feathers, hair or fur, dry scales, moist skin with no scales, scales with fins.
3. MEDIUM A penguin cannot fly and spends much of its life swimming in cold seas. Which class is it in? Give two traits that prove it.
4. MEDIUM A bat has wings and flies at night. Is a bat a bird? Explain.
5. MEDIUM Use the table from Worked Example 2 (Fish 35,000; Amphibians 8,000; Reptiles 12,000; Birds 11,000; Mammals 6,500). Which class has the fewest known kinds? How many more kinds of reptiles are there than mammals?

6. HARD A salamander and a lizard look alike: both have four legs and a long tail. How can you tell which is the amphibian and which is the reptile?
7. HARD Mia does the sponge test, but she puts the bare sponge in a sunny window and the wrapped sponge in a cool closet. (a) What is the one thing that should change in this test? (b) Why is Mia's test not fair? (c) What should she do?
8. CHALLENGE In two or three sentences, explain why scientists sort animals by traits like skin and breathing instead of by where they live. Use one example.

COMMON MISTAKES

- Thinking every animal that lives in water is a fish. Whales and dolphins are mammals, sea turtles are reptiles, and penguins are birds.
- Thinking turtles and salamanders are amphibians because they spend time in water. Turtles have dry, scaly skin and are reptiles; salamanders have moist skin and are amphibians.
- Thinking only reptiles have scales. Most fish have scales too; the difference is that fish have fins and gills.

> **Make it a game · Five Corners.** Label the four corners of a room and the middle of the floor with the five classes: Fish, Amphibians, Reptiles, Birds, Mammals. A parent calls out an animal, such as bat, eel, toad, ostrich or sea turtle. Everyone runs to the right spot. The first one there must name one trait that proves it to score a point. Tricky animals (whale, penguin, salamander) are worth two points.

> **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)

Fish, whales and birds were all made by the same Creator, each after its kind. When we sort animals into classes, we are noticing the order He placed in creation.

Practice answers

1. A vertebrate is an animal with a backbone. Examples: a dog and a robin (vertebrates); a spider and a snail (invertebrates). Other correct examples are fine.
2. Feathers: birds. Hair or fur: mammals. Dry scales: reptiles. Moist skin with no scales: amphibians. Scales with fins: fish.
3. A bird. It has feathers and a beak, and it lays hard-shelled eggs. (It also breathes with lungs.)
4. No. A bat is a mammal. It has fur, not feathers, and the mother feeds her young with milk. Flying does not make an animal a bird.
5. Mammals have the fewest. 12,000 − 6,500 = 5,500 more kinds of reptiles.
6. Look at the skin and the eggs. The salamander has smooth, moist skin with no scales, and most lay jelly eggs in water or damp places, so it is an amphibian. The lizard has dry skin covered with scales and lays leathery eggs on land (or bears live young), so it is a reptile.
7. (a) Only the covering (bare or wrapped) should change. (b) She also changed the place, so the sunny sponge might dry faster because of the warmth, not because it is bare. (c) Put both

sponges side by side in the same spot, with the same amount of water, for the same time.

8. Animals that live in the same place can be very different inside. A shark and a dolphin both live in the sea, but the shark breathes with gills and the dolphin breathes air with lungs and feeds its calf milk. Sorting by traits puts together animals that are truly alike, so the groups tell us something real.

2.2 Backbone Models

OBJECTIVES

- Describe the parts of a backbone (vertebrae, discs and the spinal cord) and explain how a chain of small bones can be both strong and bendable.
- Tell how Andreas Vesalius studied the human skeleton for himself and pictured it in his book of 1543, and count the vertebrae in each part of the human spine.
- Build two backbone models and run a fair test of how the number of vertebrae changes how far a backbone can bend.

Warm-up. Stand up and touch your toes, then twist to look behind you, then nod “yes” and shake your head “no.” Your backbone bent in every one of those moves. Now hold a ruler or a wooden spoon and try to bend it the same way. Why can your back bend when the ruler cannot? Write down your best guess.

Video. Coming soon. How the spine and vertebrae work for kids, and animal skeletons compared (giraffe neck, snake skeleton, owl neck): search SciShow Kids, Homeschool Pop (Alternate), Science Max, Smithsonian National Museum of Natural History bone hall, and natural history museum skeleton tours.

KEY TERMS

vertebra (plural vertebrae)
One of the small bones that link together to make the backbone.

backbone
The chain of vertebrae that runs down the middle of a vertebrate’s back. It is also called the spine or spinal column.

spinal cord
A thick bundle of nerves that runs through a tunnel inside the vertebrae and carries messages between the brain and the body.

disc
A tough, springy cushion between two vertebrae that lets the back bend and soaks up bumps.

skeleton
The framework of bones (or cartilage) that holds up and protects an animal’s body.

cartilage
A tough, bendable material, softer than bone. You can feel it in the tip of your nose and your ears. A shark’s whole skeleton is made of it.

CORE IDEAS

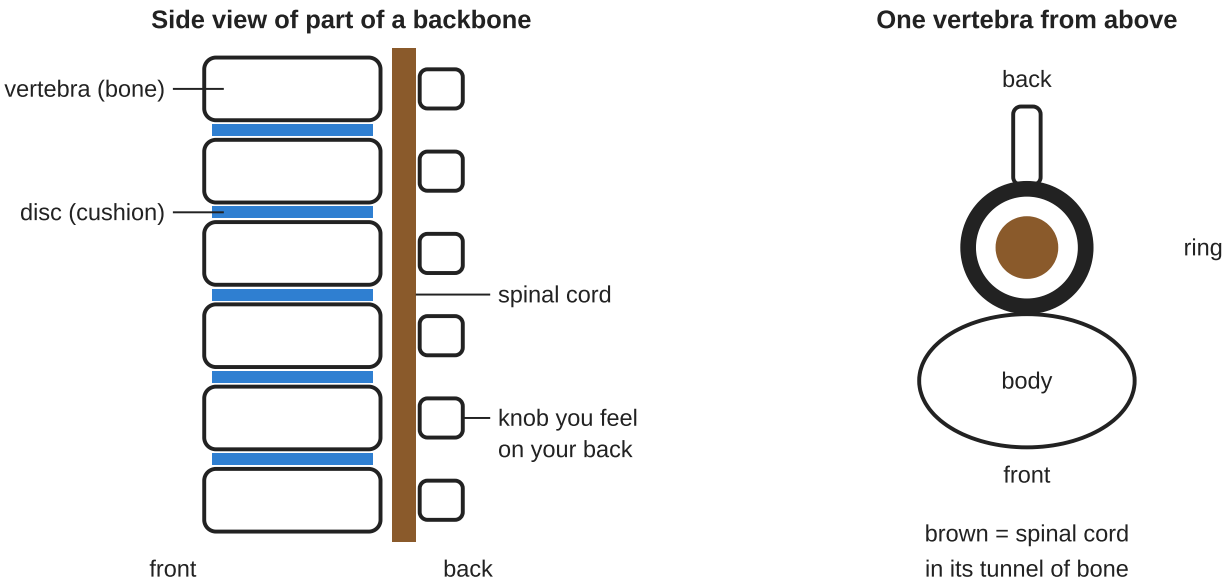
The story. In the 1530s a young doctor named Andreas Vesalius, born in Brussels, was teaching at the university in Padua, Italy. In his day, most teachers of anatomy sat in a high chair and read aloud from the books of Galen, a Greek doctor who had lived long before, while a helper did the cutting below. Vesalius came down and did the work himself. He studied real human skeletons bone by bone. In 1543, when he was twenty-eight years old, a printer in Basel, Switzerland, published his great book, *De humani corporis fabrica* ("On the Fabric of the Human Body"). Its large woodcut pictures showed the skeleton standing, walking and even leaning on a tomb as if lost in thought, with the backbone drawn more truly than anyone had drawn it before.

How they figured it out. Vesalius found many places where the old books were wrong. Galen had learned much of his anatomy by studying animals such as apes and pigs, and then guessed that people were built the same way. Vesalius trusted his own careful looking more than an old guess. That is the heart of science: observe for yourself, record exactly, and draw what is really there. Later naturalists compared the skeletons of many animals the same way and found that every vertebrate backbone follows one plan, with changes to fit each animal's life.

The big idea. A backbone is not one long bone. It is a chain of small bones called **vertebrae**. Each vertebra has a thick, round **body** in front that carries weight, and a ring of bone behind it. Stack the rings and they make a tunnel. Through that tunnel runs the **spinal cord**, the body's main message cable between the brain and the muscles, safe inside its armor of bone. Between the vertebrae lie springy **discs** that cushion every step and let the chain bend a little at each joint. The bumps you felt on your back are the bony knobs on the back of each ring. An adult human has 7 vertebrae in the neck, 12 in the chest (each one holds a pair of ribs) and 5 in the lower back. Below those, a few more are joined together into the sacrum and the tailbone.

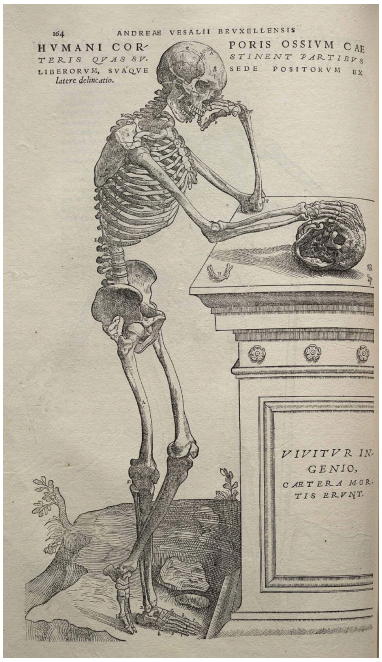
In the world today. Every vertebrate has this same plan, changed to fit its life. A giraffe has only 7 neck vertebrae, the same number as you and a mouse, but each one can be about 25 cm (10 inches) long. An owl has 14 neck vertebrae, which lets it turn its head about three-quarters of the way around. A snake may have more than 200 vertebrae, most with a pair of ribs, so it can bend into curves and coils. A fish bends its backbone from side to side to swim. A shark's backbone is made of cartilage instead of bone, but it is still a backbone, so a shark is still a vertebrate.

Try it and see. Why does a chain of many short pieces bend more easily than a few long ones? In the project you will build two backbone models of about the same length on pipe cleaners, one with a few long "vertebrae" and one with many short ones, and test which can curl around a smaller object. Then you will see why God gave the snake hundreds of vertebrae and gave your lower back a few strong ones. Our bodies are, as the psalmist says, "fearfully and wonderfully made" (Psalm 139:14).



A backbone is a chain of vertebrae. Discs cushion each joint, and the spinal cord runs through the tunnel made by the rings of bone.

PICTURE STUDY



Skeleton leaning on a tomb, from De humani corporis fabrica, Andreas Vesalius (woodcut probably made in the workshop of the painter Titian; often credited to Jan Steven van Calcar), 1543 · Woodcut · Printed in Basel by Johannes Oporinus; copies are kept in many libraries, such as the U.S. National Library of Medicine

Vesalius wanted his readers to see the skeleton as clearly as if it stood in front of them. Skilled artists cut his drawings into blocks of wood, which were inked and printed. This famous page shows the whole skeleton from the side, posed like a thoughtful person resting on a tomb, with hills and buildings behind it.

Because the skeleton is turned partly sideways, you can follow the curve of the backbone from the skull down to the hips.

Look closely

- Trace the backbone with your finger from the skull to the hips. Is it straight, or does it curve?
- Find the ribs. Where do they join the backbone?
- Compare the neck vertebrae with the lower back vertebrae. Which look bigger and thicker?
- Look at the background. Why do you think the artist put a landscape behind a skeleton?

Talk about it

1. Why are the lower back vertebrae bigger than the neck vertebrae? (Think about how much weight each one carries.)
2. Vesalius checked the old books against real bones. When is it wise to check something for yourself?

> **Safety first.** Use scissors carefully and cut away from your fingers; an adult may cut the straws for younger helpers. Keep cereal rings and beads away from babies and toddlers, who could choke on them. If you look at a backbone from a cooked chicken or fish, make sure it is cleaned and cooked, and wash your hands with soap afterward.

EXPERIMENT: BUILD A BENDY BACKBONE

Question: Does a backbone with many short vertebrae bend more than a backbone of the same length with a few long vertebrae? You will build two models and test how tightly each one can curl.

You will need

- 2 pipe cleaners, about 30 cm (12 inches) long (the spinal cords)
- 2 or 3 drinking straws (the vertebrae)
- O-shaped cereal rings or small beads (the discs)
- Scissors and a ruler marked in centimeters
- Round objects of different sizes to curl around: a large can, a mug, a thick marker, a pencil
- Tape, notebook and pencil

Steps

1. Write your prediction: Which model will curl around the smallest object, the one with few long vertebrae or the one with many short vertebrae?
2. Model A: cut 3 straw pieces, each 6 cm (about 2⅜ inches) long.

3. Model B: cut 9 straw pieces, each 2 cm (about ¾ inch) long. Both models now have 18 cm of straw in all.
4. Thread each model onto its own pipe cleaner, putting one cereal ring between each pair of straw pieces. Bend a tiny hook at each end of the pipe cleaner so nothing slides off.
5. Measure both models end to end and record their lengths. They will not be exactly the same, because Model B has more discs; write down the difference.
6. Test: try to curl each model all the way around each object, starting with the largest. Stop when the straw pieces jam together and the model will not curl farther.
7. Record in a table: Object, Model A (yes or no), Model B (yes or no). Circle the smallest object each model could wrap around.
8. Write your conclusion: Which model bent more? Why do you think so? Which animal's backbone is more like Model B?

Tips

- What we change: the number of vertebrae. What we keep the same: the amount of straw, the kind of pipe cleaner, the kind of disc and the test objects. What we measure: the smallest object each model can wrap around.
- Bend gently. If a pipe cleaner kinks, straighten it and try again so both models get a fair test.

Check your work

- I built two models that differ in only one way.
- I tested both on the same objects and recorded the results in a table.
- I can name the parts of my model: vertebrae, discs and spinal cord.
- I can explain why many short vertebrae bend more than a few long ones.

NATURE NOTEBOOK

1. Draw one vertebra seen from above. Label the body, the ring of bone, the spinal cord and the bony knob you can feel on your back.
2. Draw a simple stick outline of a person and of a giraffe. Mark the 7 neck vertebrae on each with dots. Write a sentence about what is the same and what is different.
3. If your family cooks a whole fish or chicken, ask an adult to clean a piece of the backbone for you. Draw it and count how many vertebrae you can see.

> **From history.** Around 1800 in Paris, the naturalist Georges Cuvier made comparing skeletons into a science of its own, called comparative anatomy. He laid the bones of many vertebrates side by side and showed that each part of a skeleton fits the rest: the teeth match the jaws, the jaws match the skull, and the legs match the way the animal moves. Because of this, a careful anatomist could often tell what kind of animal a single bone came from. Natural history museums still set skeletons side by side, as Cuvier did, so visitors can compare backbones, skulls and limbs.

WORKED EXAMPLES

Example 1. An adult human has 7 neck vertebrae, 12 chest vertebrae and 5 lower back vertebrae, plus the sacrum and the tailbone (each made of several joined vertebrae). How many separate vertebrae are there above the sacrum? How many bones are in the whole adult backbone if the sacrum and tailbone each count as one bone?

(Use the map or drawing "Each vertebra in the chain has a body in front and a ring of bone behind." shown earlier in this lesson.)

1. Add the separate vertebrae: 7 + 12 = 19.
2. 19 + 5 = 24 separate vertebrae.
3. Add the sacrum (1 bone) and the tailbone (1 bone): 24 + 2 = 26.

Answer: 24 separate vertebrae, and 26 bones in the whole adult backbone.

Example 2. A giraffe has 7 neck vertebrae. Suppose each one is about 25 cm (10 inches) long. About how long are the neck vertebrae laid end to end? Give the answer in centimeters and in feet and inches.

1. Multiply: 7 × 25 cm = 175 cm.
2. In inches: 7 × 10 inches = 70 inches.
3. There are 12 inches in a foot: 70 ÷ 12 = 5 with 10 left over, so 70 inches = 5 feet 10 inches.
4. Check: 175 cm is a little less than 2 meters, about as tall as a tall man.

Answer: About 175 cm, or about 5 feet 10 inches. A giraffe's neck is long because each vertebra is long, not because it has more of them.

PRACTICE

1. EASY What is one bone of the backbone called? What is the word for more than one?
2. EASY What runs through the tunnel inside the vertebrae, and why does it need protection?
3. MEDIUM Each of your 12 chest vertebrae holds one pair of ribs. How many ribs do you have in all?
4. MEDIUM Read the table of neck vertebrae: Human 7; Mouse 7; Giraffe 7; Owl 14. (a) Which animal is different? (b) How many times as many neck vertebrae does the owl have as the giraffe? (c) What pattern do the three mammals show?
5. MEDIUM A shark has no bones at all. Why is it still called a vertebrate?
6. HARD In a model backbone, each pasta "vertebra" is 3 cm long and each disc is 0.5 cm thick. How long is a model with 5 vertebrae and 4 discs? Give the answer in centimeters and about how many inches (1 inch is about 2.5 cm).

7. HARD Sam wants to test whether the kind of disc changes how far a model backbone bends. He will try cereal rings, felt circles and no discs at all. (a) What is the one thing he changes? (b) Name three things he must keep the same. (c) What will he measure?
8. CHALLENGE Explain in two or three sentences why a backbone made of many small bones is better for an animal than one long, stiff bone.

COMMON MISTAKES

- Thinking the backbone is one long bone. It is a chain of many vertebrae with discs between them.
- Thinking a long neck must have more neck bones. Almost all mammals, from mice to giraffes, have 7 neck vertebrae; a giraffe's are just much longer.
- Thinking the spinal cord is a bone. It is a bundle of nerves, soft and easily hurt, which is why it lives inside a tunnel of bone.

> **Make it a game · Spine Builder.** Each player needs 24 small blocks, cups or paper squares. Players take turns rolling one die and adding that many vertebrae to their tower, building the neck (7), then the chest (12), then the lower back (5) in order. You must say the name of each section as you finish it. To finish the lower back you need the exact number left; if you roll too high, you lose your turn. The first player to build all 24 and name all three sections wins.

> **Scripture.** "Thou hast clothed me with skin and flesh, and hast fenced me with bones and sinews." (Job 10:11, KJV)

Job says God built a fence of bones around his life. Your backbone is just that kind of fence, guarding the spinal cord while still letting you bend, run and bow.

Practice answers

1. A vertebra. More than one are vertebrae.
2. The spinal cord. It carries messages between the brain and the body, so if it is hurt the body cannot move or feel properly. The bone ring protects it.
3. 12 pairs × 2 = 24 ribs.
4. (a) The owl (a bird). (b) 14 ÷ 7 = 2, so twice as many. (c) All three mammals have 7 neck vertebrae, whether the neck is short or long.
5. A shark has a backbone made of vertebrae of cartilage instead of bone. Any animal with a backbone is a vertebrate.
6. 5 × 3 = 15 cm; 4 × 0.5 = 2 cm; 15 + 2 = 17 cm. 17 ÷ 2.5 is about 7 inches (more exactly about 6¾ inches).
7. (a) The kind of disc. (b) The same pipe cleaner, the same number and length of straw pieces, and the same test objects (also the same person bending gently). (c) How far each model bends, for example the smallest object it can wrap around.

8. Many small bones with discs between them let the back bend a little at each joint, so the animal can twist, curl, swim or run, while the bones still protect the spinal cord and hold the body up. One long bone would be strong but could not bend, and a hard knock could snap it.

2.3 Warm-Blooded and Cold-Blooded Animals

OBJECTIVES

- Explain the difference between warm-blooded animals (birds and mammals) and cold-blooded animals (fish, amphibians and reptiles), and tell how Raymond Cowles and Charles Bogert measured the body temperatures of desert reptiles.
- Read a data table and a line graph of body temperature through a day and describe what each line shows.
- Run a fair test of how a “fur coat” changes how fast a jar of warm water cools, naming what is changed, what is kept the same and what is measured.

Warm-up. Hold a metal spoon in your hand for one minute, then touch it to your cheek. It feels warm. Where did the heat come from? Now put the spoon in the refrigerator for five minutes and feel it again. The spoon cannot make its own heat; it just takes on the temperature around it. Write one sentence: Are you more like the spoon, or different from it?

Video. Coming soon. Warm-blooded and cold-blooded animals for kids (lizards basking, how animals keep warm, the wood frog that freezes): search SciShow Kids, Homeschool Pop (Alternate), Science Max, Smithsonian’s National Zoo, and nature footage of basking reptiles and winter birds.

KEY TERMS

warm-blooded (endotherm)
An animal that makes its own body heat from the food it eats and keeps a steady body temperature. Birds and mammals are warm-blooded.

cold-blooded (ectotherm)
An animal whose body temperature rises and falls with its surroundings. Fish, amphibians and reptiles are cold-blooded.

body temperature
How warm the inside of an animal’s body is, measured with a thermometer in degrees Celsius (°C) or Fahrenheit (°F).

insulation
A covering that slows the flow of heat, such as fur, feathers, fat (blubber) or a wool sweater.

basking
Lying in the sun to warm the body, as lizards, snakes and turtles do.

CORE IDEAS

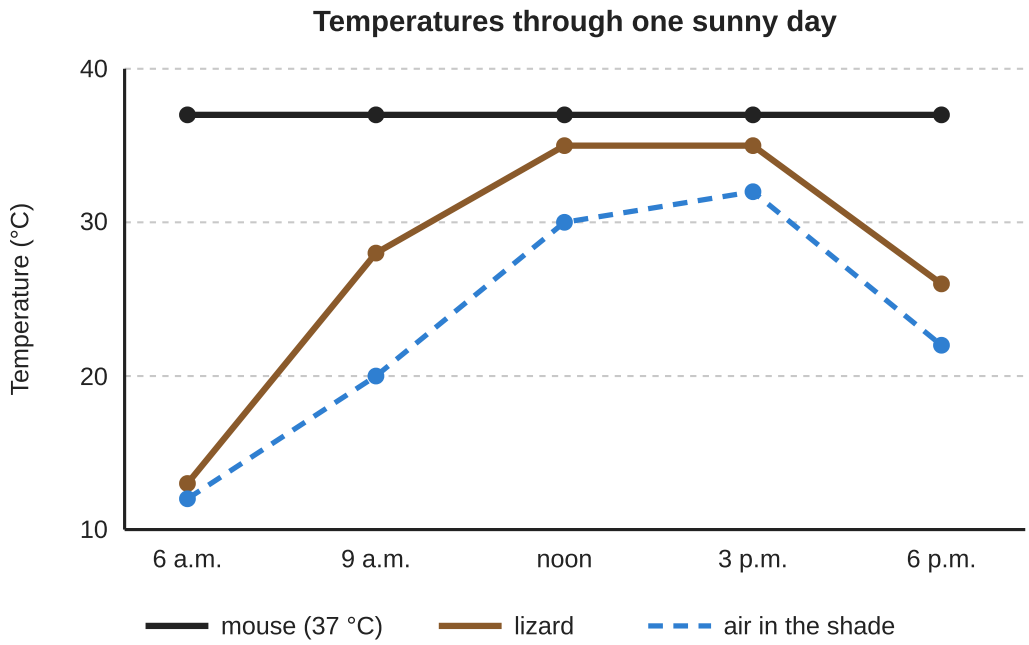
The story. In the early 1940s two American scientists, Raymond Cowles and Charles Bogert, carried thermometers into the deserts of southern California. They wanted to answer a simple question: how warm are lizards and snakes, really? People had long called reptiles “cold-blooded,” as if their blood were always chilly. So Cowles and Bogert caught desert reptiles, took their body temperatures on the spot, and wrote down the temperature of the air, the ground and the shade around them, hour after hour. In 1944 they published what they had found.

How they figured it out. Their numbers surprised many people. An active desert lizard was often as warm as you, or warmer. But it was not making that heat itself. In the cool morning the lizards lay in the sun to warm up, which is called **basking**. At midday they slipped into the shade or under the sand to keep from getting too hot. At night they hid in burrows. By moving between sun and shade, a lizard kept its body near the temperature it needed. Cowles and Bogert also saw how quickly a reptile caught in the open with no shade could overheat on a hot day. A reptile’s body temperature depends on where it is.

The big idea. Animals handle heat in two ways. **Warm-blooded** animals, the birds and mammals, burn food inside their bodies like fuel in a furnace and keep a steady temperature whether the day is hot or cold. Your body stays near 37 °C (98.6 °F), and many birds stay around 40 °C (104 °F) or a little higher. **Cold-blooded** animals, the fish, amphibians and reptiles, take their temperature from their surroundings. Scientists call them ectotherms, which means “outside heat.” Their blood is not always cold. A sunning lizard may be warmer than you, while a fish in an icy pond is nearly as cold as the water. Because cold-blooded animals do not burn food to make heat, they need far less food than a bird or mammal of the same size.

Keeping warm and keeping cool. Warm-blooded animals hold in their heat with **insulation**: fur on a fox, fluffed feathers on a winter chickadee, thick blubber on a seal. When they are cold they shiver, which makes extra heat. When they are hot, dogs pant and people sweat. Cold-blooded animals use their behavior instead: they bask, find shade, burrow, or slow down and rest through the winter. The wood frog of North America does something astonishing: in winter much of the water in its body turns to ice and its heart stops beating. In spring it thaws, its heart starts again, and it hops off to find a pond.

Try it and see. Does a fur coat make heat, or does it only hold heat in? In the project you will fill two jars with the same warm water, wrap one in a wool sock like a fur coat, leave the other bare, and measure how fast each one cools. The jar cannot make heat, so any difference must come from the coat. When the Psalm says God “giveth snow like wool,” it reminds us that He also gave the sheep its wool and the fox its fur to keep them warm through the cold.



On one sunny day the mouse (warm-blooded) stays at 37 °C, while the lizard (cold-blooded) warms and cools with the day. By basking, the lizard gets warmer than the air.

PICTURE STUDY



Batrachia (Frogs and Toads), plate from Kunstformen der Natur, Ernst Haeckel, 1899–1904 · Color lithograph printed from Haeckel's drawings · Published in Leipzig in the book *Kunstformen der Natur* (*Art Forms in Nature*), 1899–1904

Ernst Haeckel was a German zoologist who drew living things with great skill. His book *Art Forms in Nature* has one hundred pages of pictures, from tiny sea creatures to bats and

frogs. On this page he gathered many kinds of frogs and toads, the amphibians, and arranged them so you can compare them all at once.

Frogs and toads are cold-blooded. As you look, think about how each one might warm up or cool down without making its own heat.

Look closely

- Count how many frogs and toads you can find on the page.
- Compare their skin. Which look smooth and moist, and which look bumpy and dry like a toad?
- Find a frog that looks like it is climbing or clinging. Look at its toes.
- Where are the eyes placed on the head? How might that help a frog sitting low in the water?

Talk about it

1. A frog has no fur or feathers. What could a frog do to warm up on a cool morning? To cool off on a hot afternoon?
2. Why might so many colors and patterns be useful to frogs living in different places?

> **Safety first.** Use warm tap water, never boiling water, and have an adult fill the jars. Handle glass jars carefully. Use a digital or alcohol (red-line) thermometer, not an old mercury one; if a thermometer breaks, step away and tell an adult. If you watch lizards, snakes or frogs outdoors, observe them without touching, and never pick up a snake.

EXPERIMENT: THE FUR COAT JAR TEST

Question: Does a fur coat keep a warm body warm longer? Your two jars of warm water are model warm-blooded animals. One gets a “fur coat” (a wool sock), and the other stays bare. You will measure the temperature of each every 5 minutes for 30 minutes.

You will need

- Two jars of the same size and kind, with lids (pint canning jars work well)
- Warm tap water and a measuring cup
- Two thermometers that read in °C (or one, moved quickly between jars)
- A thick wool sock or knit hat that fits over one jar
- A timer, notebook and pencil

Steps

1. Write your prediction: Which jar will cool more in 30 minutes? Will the sock make the jar warmer than it started?
2. Make a table with three columns: Minutes, Bare jar (°C), Fur coat jar (°C). Write 0, 5, 10, 15, 20, 25, 30 down the first column.

3. Have an adult pour the same amount of warm tap water, about 400 mL (1⅔ cups), into each jar.
4. Put a thermometer in each jar and record the starting temperatures at 0 minutes. They should be the same or within 1 degree.
5. Pull the wool sock over one jar. Leave the other bare. Set both jars side by side on the same table, away from sun and heaters.
6. Every 5 minutes, read and record both temperatures until 30 minutes.
7. Subtract to find how many degrees each jar dropped. Make a line graph with one line for each jar.
8. Write your conclusion: Which jar stayed warmer? Did the sock make heat, or did it slow the loss of heat? How is this like fur, feathers or blubber?

Tips

- What we change: the covering (sock or no sock). What we keep the same: jar size, amount of water, starting temperature, place and time. What we measure: the temperature every 5 minutes.
- Try a second round with a jar wrapped in a plastic bag full of shortening, a “blubber coat,” and compare it with the sock.

Check your work

- I made a prediction and kept everything the same except the covering.
- I recorded temperatures every 5 minutes in a table.
- I drew a line graph with two lines and a labeled axis.
- I can explain that fur and feathers hold heat in rather than make heat.

NATURE NOTEBOOK

1. Draw a lizard on a rock in the morning sun, the same lizard in the shade at noon, and the same lizard in its burrow at night. Write a caption for each.
2. Make a two-column chart titled “Warm-Blooded” and “Cold-Blooded.” List five animals from your yard, park or kitchen table in each column.
3. Draw a bird with its feathers fluffed out on a cold day. Label the air trapped between the feathers and explain how it helps.

> **From history.** Measuring body temperature became possible with good thermometers. Around 1714 the instrument maker Daniel Gabriel Fahrenheit, working in the Dutch Republic, made reliable mercury thermometers, and his scale is still used in the United States. In 1742 the Swedish astronomer Anders Celsius of Uppsala, the same university town where Linnaeus taught, proposed a scale based on the freezing and boiling of water. His first scale ran backward, with 100 for freezing and 0 for boiling, but it was soon turned around into the Celsius scale scientists use today, with 0 °C for freezing and 100 °C for boiling.

WORKED EXAMPLES

Example 1. This table shows temperatures on one sunny day. 6 a.m.: air 12 °C, lizard 13 °C, mouse 37 °C. 9 a.m.: air 20 °C, lizard 28 °C, mouse 37 °C. Noon: air 30 °C, lizard 35 °C, mouse 37 °C. 3 p.m.: air 32 °C, lizard 35 °C, mouse 37 °C. 6 p.m.: air 22 °C, lizard 26 °C, mouse 37 °C. How much did the lizard's temperature change from 6 a.m. to noon? How much did the mouse's change? What does this tell you?

(Use the map or drawing "The same data drawn as a graph: a flat line for the mouse and a rising and falli" shown earlier in this lesson.)

1. Lizard: 35 °C at noon − 13 °C at 6 a.m. = 22 °C warmer.
2. Mouse: 37 °C − 37 °C = 0 °C. No change.
3. The lizard's temperature followed the warming day. The mouse kept the same temperature all day.
4. Notice that at 9 a.m. the lizard (28 °C) was 8 degrees warmer than the air (20 °C). It was basking in the sun.

Answer: The lizard warmed by 22 °C, and the mouse did not change at all. The lizard is cold-blooded: it takes its heat from the sun. The mouse is warm-blooded: it makes its own heat.

Example 2. In the Fur Coat Jar Test, both jars started at 50 °C. After 30 minutes the bare jar was 38 °C and the jar in the wool sock was 46 °C. How many degrees did each jar drop? How many times as much did the bare jar cool?

1. Bare jar: 50 − 38 = 12 degrees.
2. Fur coat jar: 50 − 46 = 4 degrees.
3. Compare: 12 ÷ 4 = 3.
4. Neither jar got warmer than 50 °C, so the sock did not make heat. It only slowed the loss of heat.

Answer: The bare jar dropped 12 °C and the fur coat jar dropped 4 °C, so the bare jar cooled 3 times as much. Insulation holds heat in.

PRACTICE

1. EASY Which two classes of vertebrates are warm-blooded? Which three are cold-blooded?
2. EASY True or false: A cold-blooded lizard always has cold blood. Explain.
3. MEDIUM Use the table in Worked Example 1. What was the lizard's temperature at 3 p.m. and at 6 p.m.? How many degrees did it cool?
4. MEDIUM Why does a snake lie on a warm rock on a cool morning?

5. MEDIUM A healthy dog’s body temperature is about 38.5 °C. A person’s is about 37 °C. How much warmer is the dog? Which class are both animals in?
6. HARD A pet store has a lizard and a rat that weigh about the same. Which one needs more food each week? Explain why.
7. HARD Design a fair test of whether blubber helps keep a seal warm. You have two plastic bags, a can of shortening, a bowl of ice water and a timer. (a) What will you change? (b) What will you keep the same? (c) What will you measure? (d) What is your control?
8. CHALLENGE Your little brother says, “My wool sweater makes heat.” In two or three sentences, explain why that is not quite right, and connect it to an animal’s fur.

COMMON MISTAKES

- Thinking cold-blooded animals always have cold blood. Their temperature follows their surroundings, so a basking lizard can be warmer than you.
- Thinking fur, feathers or a coat make heat. They are insulation: they only slow heat from leaving the body.
- Thinking every animal that lives in a cold place must be warm-blooded. Fish swim under the ice of frozen ponds and are cold-blooded; their bodies are nearly as cold as the water.

Make it a game · Sun, Shade or Shiver. Mark a sunny spot, a shady spot and a “burrow” (under a table) in the room. A parent calls out an animal and a weather, such as “lizard, cool morning” or “dog, hot afternoon.” If the animal is cold-blooded, players move to where it would go: sun, shade or burrow. If it is warm-blooded, players act out what it would do: shiver, fluff feathers, pant or sweat. Anyone who does the right thing first scores a point.

Scripture. “He giveth snow like wool: he scattereth the hoarfrost like ashes. He casteth forth his ice like morsels: who can stand before his cold?” (Psalm 147:16–17, KJV)

God sends the winter cold, and He also gave each creature a way to meet it: wool and fur for the sheep and fox, feathers for the chickadee, and for the wood frog the strange gift of freezing and thawing again.

Practice answers

1. Warm-blooded: birds and mammals. Cold-blooded: fish, amphibians and reptiles.
2. False. Its temperature changes with its surroundings. A lizard basking in the sun can be as warm as a person or warmer; it is cold only when its surroundings are cold.
3. 35 °C at 3 p.m. and 26 °C at 6 p.m. It cooled 35 − 26 = 9 degrees.
4. It is basking. A snake cannot make enough of its own heat, so it soaks up heat from the sun and the warm rock until its body is warm enough to move, hunt and digest food.
5. 38.5 − 37 = 1.5 °C warmer. Both are mammals, and both are warm-blooded.
6. The rat. It is warm-blooded, so it burns food all day and night to keep its body at a steady temperature. The lizard gets its warmth from its surroundings, so it needs much less food.

7. (a) Whether the bag is lined with shortening (blubber) or not. (b) The same kind of bag, the same hand or the same ice water, and the same starting temperature. (c) How long you can keep your hand in the ice water, or the temperature inside each bag after the same time. (d) The control is the bag with no shortening.
8. A sweater cannot make heat; your body makes the heat by burning food. The sweater traps warm air next to your skin and slows the heat from escaping. A fox’s fur works the same way: the fox makes the heat, and the fur holds it in.

2.4 The Vertebrate Sorting Game

OBJECTIVES

- Tell how George Shaw met the platypus in 1799 and explain why it is a mammal even though it lays eggs.
- Use a four-question dichotomous key to sort any vertebrate into its class, including tricky animals like bats, whales, penguins and salamanders.
- Make a 30-card vertebrate sorting game and test whether players sort more accurately with the key than by looks alone.

Warm-up. Your parent says the names of six animals: dolphin, eel, bat, penguin, salamander and sea turtle. Without looking anything up, write each one under the class you think it belongs to. Fold the paper and set it aside. At the end of the lesson you will open it and check your answers with the key.

Video. Coming soon. Platypus and echidna (egg-laying mammals) for kids, and tricky animals to classify (bats, whales, penguins, salamanders): search SciShow Kids, Homeschool Pop (Alternate), Smithsonian's National Zoo, San Diego Zoo Wildlife Alliance, and nature footage of platypuses in Australian streams.

KEY TERMS

classify
To sort things into groups by the traits they share.

dichotomous key
A tool for identifying living things by answering a series of two-choice questions, such as yes or no (from Lesson 1.4).

specimen
A real animal, plant or part of one (such as a skin, skeleton or pressed leaf) that is collected and kept for scientists to study.

monotreme
A mammal that lays eggs. The platypus and the echidnas are the only monotremes living today.

flipper
A broad, flat limb shaped for swimming. Whales, seals, sea turtles and penguins all have flippers, though they belong to different classes.

CORE IDEAS

The story. In 1799 the naturalist George Shaw, a keeper at the British Museum in London, studied a strange **specimen** sent from the new British colony of New South Wales in Australia. It was the dried skin of an animal no European scientist had ever described. It had

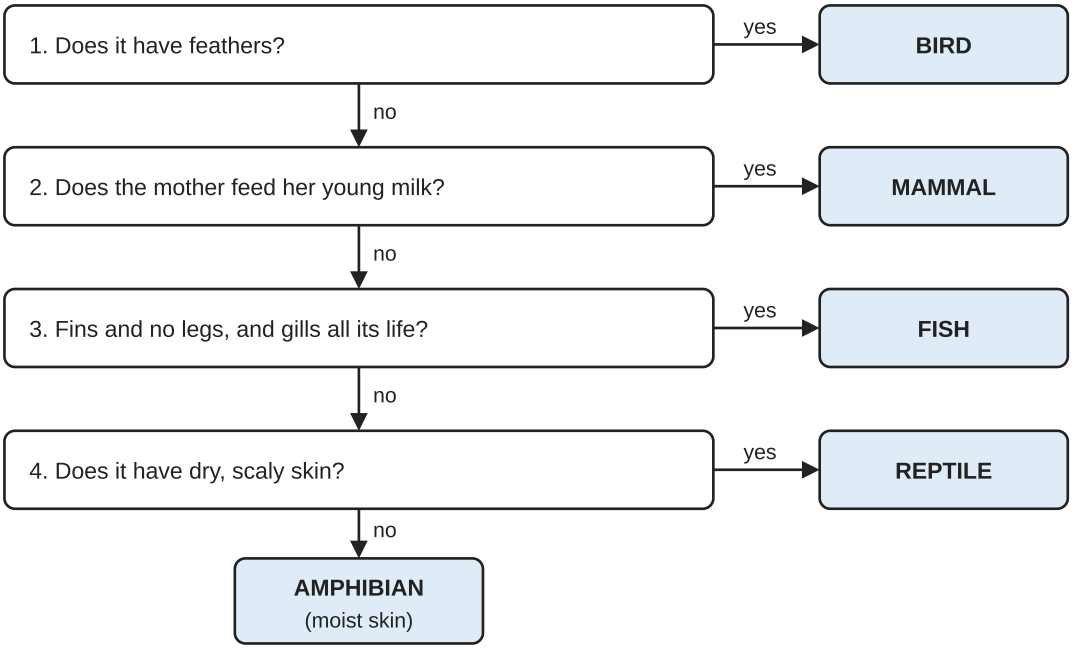
thick brown fur like an otter, a flat bill like a duck, webbed feet and a broad, flat tail. Shaw wrote that it was hard not to suspect a trick, as if someone had fastened a duck's bill onto a furry body. The story is often told that he even looked for stitches. There were none. The animal was real, and Shaw named it the platypus, a Greek word meaning "flat foot."

How they figured it out. The platypus had fur, so it looked like a mammal. Later naturalists found that platypus mothers make milk for their babies. But people in Australia also said that the platypus laid eggs, and for years many scientists in Europe doubted it. Mammals give birth to live young, they said. In 1884 a young Scottish scientist named William Caldwell, working along a river in Australia, found a mother platypus that had laid an egg. He sent a telegram with the news to scientists meeting in Montreal, Canada. The platypus and the spiny echidnas are now called **monotremes**: mammals that lay eggs. They have fur, and the mothers feed their young with milk, which seeps from patches on the mother's skin. Fur and milk, not live birth, are the true marks of a mammal.

The big idea. To **classify** well, look past the surface to the traits that really matter. A whale, a sea turtle and a penguin all swim with **flippers**, but one is a mammal, one a reptile and one a bird. A bat flies like a bird, but it is a mammal. A salamander looks like a lizard, but its moist skin makes it an amphibian. A **dichotomous key** keeps you honest by asking the important questions in order. (1) Does it have feathers? If yes, it is a bird. (2) If not, does the mother feed her young milk? If yes, it is a mammal. (3) If not, does it have fins (and no legs) and breathe with gills all its life? If yes, it is a fish. (4) If not, does it have dry, scaly skin? If yes, it is a reptile; if no, with moist skin, it is an amphibian.

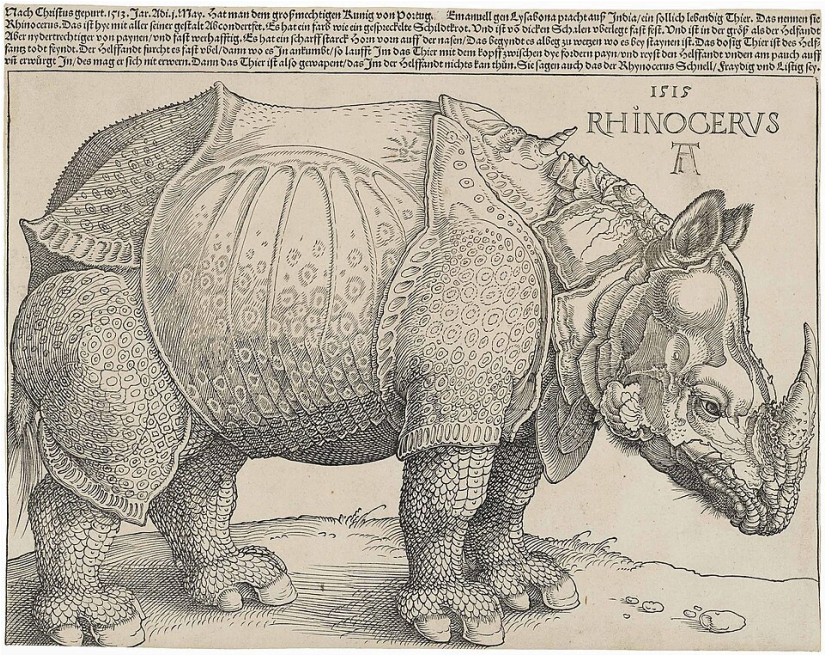
Try it and see. In the project you will make a deck of 30 animal cards, six from each class, with a picture on the front and the animal's traits on the back. You will play two rounds. In the first you sort by looks alone; in the second you use the key. Then you will count how many cards were sorted correctly each time. That turns your game into a small experiment: does the key really help?

God's handiwork. The platypus reminds us that God is not bound by our neat lists. When naturalists meet something new, the right response is not to throw out the evidence but to look closer and fix the list. Paul wrote that there is "one kind of flesh of men, another flesh of beasts, another of fishes, and another of birds." The Creator made each kind with its own design, and the more carefully we sort, the more of that design we see.



A dichotomous key for the five classes of vertebrates. Start at question 1 and follow the arrows.

PICTURE STUDY



Rhinoceros, Albrecht Dürer, 1515 · Woodcut · Prints are kept in several museums, including the British Museum, London, and the National Gallery of Art, Washington, D.C.

In 1515 a living Indian rhinoceros arrived by ship in Lisbon, Portugal, a gift to King Manuel I. No rhinoceros had been seen in Europe for many centuries, and the news spread quickly. In Nuremberg, Albrecht Dürer made this famous woodcut from a written description and a sketch sent to him. He never saw the animal himself.

His picture was copied in books for a very long time. It is wonderful art, but parts of it are wrong. It is a good warning for anyone sorting animals: look at the real thing whenever you can.

Look closely

- Find the plates that look like a knight’s armor. Do you think a real rhinoceros has rivets?
- Look at the legs. What covering did Dürer give them? Which class has that kind of covering?
- Find the small, twisted horn on the rhinoceros’s back. Real rhinoceroses do not have it.
- Look at the writing above the animal. Why might Dürer have added words to his picture?

Talk about it

1. From this picture alone, someone might guess the rhinoceros is a reptile. What traits would prove it is a mammal?
2. Dürer worked from someone else’s description. Why is it better for a naturalist to observe a real animal or specimen?

EXPERIMENT: MAKE THE VERTEBRATE SORTING GAME

Question: Do players sort animals more accurately when they use the key than when they sort by looks alone? You will make a 30-card game and test it.

You will need

- 30 index cards
- Colored pencils or markers, or pictures cut from old magazines
- Five sheets of paper labeled Fish, Amphibians, Reptiles, Birds, Mammals
- A copy of the vertebrate key from this lesson
- A timer, notebook and pencil

Steps

1. Make six cards for each class. Fish: trout, shark, seahorse, eel, salmon, goldfish. Amphibians: frog, toad, salamander, newt, axolotl, caecilian. Reptiles: lizard, snake, sea turtle, tortoise, alligator, chameleon. Birds: robin, penguin, ostrich, owl, hummingbird, eagle. Mammals: whale, bat, platypus, dog, dolphin, horse.
2. On the front of each card draw the animal and write its name. On the back write three traits: its covering, how it breathes, and how its young begin. Write the class in small letters in a corner of the back.
3. Write your prediction: How many cards out of 30 will a player sort correctly by looks alone? With the key?
4. Round 1: Shuffle. A player has 3 minutes to sort all 30 cards onto the five class sheets by looking only at the fronts. Count how many are correct.

5. Round 2: Shuffle again. The same player has 3 minutes to sort the cards using the key, reading the traits on the backs. Count how many are correct.
6. Record both scores in a table. Repeat with a second player if you can.
7. Write your conclusion: Did the key help? Which cards were missed most in Round 1, and why?

Tips

- What we change: the sorting method (looks or key). What we keep the same: the cards, the time limit and the player. What we measure: the number of cards sorted correctly.
- Fair-test trick: a player who already knows every answer cannot show whether the key helps. Try the game on a younger child or a grown-up who has not studied the unit.

Check your work

- My deck has 30 cards, six for each class, with correct traits on the backs.
- I ran two rounds with only one thing changed and recorded both scores.
- I can sort a bat, a whale, a penguin, a platypus and a salamander with the key and explain each answer.

NATURE NOTEBOOK

1. Draw the platypus and label each part that surprised George Shaw: bill, fur, webbed feet, flat tail. Under it write “Mammal” and the two traits that prove it.
2. Draw a whale, a sea turtle and a penguin in a row, each with its flipper. Under each, write its class and the trait that decides it.
3. Open your folded warm-up paper. Use the key to check each of the six animals and correct any mistakes in a different color.

> **From history.** In 1818 a New York City courtroom heard a strange case about whether a whale is a fish. A state law required fish oil to be inspected, and an inspector named James Maurice sued a candle maker, Samuel Judd, who had bought whale oil without inspection. The naturalist Samuel Latham Mitchill told the court that a whale breathes air, has warm blood and nurses its young, so it is not a fish. The jury decided for the inspector anyway, because in the everyday speech of sailors and merchants a whale was a “fish.” Science, though, followed the evidence, and whales are classified as mammals.

WORKED EXAMPLES

Example 1. Use the key to classify a bat.

(Use the map or drawing "Follow the bat through the key: no at question 1, yes at question 2." shown earlier in this lesson.)

1. Question 1: Does it have feathers? No. A bat's wings are made of thin skin stretched between long finger bones, and its body is covered with fur. Go to question 2.
2. Question 2: Does the mother feed her young milk? Yes. A mother bat nurses her pup.
3. Stop: the key says mammal.

Answer: A bat is a mammal. Flying does not make an animal a bird; feathers do.

Example 2. Grace played the sorting game. In Round 1 (looks only) she sorted 22 of 30 cards correctly. In Round 2 (with the key) she sorted 29 of 30 correctly. How many mistakes did she make each round? How many more cards did she get right with the key?

1. Round 1 mistakes: $30 - 22 = 8$.
2. Round 2 mistakes: $30 - 29 = 1$.
3. Improvement: $29 - 22 = 7$ more correct cards.

Answer: She made 8 mistakes by looks and only 1 with the key, so the key helped her get 7 more cards right. One player is a small test, so it would be wise to try more players before drawing a firm conclusion.

PRACTICE

1. EASY The platypus lays eggs. Which class is it in, and which two traits prove it?
2. EASY Use the key to classify a dolphin. Which question stops you, and what is the answer?
3. MEDIUM Use the key to classify a sea turtle. Give the answer to each question you ask.
4. MEDIUM An axolotl keeps its feathery gills all its life, but it has four legs and smooth, moist skin. Use the key to classify it.
5. MEDIUM A family counted the animals they saw on a zoo trip: Fish 12, Amphibians 3, Reptiles 9, Birds 15, Mammals 21. (a) How many animals did they see in all? (b) Which class did they see most? (c) What fraction of all the animals were birds?
6. HARD A penguin, a bat and a flying fish all move in unusual ways. Name the class of each and the one trait that decides it.
7. HARD Leo wants to know whether picture cards or word-only cards help players sort faster. (a) What should he change? (b) What should he keep the same? (c) What should he measure? (d) Why should he test more than one player?

8. CHALLENGE Why does the key ask “Does it have fins and no legs, and breathe with gills all its life?” instead of just “Does it live in water?” Use two animals in your answer.

COMMON MISTAKES

- Thinking any animal that flies is a bird. Bats are mammals, and many insects fly too.
- Thinking an animal that lays eggs cannot be a mammal. The platypus and the echidnas lay eggs but have fur and feed their young milk.
- Sorting by where an animal lives or how it looks. Whales and dolphins live in the sea but are mammals; salamanders look like lizards but are amphibians.

Make it a game · Mystery Card. One player secretly draws a card from the sorting deck. The others may ask only the four key questions, in order, and the card holder answers yes or no. After the key gives a class, the askers have three guesses to name the exact animal and may ask one extra yes-or-no question before each guess. Score 3 points for a first guess, 2 for a second and 1 for a third. Take turns until everyone has drawn three cards.

Scripture. “All flesh is not the same flesh: but there is one kind of flesh of men, another flesh of beasts, another of fishes, and another of birds.” (1 Corinthians 15:39, KJV)

Paul pointed out what any careful observer sees: God made different kinds of creatures with different bodies. Sorting them by their real traits honors the way He made them.

Practice answers

1. Mammal. It has fur, and the mother feeds her young with milk.
2. Question 1: no feathers. Question 2: yes, the mother feeds her calf milk. The dolphin is a mammal.
3. 1. Feathers? No. 2. Milk? No. 3. Fins with no legs, and gills all its life? No; its flippers are legs and it breathes air with lungs. 4. Dry, scaly skin? Yes. A sea turtle is a reptile.
4. 1. Feathers? No. 2. Milk? No. 3. Fins and no legs, with gills all its life? No, because it has legs. 4. Dry, scaly skin? No, its skin is moist. It is an amphibian.
5. (a) 12 + 3 + 9 + 15 + 21 = 60. (b) Mammals (21). (c) 15 out of 60, which is 15/60 = 1/4.
6. Penguin: bird, because it has feathers. Bat: mammal, because the mother feeds her young milk (and it has fur). Flying fish: fish, because it has fins and breathes with gills all its life.
7. (a) The kind of card: pictures or words only. (b) The same 30 animals, the same five class sheets, the same rules and the same timer. (c) The time to sort all 30 cards (and the number correct). (d) One player might just be fast or slow; testing several players shows whether the result holds.
8. Many animals that live in water are not fish. A whale lives in water but breathes air and feeds its calf milk, so it is a mammal; a tadpole lives in water with gills but grows legs and lungs and becomes a frog, an amphibian. Asking about fins, legs and gills all its life picks out only the true fish.

Unit 2 review

Answer each question. Show your work for calculations and use complete sentences for explanations. The quiz is worth 50 points.

1. (5 pts) What is the difference between a vertebrate and an invertebrate? Give one example of each.
2. (5 pts) Name the five classes of vertebrates and give the body covering of each.
3. (5 pts) Linnaeus moved whales out of the fish and into the mammals. Give two traits that show a whale is a mammal.
4. (5 pts) Name three parts of the backbone and tell what each one does.
5. (5 pts) An adult human has 7 neck vertebrae, 12 chest vertebrae and 5 lower back vertebrae. How many is that in all? How many neck vertebrae does a giraffe have, and why is its neck so long?
6. (5 pts) A shark’s skeleton has no bone in it. Is a shark a vertebrate? Explain.
7. (5 pts) Explain the difference between warm-blooded and cold-blooded animals and name the classes in each group.
8. (5 pts) Read the table. Air: 6 a.m. 12 °C, noon 30 °C. Lizard: 6 a.m. 13 °C, noon 35 °C. Mouse: 6 a.m. 37 °C, noon 37 °C. How much did the lizard warm? How much did the mouse warm? Which one is cold-blooded?
9. (5 pts) In the Fur Coat Jar Test, one jar wore a wool sock and one stayed bare. (a) What was changed? (b) Name two things kept the same. (c) What was measured? (d) Did the sock make heat?
10. (5 pts) Use the vertebrate key to classify a platypus and a bat. Explain each answer.

Unit project: my vertebrate field notebook

Make a five-section notebook, one section for each class of vertebrates. In each section draw and label three animals, at least one that lives near you, and write their covering, how they breathe and how their young begin. Add a page on the backbone with your labeled vertebra drawing and a photo or tracing of your bendy backbone models, a page with your Fur Coat Jar Test table and line graph, and a final page with the vertebrate key and five tricky animals you sorted with it (such as a bat, whale, penguin, salamander and platypus). Finish with a short paragraph on what surprised you most about God’s design of the vertebrates.

- **Accuracy**: Every animal is in the correct class, and the traits listed for each class are correct.
- **Observation and drawing**: Drawings are careful and labeled, including the vertebra, the models and at least one animal observed in real life.
- **Data and fair tests**: The jar test and backbone test each name what was changed, what was kept the same and what was measured, with complete tables and a correctly labeled graph.
- **Explanation and care**: The key is used correctly on five tricky animals, the closing paragraph is thoughtful, and the notebook is neat and easy to read.

Answer key

1. A vertebrate has a backbone; an invertebrate does not. Examples: a horse (vertebrate) and a snail (invertebrate). Other correct examples are fine.
2. Fish: scales (with fins). Amphibians: moist skin with no scales. Reptiles: dry scales. Birds: feathers. Mammals: hair or fur.
3. Any two: it breathes air with lungs (not gills); the mother feeds her calf milk; it has some hair; its young are born alive.
4. Vertebrae: small bones that hold up the body and form a tunnel of bone. Discs: springy cushions between vertebrae that let the back bend and soften bumps. Spinal cord: the bundle of nerves inside the tunnel that carries messages between the brain and the body.
5. 7 + 12 + 5 = 24. A giraffe also has 7 neck vertebrae; its neck is long because each vertebra is very long (about 25 cm, or 10 inches).
6. Yes. A shark has a backbone made of cartilage instead of bone. Any animal with a backbone is a vertebrate.
7. Warm-blooded animals make their own body heat from food and keep a steady temperature: birds and mammals. Cold-blooded animals take their temperature from their surroundings: fish, amphibians and reptiles.
8. Lizard: 35 − 13 = 22 °C. Mouse: 37 − 37 = 0 °C. The lizard is cold-blooded; its temperature followed the warming day.
9. (a) The covering (sock or no sock). (b) Any two: jar size, amount of water, starting temperature, place, time. (c) The temperature of each jar every 5 minutes. (d) No; it only slowed the loss of heat, like fur or feathers.
10. Both are mammals. Neither has feathers (question 1: no), and both mothers feed their young milk (question 2: yes). The platypus lays eggs, but fur and milk make it a mammal; the bat flies, but it has fur, not feathers.

UNIT 3

Invertebrates

In Unit 2 you met the animals with backbones. Now you will meet the far larger crowd of creatures without them: the **invertebrates**. Almost all the kinds of animals God made belong to this group. In this unit you will study four of them up close: the spider in the garden, the crab and lobster of the sea, the snail on the sidewalk after rain, and the sea star clinging to a tide-pool rock. Each one belongs to a different group, and you will learn the clues that tell them apart: legs, body parts, antennae, shells and symmetry.

You will sit up with Jean-Henri Fabre watching a garden spider build its web, test a fisherman's tale about crayfish legs with René-Antoine de Réaumur, hear about a desert snail that woke up after four years glued to a museum card, and stand on the deck with Edward Forbes as a starfish breaks itself to pieces. Along the way you will count webs, run a pill bug choice chamber, time a snail race and test a model tube foot. Each experiment will ask you to change one thing, keep everything else the same and measure carefully, just as real scientists do.

BEFORE YOU BEGIN

- Knows what a vertebrate is and can name the five classes of vertebrates (Unit 2)
- Can follow a simple two-choice dichotomous key (Unit 1)
- Can measure in centimeters with a ruler and add, subtract and divide whole numbers
- Can read and draw a simple table and bar graph

MASTERY CHECKLIST

- I can explain what an invertebrate is and name four invertebrate groups: arachnids, crustaceans, mollusks and echinoderms.
- I can tell a spider from an insect by counting body parts, legs and antennae.
- I can explain how crabs and lobsters molt and how they regrow lost legs.
- I can name the parts of a snail and explain how it survives dry weather.
- I can describe a sea star's radial symmetry, tube feet and eyespots.
- I can plan a fair test by naming what I change, what I keep the same and what I measure.

OPTIONAL BOOKS AND RESOURCES

- **Smithsonian Ocean** (https://ocean.si.edu/): Free. The Smithsonian's ocean website has photographs and short articles about crabs, lobsters, sea snails, sea stars and other sea invertebrates. Good for Lessons 3.2 and 3.4; a parent may preview.
- **NOAA Ocean Service: Ocean Facts** (https://oceanservice.noaa.gov/facts/): Free. Short, clear answers from the National Oceanic and Atmospheric Administration to questions about sea creatures and tide pools. Search the page for "sea star" or "crab."

- **Jean-Henri Fabre, *The Life of the Spider* (free at Project Gutenberg)** (https://www.gutenberg.org/ebooks/search/?query=Fabre+Life+of+the+Spider): Free. Fabre's own account of the garden spiders of his harmas, in English translation. Read aloud the chapters on the garden spider's web and its "telegraph wire" with Lesson 3.1.

3.1 Spiders ★

OBJECTIVES

- Explain what an invertebrate and an arthropod are, and name three things all arthropods share.
- Tell a spider from an insect by counting body parts, legs and antennae, and use a key to sort them.
- Describe how a garden spider builds and uses its web, as Jean-Henri Fabre watched it, and record measurements of real webs.

Warm-up. Pull a single long hair or a thin sewing thread and hold it up to a window. How easy is it to see? Now picture a thread even thinner, made by an animal smaller than your thumbnail, strong enough to stop a flying grasshopper. Write down one guess about how a spider makes such a thread, and one question you would like to ask a spider if it could answer.

Video. Coming soon. Garden orb-weaver spider building a web at night, and spider versus insect body parts for kids: search Smithsonian, SciShow Kids, Homeschool Pop (Alternate), Moody Science classics and close-up nature footage of orb weavers.

KEY TERMS

invertebrate
An animal without a backbone. Spiders, crabs, snails and sea stars are all invertebrates.

arthropod
An invertebrate with jointed legs, a hard outer covering and a body made of segments. Insects, spiders and crabs are arthropods.

exoskeleton
A hard skeleton on the outside of the body, like a suit of armor.

arachnid
An arthropod with eight legs, two main body parts and no antennae, such as a spider, tick or scorpion.

spinneret
A small tube at the back end of a spider’s abdomen that lets out silk.

molt
To shed the old exoskeleton so the animal can grow a bigger one.

CORE IDEAS

The story. In 1879 a French schoolteacher and naturalist named Jean-Henri Fabre bought a weedy plot of land at Sérignan, a village in the south of France. He called it his *harmas*, an old local word for a patch of wild, stony ground, and he spent the rest of his long life

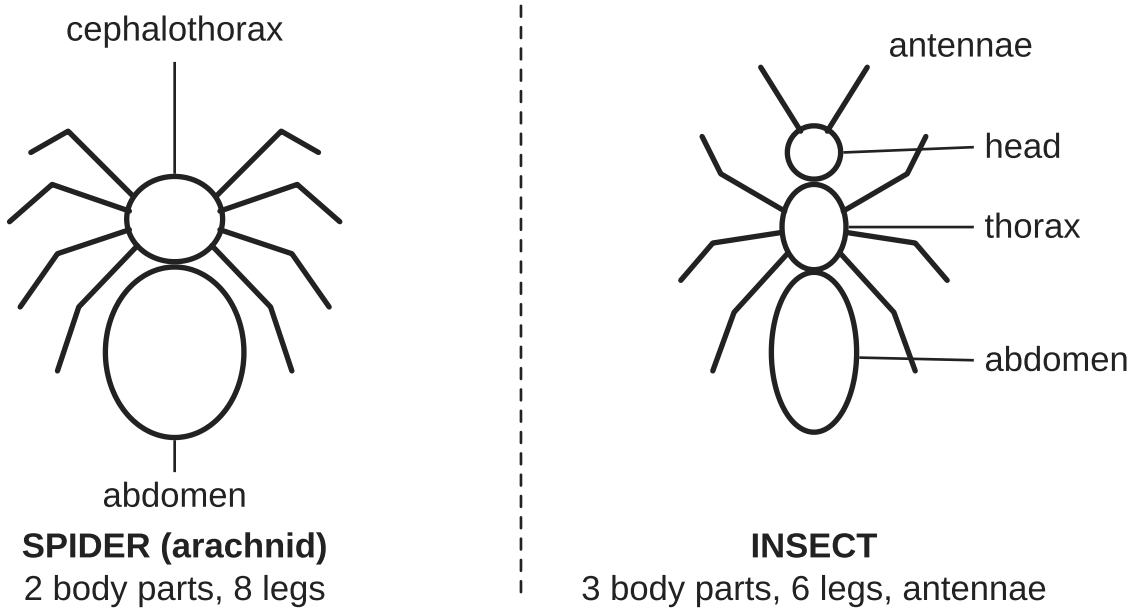
watching the small creatures that lived there. Some of his favorite neighbors were the big garden spiders that hung their round webs between the bushes. Fabre sat up in the evening with a lantern to watch them work. He saw a spider lay down straight spokes like the spokes of a wheel, then walk round and round, laying a spiral of sticky silk. By morning a new web hung where the old one had been. He wrote it all down, and his spider chapters were later gathered in English as *The Life of the Spider*.

How they figured it out. Fabre noticed that many garden spiders did not sit in the middle of the web all day. They hid in a rolled leaf nearby, and from the center of the web a single line of silk ran up to the hiding place. The spider rested with one leg on that line. When a fly or grasshopper hit the web, the line trembled, and out rushed the spider. Fabre called it a telegraph wire. He tested it by touching the web gently with a straw and by laying a dead insect on it. The spider came only when the web shook like something alive was struggling in it. Careful watching, small tests and good notes taught him more than any book of his day.

The big idea. A spider has no backbone, so it is an **invertebrate**. Almost all the kinds of animals God made are invertebrates. Spiders belong to the biggest group of invertebrates, the **arthropods**, which all have jointed legs, a body made of segments and a hard **exoskeleton** on the outside. Because that armor cannot stretch, a growing spider must **molt**, splitting out of its old skin and waiting while the new one hardens. Linnaeus first placed spiders among the insects, but later naturalists counted more carefully and gave them their own class, the **arachnids**. A spider has two body parts (the cephalothorax, or head-chest, and the abdomen), eight legs and no antennae. An insect has three body parts, six legs and two antennae. Most spiders have eight eyes, a pair of fangs, and silk-making **spinnerets** at the tip of the abdomen.

Try it and see. Spiders are easiest to find on a dewy morning, when every web sparkles. Look for round orb webs in bushes and porch corners, sheet webs in the grass and messy tangle webs in sheds. Not every spider spins a web to catch food. Wolf spiders run their prey down, and jumping spiders leap on it, using their big front eyes to judge the distance. Scientists have named more than 50,000 kinds of spiders, and new ones are found every year. Nearly all of them are harmless to people and helpful to farmers and gardeners, because they eat huge numbers of insects. In the United States, the black widow and the brown recluse are the two to leave strictly alone.

God’s handiwork. A spider’s silk starts as a liquid inside its body and becomes a solid thread as it is pulled out of the spinnerets. One spider can make several kinds of silk: dry, strong lines for the frame and spokes, sticky silk for the spiral, and soft silk for wrapping its eggs. For its weight, the strongest spider silk is tougher than steel, and engineers still study it. No one teaches a young garden spider to build its first web. It simply knows how, as God made it. “O LORD, how manifold are thy works! in wisdom hast thou made them all” (Psalm 104:24).



Count the parts: a spider (arachnid) has 2 body parts and 8 legs; an insect has 3 body parts, 6 legs and antennae.

PICTURE STUDY



Plate 18 of Metamorphosis insectorum Surinamensium (spiders, ants and a hummingbird on a guava branch), Maria Sibylla Merian, 1705 · Hand-colored engraving · Published in Amsterdam; this copy is in the British Library, London

Maria Sibylla Merian was a German-born artist and naturalist who studied insects from childhood. In 1699, when she was over fifty, she sailed with her daughter Dorothea to Suriname in South America to draw living creatures where they actually lived. Back in Amsterdam she published her great book of plates in 1705.

This plate shows a huge, hairy spider of the kind we now call a tarantula, catching a small bird beside its nest. Many readers in Europe thought she had made it up. Many years later travelers in South America saw such spiders with their own eyes, and the name “bird-eating spider” stuck.

Look closely

- Find the biggest spider. Count its legs. Can you see where its two body parts meet?
- Look for smaller spiders and ants on the branches. How are the ants different from the spiders?
- Does the big spider have a round web? How do you think it catches its food?
- Look at the leaves and fruit. Why do you think Merian drew each creature on the plant where she found it?

Talk about it

1. Merian was doubted, but later observers proved her right. Why is it important for a scientist to draw and write exactly what she sees?
2. Using what you learned about arachnids and insects, how could you prove to a friend that the big creature is a spider and not an insect?

> **Safety first.** Look, but do not pick up spiders with bare hands. A few kinds, such as the black widow (shiny black with a red hourglass underneath) and the brown recluse, have a dangerous bite. Use a clear jar and a card only with an adult, and let every spider go where you found it. Wash your hands after working outdoors.

EXPERIMENT: WEB WATCH: WHERE DO ORB WEAVERS BUILD?

Like Fabre, you will be a spider watcher. You will find orb webs around your home, measure them, and test a question about where spiders choose to build.

Question: Do orb-weaving spiders build more webs near an outdoor light (where insects gather at night) or in a darker spot? Make a prediction before you start.

You will need

- Spray bottle with plain water (to make webs easy to see)
- Metric ruler or tape measure
- Flashlight
- Notebook and pencil
- Hand lens (magnifying glass), if you have one

Steps

1. Choose two places of about the same size: one area within 2 meters (about 6½ feet) of a porch or outdoor light, and one area the same size on a darker side of the house or yard.

2. Write your prediction: Which place will have more webs?
3. Early in the morning, gently mist each area with water. Count the round orb webs you can see. Do not count broken webs or sheet webs.
4. For each orb web, measure across the widest part (the diameter) in centimeters. Do not touch the web; hold the ruler just in front of it.
5. Make a table: Day, Webs near light, Webs in dark spot, Widths (cm).
6. Repeat on three different mornings at the same time of day.
7. Add up the webs for each place. Then find the average width of all the webs you measured.
8. Write two sentences: Was your prediction right? Why might spiders build where they do?

Tips

- What we change: the place (near the light or in the dark). What we keep the same: the size of each area, the time of morning, and how we count. What we measure: the number of webs and their widths.
- A light mist shows the spiral beautifully. Too much water can break a web, so spray once, gently.
- If you see the spider, sketch it and count its eyes with the hand lens from a safe distance.

Check your work

- I counted webs in two places on three mornings.
- I measured web widths in centimeters and found the average.
- I explained what I changed, what I kept the same and what I measured.

NATURE NOTEBOOK

1. Draw an orb web you found. Label the frame lines, the spokes, the sticky spiral and the hub in the center.
2. Draw a spider and an insect side by side. Label the body parts, and write the number of legs under each.
3. Draw Fabre's "telegraph wire": the web, the line of silk and the spider hiding in a rolled leaf with one leg on the line.

> **From history.** For more than a hundred years many naturalists doubted Maria Sibylla Merian's picture of a spider eating a bird. Then the English naturalist Henry Walter Bates, exploring the Amazon, saw a huge hairy spider over two small finches it had caught. In his book *The Naturalist on the River Amazons* (1863) he described the scene and noted that Merian's old story had been doubted. A careful eyewitness proved the artist had told the truth.

WORKED EXAMPLES

Example 1. You find a small animal on a fence post. It has 2 body parts, 8 legs and no antennae. Use this key to classify it. 1a. Has a backbone → vertebrate. 1b. No backbone → go to 2. 2a. Jointed legs and an exoskeleton → arthropod, go to 3. 2b. No jointed legs → other invertebrate. 3a. 6 legs, 3 body parts, antennae → insect. 3b. 8 legs, 2 body parts, no antennae → arachnid.

(Use the map or drawing "Use the picture to check step 3 of the key." shown earlier in this lesson.)

1. Step 1: The animal has no backbone, so choose 1b and go to 2.
2. Step 2: It has jointed legs and a hard outside covering, so choose 2a. It is an arthropod. Go to 3.
3. Step 3: It has 8 legs, 2 body parts and no antennae, so choose 3b.

Answer: It is an arachnid (most likely a spider), an invertebrate arthropod.

Example 2. Sam measured the widths of five orb webs: 20 cm, 25 cm, 30 cm, 18 cm and 27 cm. Find the average width, the range (largest minus smallest), and the average in inches (1 inch = 2.54 cm).

1. Add the widths: 20 + 25 + 30 + 18 + 27 = 120 cm.
2. Divide by the number of webs: 120 ÷ 5 = 24 cm.
3. Range: largest 30 cm minus smallest 18 cm = 12 cm.
4. Change to inches: 24 ÷ 2.54 ≈ 9.4 inches.

Answer: Average width 24 cm (about 9½ inches); range 12 cm.

PRACTICE

1. EASY How many legs and how many main body parts does a spider have?
2. EASY Why is a spider called an invertebrate?
3. EASY What are the spinnerets, and where are they?
4. MEDIUM An ant has 6 legs, 3 body parts and 2 antennae. Is it an insect or an arachnid? Is it an arthropod?
5. MEDIUM Mia counted orb webs on three mornings. Near the porch light: 6, 5, 7. In the dark corner of the yard: 2, 3, 1. (a) Find the total for each place. (b) How many times as many webs were near the light?
6. HARD Lena wants to know whether garden spiders build more webs in sunny places or shady places. Plan her experiment: What will she change? Name two things she must keep the same. What will she measure?
7. HARD A harvestman (often called a daddy longlegs) has 8 legs and no antennae, but its body looks like one oval piece, and it makes no silk. Is it an arachnid? Is it a spider?

8. CHALLENGE In two or three sentences, explain why a young spider must molt several times before it is grown.

COMMON MISTAKES

- Calling spiders insects. Insects have 6 legs, 3 body parts and antennae; spiders have 8 legs, 2 body parts and no antennae, so they are arachnids.
- Thinking all spiders are dangerous. Nearly all spiders are harmless to people and helpful in gardens. Only a few, like the black widow and brown recluse, have bites that call for a doctor.
- Thinking every spider catches food in a web. Wolf spiders and jumping spiders hunt on foot, though they still make silk for safety lines and egg sacs.

> **Make it a game · Eight or Six?.** A parent calls out an animal: spider, ant, tick, beetle, scorpion, butterfly, mite, grasshopper. If it is an arachnid, hold up eight fingers. If it is an insect, hold up six. Then name one clue (legs, body parts or antennae) that proves your answer to score a point. Switch roles after ten animals.

> **Scripture.** “The spider taketh hold with her hands, and is in kings’ palaces.” (Proverbs 30:28, KJV)

Agur, the writer of Proverbs 30, lists small creatures that are “exceeding wise” (verse 24). A spider is tiny, yet it climbs and holds on everywhere, even in a king’s palace. Small things can be wise and strong when they use the gifts God gave them.

Practice answers

1. 8 legs and 2 main body parts (the cephalothorax and the abdomen).
2. Because it has no backbone. Its hard skeleton is on the outside (an exoskeleton).
3. Spinnerets are the small silk-making tubes at the back tip of a spider’s abdomen.
4. It is an insect, and yes, it is an arthropod (jointed legs, segmented body and exoskeleton).
5. (a) Near the light: 6 + 5 + 7 = 18 webs. Dark corner: 2 + 3 + 1 = 6 webs. (b) 18 ÷ 6 = 3, so three times as many webs were near the light.
6. She changes the place (sunny or shady). She keeps the same the size of each area, the time of day she counts, the number of days, and the way she counts (only orb webs). She measures the number of webs in each place.
7. It is an arachnid, because it has 8 legs and no antennae. It is not a true spider, because its body parts are joined into one oval and it has no silk glands or spinnerets.
8. A spider’s skeleton is a hard exoskeleton on the outside, and it cannot stretch. To grow, the spider must split out of the old one, swell a little while the new soft skin is still stretchy, and wait for it to harden. It repeats this each time it outgrows its armor.

3.2 Crabs and Lobsters ★

OBJECTIVES

- Name the features of crustaceans (two pairs of antennae, gills, a hard shell and many jointed legs) and identify crabs, lobsters, crayfish, shrimp and pill bugs as crustaceans.
- Explain how a crab or lobster molts and how Réaumur discovered that a crayfish can regrow a lost leg.
- Run a pill bug choice experiment, record the results in a table and bar graph, and name the variable and what was kept the same.

Warm-up. Put on a stiff rain boot or a winter glove that is a little too small. Try to wiggle and stretch. Now imagine your whole skin were a hard shell that never grew. What would you have to do to get bigger? Talk it over, then write your best idea in one sentence.

Video. Coming soon. Lobster and crab molting (shedding the old shell), crustacean body parts, and pill bug behavior for kids: search NOAA Ocean Service, Smithsonian Ocean, Monterey Bay Aquarium and other public aquarium channels, SciShow Kids and underwater nature footage.

KEY TERMS

crustacean
An arthropod with two pairs of antennae and a hard shell, that usually breathes with gills, such as a crab, lobster, shrimp, crayfish or pill bug.

decapod
A crustacean with ten legs (five pairs), like a crab, lobster, shrimp or crayfish. The name means “ten feet.”

carapace
The hard shield that covers the head and chest of a crab, lobster or crayfish.

gills
Feathery body parts that take oxygen out of water.

regenerate
To grow back a lost body part, such as a leg or claw.

CORE IDEAS

The story. In 1712 a young French scientist named René-Antoine Ferchault de Réaumur stood before the Royal Academy of Sciences in Paris with a surprising report about crayfish, the small freshwater cousins of the lobster. Fishermen had long said that a crayfish could grow back a lost leg. Most learned men thought it was a tale. Réaumur decided to find out for himself. He kept live crayfish in water, removed a leg from some of them, and watched

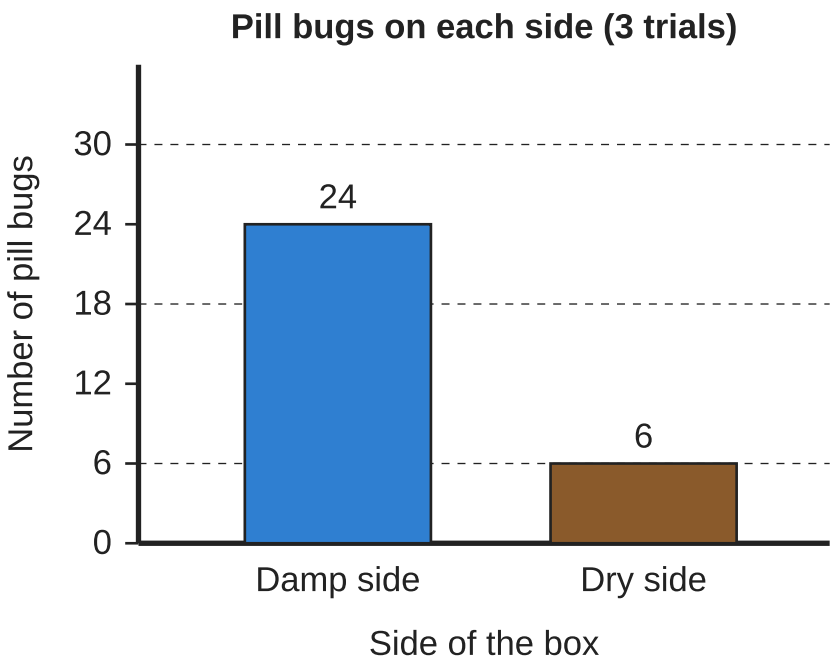
them week after week. Little by little a new leg appeared, small at first and then larger, until it was nearly the size of the old one.

How they figured it out. Réaumur did not just say “it grows back.” He watched exactly *where* a leg broke off, and found that a crayfish’s leg snaps most easily at one particular joint near the body, where the wound closes quickly. He noticed that the new leg grows folded up inside a little sac and shows itself fully when the crayfish sheds its old shell. That is the key: a crab, lobster or crayfish can only **regenerate** a leg or claw a bit at a time, with each molt. A young lobster that loses a claw may need several molts before the new claw matches the old one. Réaumur’s careful notes turned a fisherman’s story into tested science.

The big idea. Crabs and lobsters are arthropods like spiders, with jointed legs and a hard exoskeleton, but they belong to a different class: the **crustaceans**. Crustaceans have **two pairs of antennae**, a shell made extra hard with the same mineral found in chalk, and most of them breathe with **gills**. Crabs, lobsters, shrimp and crayfish are **decapods**, with ten legs. In lobsters and crabs the front pair are big claws. A lobster has a long, muscular tail it can snap under its body to shoot backward away from danger. A crab keeps a short tail folded flat underneath, and most crabs walk sideways. The hard **carapace** covers the head and chest like a shield.

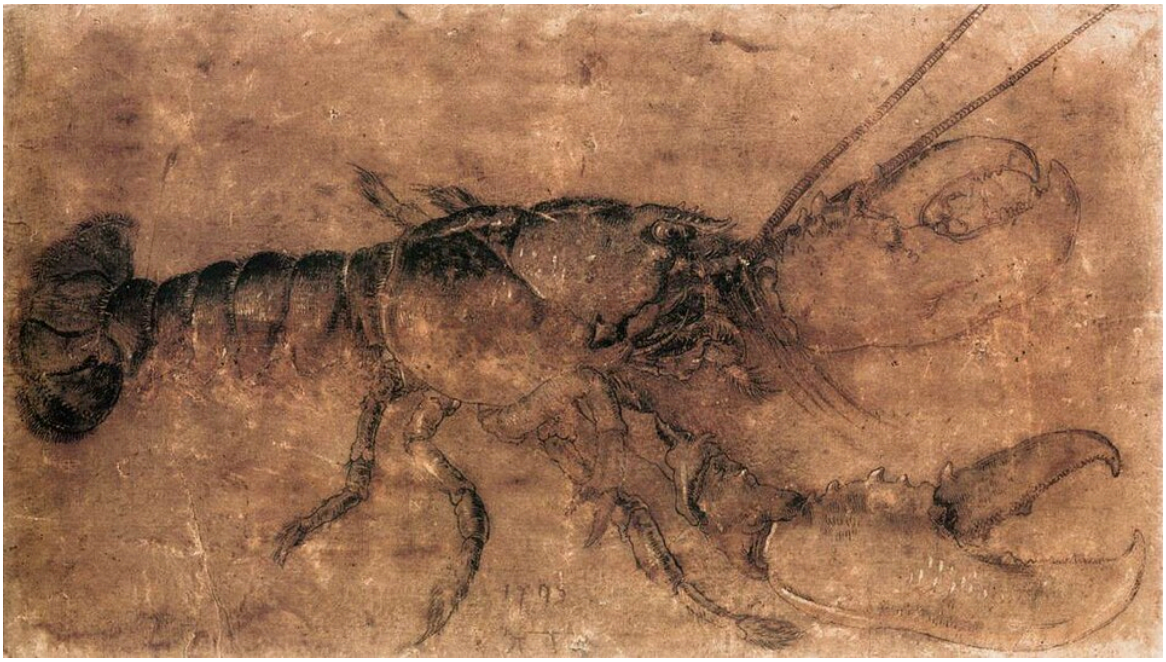
In the world today. To grow, a lobster must **molt**. First a new, soft shell forms underneath the old one. Then the old shell splits open between the carapace and the tail, and the lobster slowly pulls itself out, even its claws and the thin linings of its stomach. It takes in water and swells up, then hides for weeks while the new shell hardens. A young lobster molts many times in its first year. A big, old lobster may molt only every few years. The largest American lobster on record weighed about 20 kilograms (44 pounds). Not all crustaceans live in the sea. The little gray pill bug, or roly-poly, under your garden rocks is a land crustacean with fourteen legs. It breathes with gill-like parts that must stay damp, so it hides in moist, dark places.

God’s handiwork. A living lobster is not red. Most American lobsters are a mottled greenish-brown that blends with the rocky sea floor. The red color is hidden in the shell, held by a protein, and it only shows when the lobster is cooked. The Japanese spider crab can stretch its legs about 3.7 meters (12 feet) from tip to tip, while some crabs are smaller than a pea. The psalmist looked at the sea and wrote that in it are “things creeping innumerable, both small and great beasts” (Psalm 104:25).



Pill bug choice experiment: total pill bugs found on each side after three 10-minute trials.

PICTURE STUDY



Lobster, Albrecht Dürer, 1495 · Pen and ink with watercolor on paper · Kupferstichkabinett (Museum of Prints and Drawings), Berlin

Albrecht Dürer was a German artist from Nuremberg. As a young man of about twenty-four he traveled to Venice, a city on the sea, where he saw sea creatures he had never seen at home. He made careful drawings of a lobster and of a crab, studying them as closely as any naturalist would.

Dürer believed that an artist should learn from nature itself. He drew every joint, spine and plate, so that more than five hundred years later we can still count the parts of his lobster.

Look closely

- Count the walking legs you can see. How many claws are there?
- Find the long antennae. Can you find a second, shorter pair?
- Find the carapace that covers the head and chest. Then count the segments of the tail.
- How did Dürer make the shell look hard and shiny?

Talk about it

1. Which features in the drawing tell you this animal is a crustacean and not an insect or a spider?
2. Why might an artist's careful drawing be useful to a scientist?

> **Safety first.** Handle pill bugs gently, keep them out of the sun, and return them to the same spot within an hour. Wash your hands after touching them or any soil. If you visit a fish market or tide pool, keep fingers away from live crabs' and lobsters' claws, and tell an adult about any seafood allergy before touching shellfish.

EXPERIMENT: THE PILL BUG CHOICE CHAMBER

Pill bugs are crustaceans that live on land. Their gill-like breathing parts must stay moist. Will they choose a damp place or a dry place when they are given a choice?

Write your prediction before you start. Then test it the way Réaumur would: carefully, more than once, and with good notes.

You will need

- 10 pill bugs (roly-polies), gathered from under logs, stones or damp leaves
- A shoebox or a long plastic food container with a lid
- Two paper towels the same size, one damp and one dry
- A clock or timer
- Pencil, notebook and graph paper

Steps

1. Lay the damp paper towel in one half of the box and the dry paper towel in the other half. Draw a pencil line on the box to mark the middle.
2. Write your prediction: Which side will most pill bugs choose?
3. Gently set all 10 pill bugs along the middle line. Close the lid so both sides are equally dark.
4. Wait 10 minutes. Open the lid and quickly count the pill bugs on each side. Record: Trial, Damp side, Dry side.

5. Move the pill bugs back to the middle. Swap the towels so the damp one is on the other end. Run the trial again.
6. Do a third trial. Add up each column.
7. Draw a bar graph with one bar for the damp side and one bar for the dry side.
8. Write your conclusion in two sentences, then return the pill bugs to the place where you found them.

Tips

- What we change: damp or dry. What we keep the same: the box, the darkness, the number of pill bugs, the wait time and the temperature. What we measure: how many pill bugs are on each side.
- Swapping the towels between trials makes sure the pill bugs are choosing dampness, not just one end of the box.
- If a pill bug sits exactly on the line, count it as half for each side, or decide on a rule before you begin and keep it.

Check your work

- I ran three trials and recorded each one in a table.
- I drew a bar graph of my totals.
- I can say what I changed, what I kept the same and what I measured.

NATURE NOTEBOOK

1. Draw a lobster from above. Label the carapace, claws, walking legs, two pairs of antennae and tail. Write how many legs in all.
2. Draw three pictures in a row: a lobster in its old shell, the lobster backing out of the split shell, and the soft lobster beside the empty shell.
3. Sketch a pill bug from the side and from underneath with your hand lens. Count its legs and write the number.

> **From history.** Réaumur went on to become one of the great naturalists of France. In 1730 he made a thermometer with his own temperature scale, on which water froze at 0 and boiled at 80. The Réaumur scale was used in parts of Europe for many years. He also wrote six large volumes about insects, packed with his own observations of bees, caterpillars and wasps.

WORKED EXAMPLES

Example 1. In a pill bug experiment, Josiah ran three 10-minute trials with 10 pill bugs. Trial 1: damp 8, dry 2. Trial 2: damp 7, dry 3. Trial 3: damp 9, dry 1. Find the total for each side and the percent of all the counts that were on the damp side.

(Use the map or drawing "Josiah's totals shown as a bar graph." shown earlier in this lesson.)

1. Damp total: 8 + 7 + 9 = 24.
2. Dry total: 2 + 3 + 1 = 6.
3. All counts: 24 + 6 = 30 (10 pill bugs × 3 trials).
4. Percent on the damp side: 24 ÷ 30 = 0.8, which is 80 percent.

Answer: Damp side 24, dry side 6. 80 percent of the counts were on the damp side, so pill bugs chose damp places.

Example 2. A scientist measured the carapace of a young lobster before and after three molts (sample data): 40 mm, then 46 mm, then 53 mm, then 61 mm. How much did it grow at each molt, and how much in all? Give the final length in centimeters and in inches (1 inch is about 25 mm).

1. Molt 1: 46 − 40 = 6 mm. Molt 2: 53 − 46 = 7 mm. Molt 3: 61 − 53 = 8 mm.
2. Total growth: 6 + 7 + 8 = 21 mm (check: 61 − 40 = 21 mm).
3. 61 mm = 6.1 cm, because 10 mm = 1 cm.
4. 61 ÷ 25 ≈ 2.4 inches.

Answer: It grew 6 mm, 7 mm and 8 mm, for 21 mm in all. The final carapace was 6.1 cm, about 2.4 inches.

PRACTICE

1. EASY Name three features that crabs and lobsters share as crustaceans.
2. EASY How many legs does a decapod have? What does the word mean?
3. EASY What is a carapace?
4. MEDIUM A crayfish lost a claw. Sample data for the new claw's length after each molt: molt 1, 8 mm; molt 2, 15 mm; molt 3, 21 mm; molt 4, 26 mm. The lost claw was 30 mm long. (a) How much did the new claw grow between molt 1 and molt 4? (b) How much shorter than the old claw is it after molt 4?
5. MEDIUM Is a pill bug an insect? Give two reasons.
6. HARD Ruth wants to test whether pill bugs prefer light or dark. What should she change? Name three things she must keep the same. What should she count? Why should she run more than one trial?
7. HARD Why does a lobster hide for several weeks right after it molts?

8. CHALLENGE A spider and a crab are both arthropods. Give one way they are alike and two ways they are different.

COMMON MISTAKES

- Thinking lobsters are red in the sea. Most American lobsters are greenish-brown; the red color shows only after cooking.
- Thinking a crab or lobster is a kind of fish because it is called “shellfish.” It is an invertebrate crustacean with no backbone.
- Thinking a lost claw is gone for good, or that it grows back all at once. It regrows a little with each molt.

> **Make it a game · Crustacean or Not?.** A parent names an animal: crab, spider, shrimp, ant, barnacle, crayfish, pill bug, scorpion, lobster, beetle. Stand up and pinch the air with your hands like claws if it is a crustacean; stay seated if it is not. Give one reason to earn a point. Bonus point if you can also name its class (insect, arachnid or crustacean).

> **Scripture.** “So is this great and wide sea, wherein are things creeping innumerable, both small and great beasts.” (Psalm 104:25, KJV)

The sea is full of creatures that creep: crabs on the bottom, lobsters among the rocks, tiny shrimp by the millions. The psalmist could not count them, and neither can we, but God made and knows every one.

Practice answers

1. Any three: two pairs of antennae; a hard exoskeleton (shell); jointed legs; gills for breathing; a carapace over the head and chest.
2. Ten legs (five pairs). Decapod means “ten feet.”
3. The hard shield covering the head and chest of a crab, lobster or crayfish.
4. (a) 26 − 8 = 18 mm. (b) 30 − 26 = 4 mm shorter.
5. No. It is a crustacean. It has 14 legs, not 6, and it breathes with gill-like parts that must stay damp. (It also has two pairs of antennae, though one pair is very tiny.)
6. Change: one side lit, one side covered dark. Keep the same: the dampness of both sides, the temperature, the number of pill bugs, the wait time and the box. Count: the pill bugs on each side after the wait. More trials (and swapping sides) make sure the result was not luck or a preference for one end of the box.
7. Its new shell is soft at first, so it cannot protect the lobster from fish, crabs and other lobsters. It hides until the shell hardens.
8. Alike: both have jointed legs, a segmented body and a hard exoskeleton, and both must molt to grow. Different: a crab has two pairs of antennae, a spider has none; a crab (a decapod) has 10 legs, a spider has 8; most crabs breathe with gills in water, a spider breathes air.

3.3 Snails

OBJECTIVES

- Explain what a mollusk is and name the main parts of a land snail: shell, mantle, foot, tentacles, eyes, breathing pore and radula.
- Describe how a snail survives dry weather by sealing its shell, using the true story of the British Museum desert snail.
- Measure a snail's speed in centimeters per minute and run a fair food-choice test, naming what was changed and what was kept the same.

Warm-up. Lay a piece of clear plastic wrap or a clean glass dish on the table. Smear a thin line of water on it with your finger, and a thin line of hair gel or dish soap beside it. Slide a small coin along each line. Which is easier to push through? A snail crawls on a ribbon of slime it makes itself. Guess why slime might work better than plain water.

Video. Coming soon. Garden snail crawling on glass seen from underneath (the moving foot), snail eye tentacles and radula for kids: search Smithsonian, SciShow Kids, Homeschool Pop (Alternate), Moody Science classics and close-up nature footage of land snails.

KEY TERMS

mollusk
A soft-bodied invertebrate, usually with a muscular foot and often a shell, such as a snail, slug, clam, oyster, squid or octopus.

gastropod
The mollusk group that includes snails and slugs. The name means "stomach-foot," because the animal seems to crawl on its belly.

mantle
A thin layer of the body that covers a mollusk's organs and makes its shell.

radula
A ribbon-like tongue covered with rows of tiny teeth that a snail uses to scrape up food.

tentacle
A soft feeler on a snail's head. A land snail's upper pair carries its eyes; the lower pair feels and smells.

estivation
A deep rest some animals take during hot, dry weather, like hibernation in summer.

CORE IDEAS

The story. In 1846 a small, pale snail from the deserts of Egypt arrived at the British Museum in London. It looked dry and dead, so a museum worker glued its shell to a card and

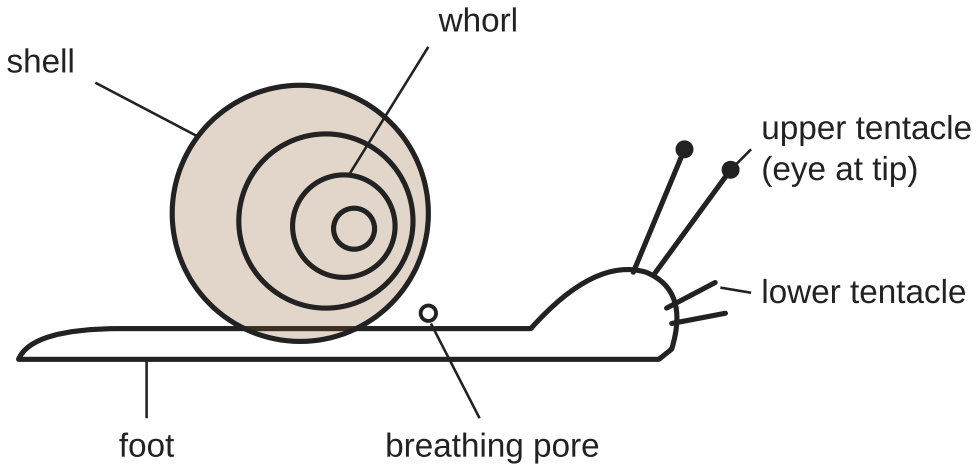
put it in the collection as a specimen. About four years later, in 1850, someone noticed signs that the animal inside might still be alive. The snail was soaked in warm water, and to everyone's amazement it slowly crept out of its shell, alive. The naturalist Samuel Woodward, who worked at the museum, told the story in his book on mollusks, and people have repeated it ever since.

How they figured it out. Naturalists who kept snails noticed what the desert snail had done. When the weather turns hot and dry, a land snail pulls its whole body into its shell and seals the opening with a thin, papery door of dried slime. Inside, its heartbeat and breathing slow way down, and it uses almost no energy. This deep summer rest is called **estivation**. A snail in estivation can last a long time without food or water. When rain comes, it wakes, pushes the door aside and goes looking for something to eat. Try it yourself: a snail that has sealed itself up in a dry jar will often come out within minutes of a gentle sprinkle of water.

The big idea. A snail is a **mollusk**, a soft-bodied invertebrate. Snails and slugs are **gastropods**, meaning "stomach-foot," because they glide on one broad muscular foot under the body. Little waves of muscle ripple along the foot from back to front, pushing the snail over a ribbon of slime that it makes as it goes. The slime lets it crawl up walls and even upside down under a leaf. A land snail has two pairs of **tentacles**. The upper, longer pair carry its eyes at their tips, and the lower, shorter pair feel and smell the ground. It breathes air through a hole on its right side called the breathing pore, and it eats with a **radula**, a tongue covered with thousands of tiny teeth that rasp leaves like a file.

In the world today. The shell is made by the **mantle**, a thin layer of the body that lines it. A snail never leaves its shell, because its body is attached inside. As the snail grows, the mantle adds new shell at the lip of the opening, so the shell grows in a widening spiral of turns called whorls. The tiny tip of the spiral is the part the snail made when it was a baby. Most snails coil to the right: hold a shell with the tip up and the opening facing you, and the opening is usually on your right. Mollusks are a huge group. Besides snails and slugs, it includes clams, oysters and mussels with two shells, and the octopus and squid, which have no outer shell at all.

God's handiwork. A snail's shell is a lifelong record. Every ridge and growth line marks a time the snail grew, so a careful observer can read its history from tip to lip. The spiral is so beautiful that artists, builders and shell collectors have admired it for thousands of years. "He hath made every thing beautiful in his time" (Ecclesiastes 3:11), even a creature we pass on the sidewalk after rain.



Parts of a land snail. The eyes are at the tips of the upper tentacles.

PICTURE STUDY



The Shell (Conus marmoreus), Rembrandt van Rijn, 1650 · Etching, drypoint and engraving · Impressions are kept in many museums, including the Rijksmuseum in Amsterdam

Rembrandt, the great Dutch painter, also made prints by scratching lines into a copper plate, inking it and pressing it onto paper. In 1650 he made a print of a single shell (Rembrandt collected shells himself): a marbled cone shell, the shell of a sea snail from the warm waters of the Indian and Pacific Oceans. Many Dutch people of his day collected seashells brought home by trading ships.

Rembrandt drew the shell on the plate just as it looked to him. But a print always comes out backward from the plate, like a stamp. So in his print the spiral turns the wrong way, the

opposite of every real shell of that kind. Shell collectors have noticed this mirror-image shell ever since.

Look closely

- Find the spiral tip of the shell. Can you follow the turns (the whorls) around it?
- Look at the net of light and dark patches. How did Rembrandt make dark areas using only lines?
- Find the long, narrow opening of the shell, where the snail's foot once came out.
- Look at the background. Why do you think he made it so dark?

Talk about it

1. Most snail shells coil to the right. Using what you learned about prints, explain why Rembrandt's shell coils the other way.
2. Why do you think an artist would spend so much time on one small shell?

> **Safety first.** Snails and slugs can carry germs and tiny worms, so wear gloves or wash your hands with soap after touching them, and never put a snail, or fingers that touched one, near your mouth. Never put salt on a snail. Keep snails damp and shaded, and return them to the exact place you found them; do not carry snails from one area to another.

EXPERIMENT: THE SNAIL CAFÉ: A FOOD-CHOICE TEST

Snails are picky eaters. In this experiment you will offer garden snails three foods and measure which they eat most.

Question: Which food do garden snails eat the most of: lettuce, cucumber or carrot? Write your prediction first.

You will need

- 3 to 5 garden snails, gathered on a damp evening or after rain
- A clear plastic box with air holes in the lid
- A damp paper towel
- Lettuce, cucumber and carrot, each cut into a 3 cm by 3 cm square (about 1¼ inches) and the same thickness
- Graph paper with 1 cm squares
- Ruler, timer, pencil and notebook

Steps

1. Trace each food square onto graph paper so you know its starting size: 9 squares each.
2. Put the damp paper towel in the box. Place the three foods at equal distances from the center.
3. Set the snails in the center. Close the lid and put the box in a cool, shady place overnight.

4. In the morning, lay each food piece on the graph paper and count how many squares were eaten. Count a half-eaten square as one half.
5. Record: Food, Squares eaten. Then draw a bar graph.
6. Bonus speed test: put one snail at the start of a 30 cm line on a damp tray. Time how long it takes to crawl to the end, and find its speed in centimeters per minute.
7. Write your conclusion in two sentences, and return the snails to where you found them.

Tips

- What we change: the kind of food. What we keep the same: the size of each piece, how fresh it is, its distance from the snails, the box and the time. What we measure: squares eaten.
- Use fresh food cut at the same time, so one piece is not drier than another.
- Watch a snail crawl on the underside of clear glass to see the waves moving along its foot.

Check your work

- I measured food eaten by counting squares on graph paper.
- I made a table and a bar graph.
- I named what I changed, what I kept the same and what I measured.

NATURE NOTEBOOK

1. Draw a land snail from the side, life-size and then twice as large. Label the shell, whorls, foot, upper and lower tentacles, eyes and breathing pore.
2. Let a snail crawl across a sheet of dark paper and sketch the shiny slime trail it leaves. Measure the trail in centimeters.
3. Find two empty snail shells. Draw each one with the tip up and opening facing you. Which way does each coil?

> **From history.** One of the first great books of shells was made by an English doctor, Martin Lister, and his daughters. Between 1685 and 1692 Lister published *Historiae Conchyliorum*, a history of shells with more than a thousand pictures. His daughters Susanna and Anna drew the shells and engraved many of the copper plates, careful work that took them years.

WORKED EXAMPLES

Example 1. A garden snail crawled 24 cm in 4 minutes. What was its speed in centimeters per minute? At that speed, about how long would it take to crawl 1 meter? How many inches did it crawl (1 inch = 2.54 cm)?

(Use the map or drawing "The snail moves by waves of muscle along its foot." shown earlier in this lesson.)

1. Speed = distance ÷ time = 24 cm ÷ 4 min = 6 cm per minute.
2. 1 meter = 100 cm. 100 ÷ 6 ≈ 16.7, so about 17 minutes.
3. 24 ÷ 2.54 ≈ 9.4 inches.

Answer: 6 cm per minute; about 17 minutes to crawl 1 meter; about 9.4 inches in 4 minutes.

Example 2. In a snail café test, each food started as 9 graph-paper squares. In the morning the snails had eaten: lettuce 6 squares, cucumber 4 squares, carrot 1 square. Which food did they eat most? What fraction of the lettuce did they eat? How many squares were eaten in all?

1. Compare: 6 > 4 > 1, so lettuce was eaten most and carrot least.
2. Fraction of lettuce eaten: 6 out of 9 = 6/9 = 2/3.
3. Total eaten: 6 + 4 + 1 = 11 squares.

Answer: Lettuce was eaten most; they ate 2/3 of the lettuce; 11 squares were eaten in all.

PRACTICE

1. EASY To which big group of invertebrates do snails belong? Name two other animals in that group.
2. EASY Where are a land snail's eyes?
3. EASY What is a radula, and what does a snail use it for?
4. MEDIUM Three snails raced for 5 minutes. Snail A crawled 30 cm, Snail B 20 cm and Snail C 45 cm. Find each snail's speed in centimeters per minute. Which was fastest?
5. MEDIUM Why does a land snail seal the opening of its shell during hot, dry weather?
6. HARD Caleb wants to know if snails prefer a shady side or a sunny side of a box. What should he change? Name three things to keep the same. What should he record?
7. HARD A hermit crab lives in a snail shell. How is the hermit crab's use of a shell different from a snail's?
8. CHALLENGE A snail shell has 5 whorls. Explain which part of the shell is oldest and which is newest, and why the snail never needs to move to a new shell.

COMMON MISTAKES

- Thinking a snail can crawl out of its shell and find a bigger one. A snail is attached to its shell and makes it bigger as it grows; it is hermit crabs that switch shells.
- Thinking a snail's eyes are on its face like ours. A land snail's eyes are at the tips of its upper tentacles.
- Thinking snails are insects or worms. Snails are mollusks, with a soft body, a mantle and a muscular foot.

Make it a game · Snail Says. Play like Simon Says, but every move is a snail move. "Snail says raise your eye tentacles" (point both index fingers up from your head). "Snail says feel the ground" (two short fingers down by your chin). "Snail says estivate" (curl up tight). "Snail says scrape with your radula" (pretend to file a leaf). If the leader leaves off "Snail says," anyone who moves must name one snail part to stay in.

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 snail shell grows one turn at a time, and each stage has its own beauty. We can study God's works all our lives and still find more to wonder at.

Practice answers

1. Mollusks (snails are gastropods). Other mollusks: slugs, clams, oysters, mussels, squid, octopus (any two).
2. At the tips of its upper, longer pair of tentacles.
3. A tongue covered with rows of tiny teeth. The snail uses it to scrape and rasp up food such as leaves.
4. A: 30 ÷ 5 = 6 cm per minute. B: 20 ÷ 5 = 4 cm per minute. C: 45 ÷ 5 = 9 cm per minute. Snail C was fastest.
5. To keep from drying out. It closes the opening with a door of dried slime and rests (estivation), using very little energy until rain returns.
6. Change: one half of the box shaded, one half in light. Keep the same: dampness on both sides, food (none, or the same on both sides), the number of snails, the starting spot in the middle and the waiting time. Record: how many snails are on each side after the wait, over several trials.
7. The snail makes its own shell with its mantle, is attached to it and never leaves it. The hermit crab is a crustacean that borrows an empty snail shell and moves into a bigger one as it grows.
8. The tiny tip of the spiral is oldest; the snail made it as a baby. The lip at the opening is newest, because the mantle adds new shell there as the snail grows. The shell grows along with the snail, so it never has to move out.

3.4 Starfish (Sea Stars)

OBJECTIVES

- Explain why a starfish is an invertebrate echinoderm and not a fish, and name some of its relatives.
- Describe radial symmetry, tube feet, eyespots and how a sea star eats a clam and regrows a lost arm.
- Test how a suction-cup “tube foot” holds a load, counting pennies and naming the variable and what was kept the same.

Warm-up. Press a small suction cup (or the bottom of a soft plastic bottle cap) onto a smooth, clean window, first dry and then with a drop of water. Which one grips better? A sea star walks and pulls on hundreds of tiny tube feet. Guess how many tube feet you think a sea star has, and write your guess down to check at the end of the lesson.

Video. Coming soon. Sea star tube feet moving in a tide pool, a sea star opening a clam, and a sea star regrowing an arm, for kids: search NOAA Ocean Service, Smithsonian Ocean, Monterey Bay Aquarium and other public aquarium channels, SciShow Kids and underwater nature footage.

KEY TERMS

echinoderm
A sea animal with spiny or bumpy skin, tube feet and body parts arranged around a center, such as a sea star, sea urchin, sand dollar or sea cucumber. The name means “spiny skin.”

radial symmetry
A body plan with matching parts arranged around a center, like the spokes of a wheel or the slices of a pie.

tube feet
Hundreds of tiny, soft, water-filled tubes under a sea star’s arms that it uses to walk, grip and pull.

water vascular system
A set of water-filled canals inside an echinoderm that pushes water into the tube feet to move them.

eyespot
A simple eye at the tip of each sea star arm that can tell light from dark and see large shapes.

CORE IDEAS

The story. In 1841 a young naturalist from the Isle of Man named Edward Forbes published *A History of British Starfishes*. Forbes loved to drag a small iron dredge along the sea floor

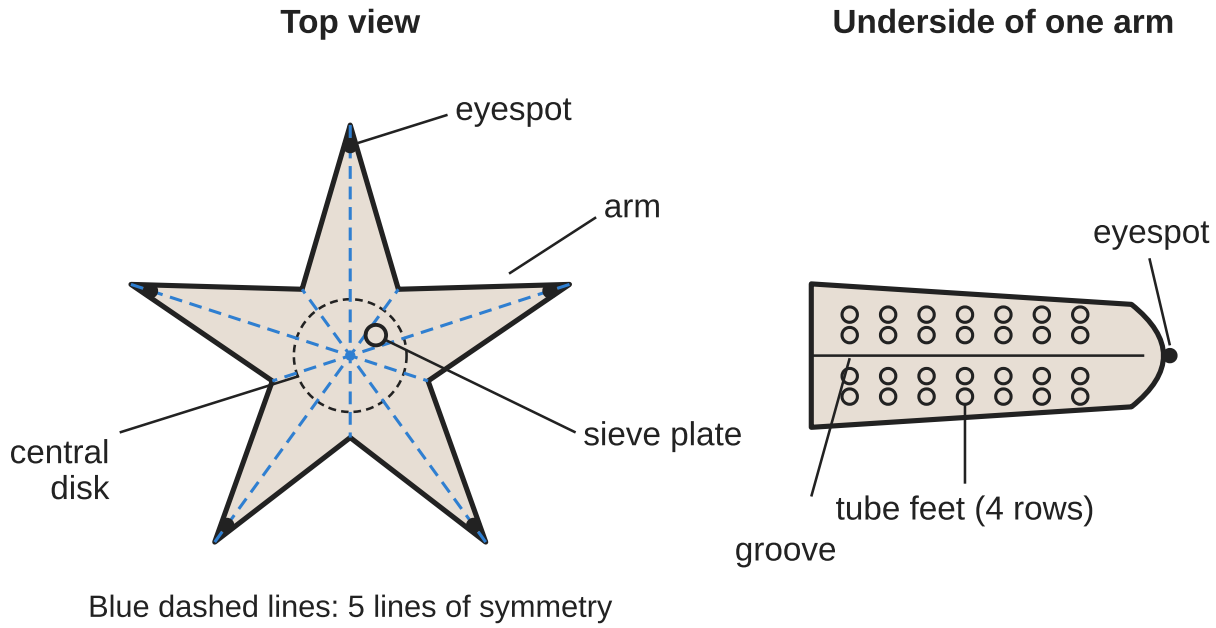
from a boat and sort through whatever came up. One day the dredge brought up a large, long-armed starfish of a kind called *Luidia*, which he had long wanted to keep whole for his collection. Forbes knew that this kind of starfish often breaks apart when it is caught, so he plunged it into a bucket of cold fresh water, hoping to keep it still and whole. Instead, the shock made it throw off its arms and fall to pieces. He saved only part of one arm and joked that the little eye on its tip seemed to wink at him.

How they figured it out. Forbes and other naturalists kept sea stars in pools and jars and watched them closely. They learned that a sea star can drop an arm to escape a crab or a gull, and then **regenerate** it, slowly growing a new one over many months. A few kinds can even grow a whole new body from one arm, as long as it keeps part of the center. Turning a sea star over, they saw hundreds of tiny **tube feet** waving in grooves under each arm. Water enters through a small sieve plate on top of the body and flows through a set of canals, the **water vascular system**, that squeeze water into the tube feet to stretch them out and move them. Each tube foot grips like a little suction cup with sticky help.

The big idea. A starfish is not a fish at all. It has no backbone, no gills and no fins, so many scientists prefer the name **sea star**. It belongs to the **echinoderms**, “spiny skin” animals, along with sea urchins, sand dollars, brittle stars and sea cucumbers. Under its skin are many small, hard plates, but there is no backbone, so it is an invertebrate. A sea star has **radial symmetry**: its arms are arranged around a center, usually five, though the sunflower sea star of the Pacific may have up to 24 arms and grow about 1 meter (3 feet) across. It has no brain. Instead, a ring of nerves circles its mouth, with a nerve running down each arm, and an **eyespot** at each arm tip tells light from dark.

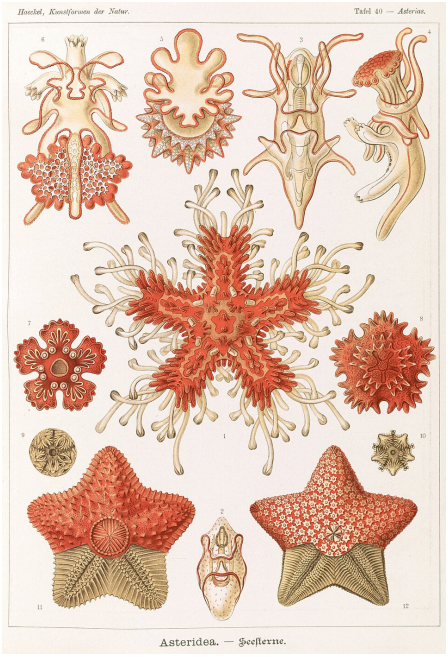
Try it and see. A sea star’s mouth is in the middle of its underside. When it finds a clam or mussel, it wraps its arms around the two shells and pulls with its tube feet, steadily, for a long time, until the clam’s muscle tires and the shells open just a crack. Then the sea star does something amazing: it pushes its own stomach out through its mouth, slips it through a gap as thin as a sheet of paper, and digests the clam inside its own shell. If you visit a rocky shore at low tide, look in tide pools for sea stars clinging to the rocks. Touch one gently with a wet finger, if an adult says it is safe, and feel the rough, bumpy skin, but never pull one off the rock.

God’s handiwork. Linnaeus named the common starfish of European shores *Asterias rubens*, “the red star.” A sea star has no brain, yet its hundreds of feet work together to carry it over rocks, and its body can heal and regrow what it loses. As Job says, “speak to the earth, and it shall teach thee: and the fishes of the sea shall declare unto thee” (Job 12:8).



A sea star from above (with its 5 lines of symmetry dashed) and the underside of one arm with its tube feet.

PICTURE STUDY



Asteridea (Sea Stars), a plate from Kunstformen der Natur (Art Forms in Nature), Ernst Haeckel, 1899–1904 · Color lithograph · Published in Leipzig, Germany; copies are kept in many libraries

Ernst Haeckel was a German zoologist who spent years drawing sea creatures under the microscope and from life. Between 1899 and 1904 he published *Kunstformen der Natur*, "Art Forms in Nature," a set of one hundred printed plates showing jellyfish, shells, sea stars, tiny one-celled creatures and much more.

On this plate Haeckel arranged many kinds of sea stars into a balanced pattern. He loved symmetry, and sea stars, with their arms arranged around a center, were perfect for showing

it.

Look closely

- Find a sea star with five arms. Then find one with more than five. How many arms does it have?
- Find a sea star shown from underneath. Can you see the grooves where the tube feet are?
- Look at the skin of the sea stars. Is it smooth, bumpy or spiny?
- How did Haeckel arrange the whole page? Where is its center?

Talk about it

1. How many lines of symmetry does a five-armed sea star have? Can you find them in the picture?
2. Haeckel’s pictures are science and art at once. What do you think a scientist can learn from drawing a creature carefully?

> **Safety first.** Tide pools have slippery rocks and sudden waves, so go only with an adult, check the tide times, and never turn your back on the sea. Do not pull sea stars or other animals off the rocks; touch gently with one wet finger or just look. Keep animals in the water. Suction cups should be used only on smooth, unbreakable surfaces, with pennies kept away from small children.

EXPERIMENT: TUBE FOOT TEST: WET OR DRY?

A sea star’s tube feet grip rocks and pull clams open. You will use a suction cup as a model tube foot and test how much weight it can hold.

Question: Does a suction cup hold more pennies when its rim is wet or when it is dry? Write your prediction first.

You will need

- One small suction cup with a hook (from a hardware or craft store)
- A smooth, clean surface: a glazed tile, a mirror or the side of a refrigerator
- A small zip-top sandwich bag with a paper clip through the top to hang it
- A jar of pennies (a U.S. penny made since 1983 has a mass of 2.5 grams)
- A small cup of water, a towel, pencil and notebook

Steps

1. Make a table with three columns: Trial, Dry (pennies held), Wet (pennies held).
2. Dry trial: wipe the cup and surface dry. Press the suction cup firmly in place and hang the bag on the hook.
3. Add pennies one at a time, gently. Count until the cup lets go. Record the last number of pennies it held.

4. Wet trial: dip the rim of the suction cup in water, press it on the same spot just as firmly, and repeat.
5. Do three dry trials and three wet trials. Find the average for each.
6. Change your average number of pennies to grams by multiplying by 2.5.
7. Bonus: hang the bag from a pencil held by two suction cups side by side. Do two “tube feet” hold about twice as much?
8. Write your conclusion in two sentences. How does this help explain why a sea star works best in water and uses many tube feet at once?

Tips

- What we change: wet or dry. What we keep the same: the cup, the surface, the spot, how hard you press, the bag and how gently you add pennies. What we measure: the number of pennies held.
- Pressing harder in one trial than another would make the test unfair, so press the same way each time.
- Real tube feet use a sticky substance as well as suction, and a sea star uses hundreds of them at once.

Check your work

- I ran three wet and three dry trials and found the averages.
- I changed pennies to grams.
- I named what I changed, what I kept the same and what I measured.

NATURE NOTEBOOK

1. Draw a sea star from above and from below. Label the arms, central disk, eyespots, mouth and tube feet. Draw its lines of symmetry with a ruler.
2. Draw three stages of a sea star regrowing a lost arm: just lost, half grown and fully grown.
3. Draw a sea star wrapped around a clam. Use arrows to show which way the tube feet pull.

> **From history.** Edward Forbes dredged so much in shallow seas that he came to believe almost nothing could live in the deep ocean below about 550 meters (300 fathoms, or about 1,800 feet). Later sailors and scientists proved him wrong. Telegraph cables hauled up from the deep sea came up with animals attached, and the British ship HMS *Challenger*, on a voyage from 1872 to 1876, dredged living creatures, including sea stars, from the deepest waters it could reach. Good scientists change their minds when new observations show they were mistaken.

WORKED EXAMPLES

Example 1. How many lines of symmetry does a regular five-armed sea star have? How many would a regular sunflower sea star with 20 arms have?

(Use the map or drawing "Each dashed line runs from an arm tip through the center to the opposite notch." shown earlier in this lesson.)

1. A line of symmetry cuts a shape into two mirror-image halves.
2. In a five-armed sea star, a line can run from the tip of each arm through the center to the notch between the two opposite arms. That gives one line for each arm.
3. Five arms give 5 lines of symmetry.
4. For a regular sea star with 20 arms, each line through the center passes through two opposite arms, so 20 arms make 20 ÷ 2 = 10 lines through arm tips, plus 10 lines through the notches between arms: 20 lines in all.

Answer: 5 lines for a five-armed sea star; 20 lines for a regular 20-armed sea star (one line for each arm).

Example 2. A sea star has 5 arms. Under each arm are 4 rows of tube feet, and each row has 60 tube feet (sample numbers). How many tube feet does one arm have? How many in all?

1. One arm: 4 rows × 60 tube feet = 240 tube feet.
2. Whole sea star: 5 arms × 240 = 1,200 tube feet.
3. Check: 4 × 60 × 5 = 20 × 60 = 1,200.

Answer: 240 tube feet per arm and 1,200 tube feet in all. Compare this with your guess from the warm-up.

PRACTICE

1. EASY Is a starfish a fish? Give two reasons, and give the name many scientists prefer.
2. EASY What does a sea star use its tube feet for?
3. EASY Where are a sea star's eyespots, and what can they sense?
4. MEDIUM Sample data for a sea star regrowing an arm. Month 0: 0 cm. Month 2: 1.5 cm. Month 4: 3.0 cm. Month 6: 4.5 cm. Month 8: 6.0 cm. (a) How much does the arm grow every 2 months? (b) If it keeps growing at the same rate, in which month will it reach its full length of 9 cm?
5. MEDIUM A regular sea star has 6 arms. How many lines of symmetry does it have? What kind of symmetry is this?
6. HARD Grace wants to test whether more suction cups (model tube feet) can hold more pennies. Plan her experiment. What will she change? Name three things to keep the

same. What will she measure?

7. HARD Explain in order how a sea star eats a clam.
8. CHALLENGE Sort these four invertebrates into their groups: spider, crab, snail, sea star. Which two are most closely alike, and why?

COMMON MISTAKES

- Thinking a starfish is a fish. It is an invertebrate echinoderm with no backbone, gills or fins.
- Thinking every sea star has five arms. Five is common, but some kinds have many more, like the sunflower sea star with up to 24.
- Thinking a sea star has no eyes. It has a simple eyespot at the tip of each arm that senses light and dark.

Make it a game · Sea Star Says Regrow. Stand with your arms and legs spread like a five-armed sea star (your head is the fifth arm). A parent calls out an action: “a gull took an arm!” (tuck one arm behind your back), “regrow!” (slowly stretch it out again), “find a clam!” (wrap your arms around a pillow and squeeze), “low tide!” (hold still and cling to the floor). Then the parent asks one question about sea stars; a right answer earns a point and a turn as the caller.

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

Job tells us that the creatures themselves can teach us about God’s wisdom and power. A sea star in a tide pool, with its hundreds of feet and its arms that grow back, has much to teach anyone who looks closely.

Practice answers

1. No. It has no backbone, no gills and no fins (any two). Scientists often call it a sea star.
2. To walk, to grip rocks and to pull open clams and mussels.
3. At the tip of each arm. They can tell light from dark and see large shapes.
4. (a) 1.5 cm every 2 months. (b) Month 10: 7.5 cm; month 12: 9.0 cm. It reaches 9 cm at month 12.
5. 6 lines of symmetry. It is radial symmetry, with parts arranged around a center.
6. Change: the number of suction cups (for example 1, 2, then 3). Keep the same: the size and kind of cup, the surface, wet or dry rims, how hard she presses and how gently she adds pennies. Measure: the number of pennies held before the cups let go, over several trials.
7. It wraps its arms around the clam, grips both shells with its tube feet and pulls steadily until the clam’s muscle tires and the shells open a crack. Then it pushes its stomach out through its mouth, slips it into the clam’s shell and digests the clam there.

8. Spider: arthropod (arachnid). Crab: arthropod (crustacean). Snail: mollusk (gastropod). Sea star: echinoderm. The spider and crab are most alike, because both are arthropods with jointed legs, segmented bodies and exoskeletons that they molt.

Unit 3 review

Answer each question. Show your work for calculations and use complete sentences for explanations. The quiz is worth 50 points.

1. (5 pts) What is an invertebrate? Name the three things all arthropods share.
2. (5 pts) A bug has 3 body parts, 6 legs and 2 antennae. Another has 2 body parts, 8 legs and no antennae. Classify each one.
3. (5 pts) Fabre saw a garden spider hiding in a leaf with one leg on a single line of silk. What was the line for?
4. (5 pts) Name two features of crustaceans and three animals that are crustaceans.
5. (5 pts) Describe what happens when a lobster molts, and explain why it hides afterward.
6. (5 pts) In a choice chamber, 10 pill bugs were tested 3 times. Damp side: 9, 8, 7. Dry side: 1, 2, 3. Find each total. What percent of the counts were on the damp side? What is the variable in this experiment?
7. (5 pts) Name four parts of a land snail and tell what each one does.
8. (5 pts) A snail crawled 35 cm in 5 minutes. What was its speed in centimeters per minute? How far would it go in 12 minutes at the same speed?
9. (5 pts) Why is a starfish not a fish? What group does it belong to, and what are two of its relatives?
10. (5 pts) A five-armed sea star has 4 rows of 50 tube feet under each arm. How many tube feet does it have in all? How many lines of symmetry does it have?

Unit project: my invertebrate field notebook

Make a four-page field notebook, one page for each invertebrate in this unit: a spider, a crab or lobster (or a pill bug, its land cousin), a snail and a sea star. On each page draw the animal carefully from life or from a good photograph, label at least five body parts, write its group (arachnid, crustacean, mollusk or echinoderm) and list three facts in your own words. Include the data table and graph from one of your experiments (web count, pill bug choice chamber, snail café or tube foot test), and finish with a simple dichotomous key that sorts all four animals.

- **Accurate drawings**: Each animal is drawn carefully with the correct number of legs, arms or tentacles, and at least five parts are labeled correctly.
- **Classification**: Each animal is placed in the right group, and the dichotomous key correctly sorts all four animals using clues such as legs, antennae, shells and symmetry.
- **Experiment record**: The table and graph are complete and labeled, and a short paragraph names what was changed, what was kept the same and what was measured.
- **Care and wonder**: The notebook is neat and colorful, the facts are written in the student’s own words, and the student treated every living animal gently and returned it safely.

Answer key

1. An invertebrate is an animal without a backbone. All arthropods have jointed legs, a segmented body and a hard exoskeleton.
2. The first is an insect. The second is an arachnid, such as a spider.
3. It was a signal line, a “telegraph wire.” When an insect struggled in the web, the line shook and told the hidden spider to rush out.
4. Features (any two): two pairs of antennae, a hard exoskeleton, gills, a carapace, many jointed legs. Animals (any three): crab, lobster, shrimp, crayfish, pill bug, barnacle.
5. A new soft shell forms under the old one. The old shell splits between the carapace and the tail, and the lobster pulls itself out. It takes in water and swells, then hides until the new soft shell hardens, because it cannot protect itself while soft.
6. Damp: 9 + 8 + 7 = 24. Dry: 1 + 2 + 3 = 6. 24 out of 30 = 80 percent on the damp side. The variable is damp or dry.
7. Any four: shell (protects the body), mantle (makes the shell), foot (crawls on waves of muscle over slime), upper tentacles (carry the eyes), lower tentacles (feel and smell), breathing pore (lets air in), radula (scrapes food).
8. 35 ÷ 5 = 7 cm per minute. 7 × 12 = 84 cm in 12 minutes.
9. It has no backbone, gills or fins. It is an echinoderm (“spiny skin”). Relatives (any two): sea urchin, sand dollar, brittle star, sea cucumber.
10. 4 × 50 = 200 per arm; 200 × 5 = 1,000 tube feet. It has 5 lines of symmetry (radial symmetry).

UNIT 4

Birds in Depth

On the fifth day of creation God made “every winged fowl after his kind” (Genesis 1:21), and birds are still the wild animals children see most often: at the feeder, on the lawn, in the sky. In this unit you will study the class of birds the way real ornithologists do. You will learn the traits every bird shares, read a bird’s diet from its beak and its way of life from its feet, count birds with the same rules scientists use, and draw birds carefully enough that someone else could name them from your picture.

You will follow John James Audubon across the ocean with his portfolio of life-size paintings, watch Peter and Rosemary Grant measure finch beaks on a tiny Galápagos island in a year with almost no rain, join Frank Chapman’s first Christmas Bird Count in 1900, and learn the arrows-and-field-marks trick that made Roger Tory Peterson’s field guide famous. Along the way you will run fair tests with beak tools and bird counts, find averages, and read bar graphs. By the end you will have the beginnings of your own bird book.

BEFORE YOU BEGIN

- Knows the five classes of vertebrates and the meaning of warm-blooded (Unit 2)
- Can follow a simple dichotomous key (Unit 1)
- Can measure in centimeters and millimeters with a ruler
- Can add, subtract and divide two-digit numbers to find an average

MASTERY CHECKLIST

- I can name the traits that make an animal a bird and tell the story of Audubon’s *Birds of America*.
- I can match a bird’s beak and feet to what it eats and how it lives.
- I can explain how the Grants’ finch measurements showed variation within a kind.
- I can do a 15-minute bird count using the “most seen at one time” rule and make a bar graph of my data.
- I can draw a bird with correct proportions, label its parts and point out its field marks.
- I can plan a fair test: change one thing, keep the rest the same, and measure the result.

OPTIONAL BOOKS AND RESOURCES

- **All About Birds, from the Cornell Lab of Ornithology** (https://www.allaboutbirds.org/): Free. Photos, sounds, lengths and field marks for North American birds. Use it to identify the birds in your counts and to check sizes for your drawings (Lessons 4.3 and 4.4).
- **Great Backyard Bird Count** (https://www.birdcount.org/): Free. Every February, families anywhere in the world count birds for at least 15 minutes and send in their lists. A parent should help with sign-up and submitting data (Lesson 4.3).

- **National Audubon Society** (https://www.audubon.org/): Free. The society is named for John James Audubon; its website lets you view and read about all 435 plates of *The Birds of America* (Lessons 4.1 and 4.2).

4.1 Audubon's Birds of America (1827–1838) ★

OBJECTIVES

- Tell the story of John James Audubon and how he made *The Birds of America*, with its 435 life-size plates printed from 1827 to 1838.
- Name the traits that put an animal in the class of birds (Aves) and use them to sort animals into birds and not-birds.
- Use measuring and simple scale to compare a bird's real size with a picture of it, as Audubon did.

Warm-up. Lay your hand flat on a sheet of paper and trace around it. With a ruler, measure your real hand from the wrist crease to the tip of your middle finger, then measure the tracing the same way. Are they the same? Then your tracing is *life-size*. Now guess: how big would a page have to be to paint a wild turkey life-size? Write your guess down and check it at the end of the lesson.

Video. Coming soon. John James Audubon and The Birds of America for kids: search Smithsonian, National Audubon Society, the New-York Historical Society, natural-history library and museum channels, and nature footage of wild turkeys and songbirds.

KEY TERMS

naturalist
A person who studies living things by watching, collecting, drawing and recording them carefully.

ornithologist
A scientist who studies birds. The study of birds is called ornithology.

plate
A full-page printed picture in a book. In Audubon's time a plate was printed from a picture cut into a sheet of copper.

life-size
Drawn at the same size as the real thing, so a 25 cm (10 in) bird is 25 cm (10 in) long on the page.

feather
A light, strong body covering made of keratin, the same material as your fingernails. Only birds have feathers.

CORE IDEAS

The story. In July 1826 a forty-one-year-old American woodsman stepped off a ship at Liverpool, England, carrying a heavy portfolio of paintings. His name was John James Audubon. He had been born in 1785 on the island of Saint-Domingue (today Haiti), grew up

in France, and came to his father's farm, Mill Grove, near Philadelphia, when he was eighteen. For years he had tramped the forests, swamps and riverbanks of America with a gun, a sketchbook and a box of watercolors, trying to paint every kind of bird in the country. His stores in Kentucky had failed. Once he opened a box and found that rats had chewed up about two hundred of his drawings, so he went back to the woods and drew them all again. His wife, Lucy, taught school to support the family while he floated down the Ohio and Mississippi rivers drawing birds. No printer in America would take on a book as big as he dreamed of, so he crossed the ocean. In 1827 the first plates were printed, and by 1838 the whole work was done: *The Birds of America*, with 435 hand-colored plates.

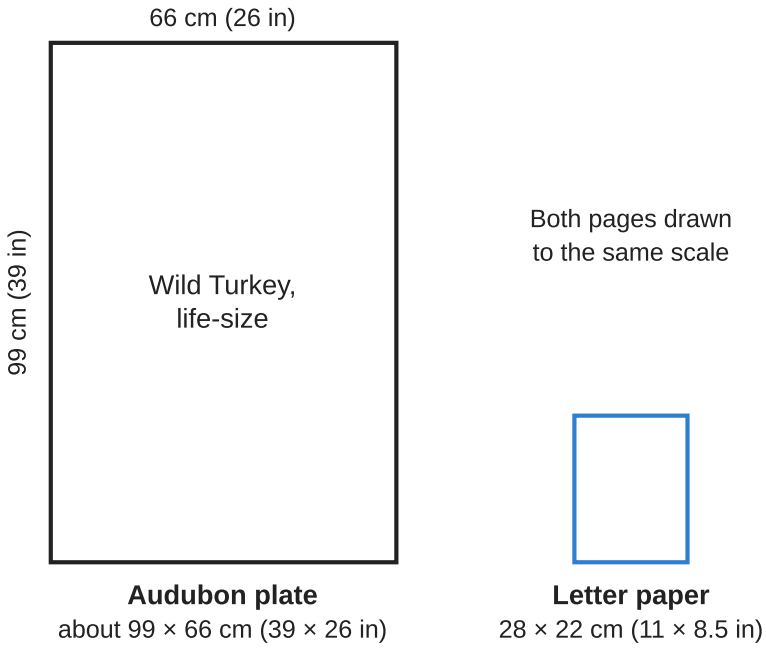
How they figured it out. Most bird artists before Audubon copied stiff, stuffed skins, so their birds looked like stuffed toys. Audubon first watched living birds feed, fight, court and fly. Then, as naturalists of his day did, he collected a fresh specimen and set it in a lifelike pose with wires on a board marked off in squares. The squares let him measure each part and copy it at true size onto paper marked with the same grid. His pages were about 99 cm by 66 cm (39 by 26 in), a size called "double elephant." A Wild Turkey filled a whole page. To fit a tall bird like the American Flamingo, he drew it with its long neck bent down. The first ten plates were engraved by William Lizars in Edinburgh; then the London engraver Robert Havell Jr. took over and cut all the rest into copper plates. The plates were printed in ink, and then a team of colorists painted every copy by hand with watercolors. Buyers received the plates in sets of five as they were finished. Only about two hundred complete sets were ever made.

The big idea. Every one of Audubon's plates shows an animal in the class of birds, which scientists call **Aves** (AY-veez). In Unit 2 you met the five classes of vertebrates. Birds are the easiest class to spot, because only birds have **feathers**. Every bird also has a beak with no teeth, two scaly legs and two wings, though not every bird can fly (think of the ostrich and the penguin). Birds have a backbone, they are warm-blooded, and they lay eggs with hard shells. Many of their bones are hollow and light, with thin struts inside like the braces of a bridge. Ornithologists know of more than 10,000 species of birds. An animal that flies is not always a bird: a bat has fur, and a butterfly has six legs. But an animal with feathers is always a bird.

Try it and see. Field guides list each bird's length from the tip of the bill to the tip of the tail. An American Robin is about 25 cm (10 in) long. A Black-capped Chickadee is about 13 cm (5 in). A tiny Ruby-throated Hummingbird is only about 8 cm (3 in). Measure those lengths with a ruler on a piece of string and you can hold a life-size bird in your hands. Compare an Audubon page with a sheet of letter paper (see the figure): his page is about three and a half sheets tall. A scientist does not just say "big" or "small." A scientist measures.

God's handiwork. On the fifth day of creation God made "every winged fowl after his kind: and God saw that it was good" (Genesis 1:21). Robins hatch robins and turkeys hatch turkeys, just as Audubon saw year after year. He spent his whole life looking hard at what God had made, and his paintings still teach millions of people to notice the birds outside

their windows. You can begin the same way: look closely, measure carefully, and write down what you see.



Audubon's "double elephant" page compared with a sheet of letter paper, drawn to the same scale.

PICTURE STUDY



Wild Turkey (Plate 1 of The Birds of America), John James Audubon; engraved by William H. Lizars of Edinburgh, Printed 1827 · Hand-colored engraving, from Audubon's watercolor · Audubon's original watercolor is at the New-York Historical Society, New York. Printed copies are kept in libraries and museums in many countries.

Audubon chose the Wild Turkey, a bird found only in North America, to be the very first plate of his great book. He painted a male, called a gobbler, at full size. Because a big gobbler is longer than the page is tall, Audubon showed him walking forward with his head and neck bent low, so the whole bird could fit.

Look at how the turkey seems to be moving. Audubon wanted people to feel they had met a living bird in the woods, not a stuffed one in a glass case.

Look closely

- Find the bird's feet. How many toes can you see on one foot, and which way do they point?
- Look at the feathers on the back and wings. What colors can you find? Do the feathers shine?
- Find the bare red skin on the head and neck, and the dark tuft of bristles (the "beard") hanging from the chest.
- Look at the plants around the turkey. Do they make the bird look large or small?

Talk about it

1. Which bird traits from the lesson can you see in this picture? Which ones can you not see?
2. Why do you think Audubon chose to paint his birds life-size instead of small?
3. If you could ask Audubon one question about this painting, what would you ask?

EXPERIMENT: AUDUBON'S GRID: DOES A GRID HELP ME DRAW A BIRD THE RIGHT SIZE?

Audubon set his birds against a board marked in squares so he could copy each part at the right size. In this small experiment you will test his trick. **Question:** Does drawing on a grid make my copy of a bird closer to the right size than drawing without a grid? Write your **prediction** before you start.

You will need

- One clear bird picture from a field guide, a library book, or a printed Audubon plate (about the size of your hand)
- Tracing paper or a clear plastic sheet protector
- Two sheets of plain paper
- Ruler marked in centimeters and millimeters
- Pencil and eraser, and a dry-erase marker if you use a sheet protector
- Timer
- Science notebook

Steps

1. Lay the tracing paper over the bird picture. With the ruler, draw a grid of 2 cm squares over the whole bird.
2. On plain paper sheet A, draw the same grid of 2 cm squares. Leave sheet B blank.
3. **What we change:** grid or no grid. On sheet A, copy the bird one square at a time for 10 minutes. On sheet B, copy the same bird freehand, at what you think is the same size, for 10 minutes.
4. **What we keep the same:** the same bird picture, the same pencil, the same 10 minutes, and the same artist (you).
5. **What we measure:** On the original picture and on both copies, measure in millimeters (1) the bill length, (2) the tail length, and (3) the whole bird from bill tip to tail tip.
6. Record a table with columns: Part, Original (mm), Grid copy (mm), Freehand copy (mm). For each copy, find how many millimeters it was off from the original for each part.
7. Add up the three "off by" numbers for each copy. The smaller total is the more accurate copy. Write one sentence: Was your prediction right?

Tips

- Measure the bill from where the feathers stop to the tip, and do it the same way every time.
- One trial is a start. A real scientist would repeat the test with a second bird to be more sure.

Check your work

- I wrote a question and a prediction before I began.
- I changed only one thing (grid or no grid) and kept the rest the same.
- I measured in millimeters, recorded a table, and wrote a conclusion.

NATURE NOTEBOOK

1. Cut three pieces of string to life-size bird lengths: 8 cm (3 in) for a hummingbird, 13 cm (5 in) for a chickadee and 25 cm (10 in) for a robin. Tape them in your notebook and label each one.
2. Draw a T-chart titled "Bird or Not?" List five animals that fly or swim and sort them by the bird traits. Write the trait that decided each one.
3. Watch one bird outside for five minutes. Write the date, time and weather, then three things the bird *did*, as Audubon would.

> **From history.** Audubon may have done the first bird banding in North America. In 1804, at Mill Grove in Pennsylvania, he tied light silver threads around the legs of young Eastern Phoebes nesting near a creek. The next spring, he wrote, phoebes with threads on their legs came back to nest nearby, showing that the same birds return to the same place. Today scientists put small numbered metal bands on birds' legs to learn the same kinds of things.

WORKED EXAMPLES

Example 1. A large male Wild Turkey can be about 110 cm (43 in) long from bill tip to tail tip. Audubon's page was about 99 cm (39 in) tall and 66 cm (26 in) wide. Would the gobbler fit standing straight up the page? How did Audubon fit him life-size?

1. Compare the turkey with the page height: 110 cm − 99 cm = 11 cm. The turkey is about 11 cm (4 in) too long to fit straight up the page.
2. It is even further too long for the width: 110 cm − 66 cm = 44 cm.
3. Measured corner to corner, the page is about 119 cm (47 in) long, which is longer than the turkey.
4. So a long bird fits best when it is posed slanting across the page or with its neck bent. Audubon showed the gobbler walking with his head and neck bent low.

Answer: No. The turkey is about 11 cm too long for the page height, so Audubon posed him with his head bent low and his body slanting across the page.

Example 2. *The Birds of America* had 435 plates, sent to buyers in sets of five. The first plates came out in 1827 and the last in 1838. How many sets were there? About how many plates were finished each year?

1. Number of sets: 435 ÷ 5 = 87 sets.
2. Number of years: 1838 − 1827 = 11 years.
3. Plates per year: 435 ÷ 11 is about 39.5, so about 40 plates a year.
4. Check: 40 × 11 = 440, which is close to 435.

Answer: 87 sets of five plates, finished at a pace of about 40 plates (about 8 sets) a year.

PRACTICE

1. EASY Name four traits that every bird has.
2. EASY How many plates are in *The Birds of America*, and in what years were they printed?
3. EASY A bat can fly. Is a bat a bird? Give the trait that decides it.
4. MEDIUM Audubon's page was about 99 cm tall and 66 cm wide. A sheet of letter paper is about 28 cm tall and 22 cm wide. About how many sheets of letter paper tall is the page? How many sheets wide?
5. MEDIUM Use the table of bird lengths (bill tip to tail tip).
   Ruby-throated Hummingbird: 8 cm (3 in)
   Black-capped Chickadee: 13 cm (5 in)
   House Sparrow: 16 cm (6 in)
   American Robin: 25 cm (10 in)
   Blue Jay: 28 cm (11 in)

(a) Which bird is longest? (b) How much longer is the robin than the chickadee? (c) How many hummingbird lengths equal one Blue Jay?

6. MEDIUM Why did Audubon draw the American Flamingo with its neck bent down?
7. HARD Mia wants to test whether a grid helps her copy a bird picture at the right size. Name the variable she changes, two things she should keep the same, and what she should measure.
8. CHALLENGE Audubon painted birds feeding, fighting and flying instead of sitting stiffly. In two or three sentences, explain why a bird's behavior is useful to someone trying to identify or classify it.

COMMON MISTAKES

- Thinking every animal that flies is a bird. Bats are mammals and butterflies are insects. The trait that marks a bird is feathers.
- Thinking a bird that cannot fly is not a real bird. Ostriches, emus and penguins have feathers, beaks and hard-shelled eggs, so they are birds.
- Saying a bird is "big" or "small" without measuring. Scientists give the length in centimeters (or inches) from bill tip to tail tip.

Make it a game · Bird or Not a Bird?. A parent names an animal: penguin, bat, ostrich, butterfly, chicken, flying fish, hummingbird and so on. Say "Bird!" or "Not a bird!" and give the one trait that proves it. A correct answer with the right trait earns 2 points; a correct answer with no trait earns 1. Play to 15 points, then switch and try to stump your parent.

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)

Jesus told His listeners to *behold*, to look closely at, the birds. Audubon spent his life doing just that. Every bird you see is fed by God, and you are worth even more to Him.

Practice answers

1. Any four of: feathers, a beak with no teeth, two wings, two scaly legs, a backbone, warm blood, and hard-shelled eggs.
2. 435 plates, printed from 1827 to 1838.
3. No. A bat has fur, not feathers, and it feeds its babies milk. It is a mammal. Only birds have feathers.
4. Tall: 99 ÷ 28 is about 3.5 sheets. Wide: 66 ÷ 22 = 3 sheets.
5. (a) The Blue Jay. (b) 25 − 13 = 12 cm (about 5 in). (c) 28 ÷ 8 = 3.5 hummingbird lengths.
6. He painted every bird life-size, and a flamingo standing tall is taller than his page. Bending the neck let the whole bird fit at full size.
7. Variable she changes: drawing with a grid or without a grid. Keep the same: the bird picture, the time allowed, the pencil and the artist (any two). Measure: how many millimeters each copy's bill, tail and total length are off from the original.

8. Sample answer: Birds that look alike often act differently, such as how they climb, hop, perch or hunt. A nuthatch creeps headfirst down a tree, and a woodpecker props itself up with its tail. Watching what a bird does, and what it eats, gives clues to its beak, feet and group.

4.2 Beaks and Feet

OBJECTIVES

- Match common beak shapes (cone, hook, tweezers, tube, flat bill, chisel, spear) and foot shapes (perching, talons, webbed, climbing) to the food and way of life each one fits.
- Tell how Peter and Rosemary Grant measured finch beaks on Daphne Major in the 1977 drought and explain what they saw as variation within a kind.
- Plan and run a fair test with beak tools, keeping all but one thing the same, and find the average of three trials.

Warm-up. Gather a pair of tweezers, a clothespin, a spoon and a drinking straw. Look at each one and guess which would be best for picking up a sunflower seed, scooping water, or sipping juice from a narrow bottle. Write your guesses. Each of these tools works like the beak of a real bird.

Video. Coming soon. Bird beaks and feet adaptations for kids, and the Galápagos finches studied by Peter and Rosemary Grant: search Cornell Lab of Ornithology (All About Birds), HHMI BioInteractive, Smithsonian, SciShow Kids, Homeschool Pop (Alternate), and nature footage of herons, woodpeckers, hawks and hummingbirds feeding.

KEY TERMS

beak
The hard, toothless mouth of a bird, made of bone covered with keratin. It is also called a bill.

adaptation
A body part or behavior that fits a living thing for the place it lives and the food it eats.

variation
The small differences between members of the same kind, such as finches with slightly bigger or smaller beaks.

talons
The long, sharp, curved claws of hawks, eagles and owls, used to catch and hold prey.

webbed foot
A foot with skin stretched between the toes, which pushes against the water like a paddle.

perching foot
A foot with three toes pointing forward and one pointing back, made for gripping a branch.

CORE IDEAS

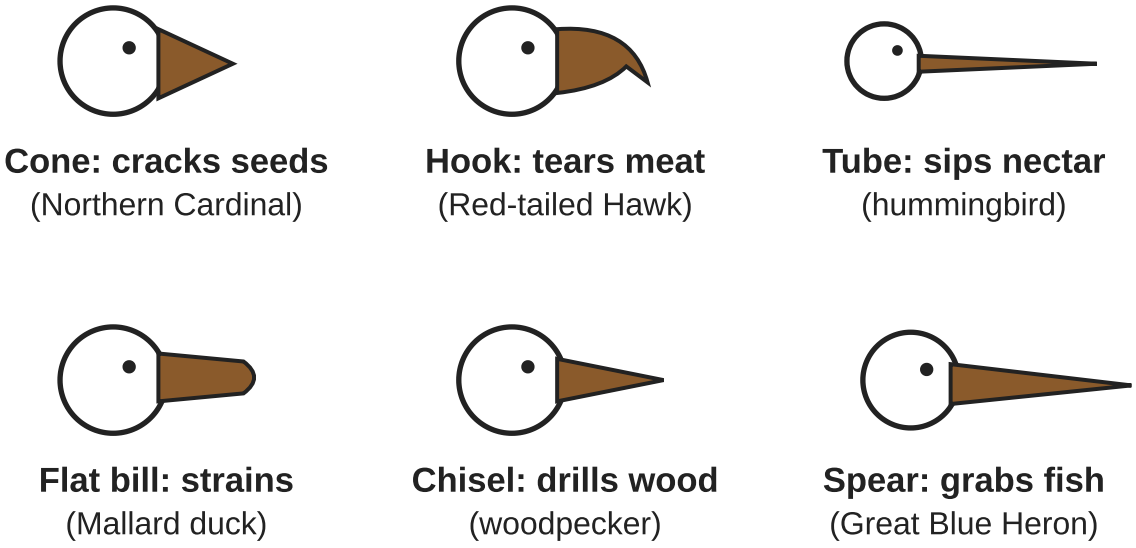
The story. Far out in the Pacific Ocean, in the Galápagos Islands, sits a tiny, rocky island called Daphne Major. Starting in 1973, two scientists, Peter and Rosemary Grant, went there year after year to study its finches. In 1977 almost no rain fell. The plants made very few new seeds, and the finches ate up the small, soft seeds first. Soon all that was left were big, hard, spiky seed cases from a plant called caltrop. Many medium ground finches could not crack them and starved. But the birds with slightly deeper, stronger beaks could crack the caltrop seeds, and more of them lived. The next year their chicks hatched with beaks that were, on average, a little deeper than before the drought.

How they figured it out. The Grants did not guess. They caught the finches in soft nets, put a colored band on each bird's leg so they could tell it apart, and measured its beak with calipers to a tenth of a millimeter. They weighed every bird, counted the seeds on the ground, and tested how much force it took to crack each kind of seed. Because they knew each bird, they could see which ones lived through the drought and which did not. The difference in beak depth was small, less than a millimeter on average, yet it decided which birds could eat. The finches were still finches. Within that kind, God built in variation, and in the dry year the birds with bigger beaks did better. In later wet years, when small seeds came back, smaller beaks did well again.

The big idea. A bird's beak is its tool kit, and you can read a bird's diet from it (see the figure). A short, thick **cone** cracks seeds (Northern Cardinal). A sharp **hook** tears meat (Red-tailed Hawk, owls). A thin **tweezers** beak picks insects from leaves (warblers). A long, thin **tube** reaches nectar deep in flowers (hummingbirds). A wide, **flat bill** strains food from water and mud (Mallard). A strong **chisel** drills into wood (woodpeckers). A long **spear** grabs fish and frogs (Great Blue Heron).

Feet tell a story too. A **perching foot**, with three toes forward and one back, grips a twig; more than half of all bird species, the songbirds and their relatives, have this kind of foot. Hawks, eagles and owls have strong toes armed with **talons** for grabbing prey. Ducks, geese and gulls have **webbed feet** for paddling. Woodpeckers and parrots have **climbing feet** with two toes forward and two back, which hold tight to tree bark. Herons have long, spread-out toes for wading in soft mud, and chickens and turkeys have strong, blunt toes for scratching the ground. Ornithologists use beaks and feet together to sort birds into groups: hooked beak plus talons means a bird of prey; flat bill plus webbed feet means waterfowl.

God's handiwork. "O LORD, how manifold are thy works! in wisdom hast thou made them all" (Psalm 104:24). Every beak in your backyard is shaped for a job, and the variation in each kind lets birds get through dry years and wet ones. When you watch a bird eat, look first at its beak and then at its feet. They will tell you how it lives.



Six beak shapes and the job each one does.

PICTURE STUDY



American Flamingo (Plate 431 of The Birds of America), John James Audubon; engraved and printed by Robert Havell Jr., Printed 1838 · Hand-colored engraving with aquatint, from Audubon's watercolor · Audubon's original watercolor is at the New-York Historical Society, New York. Printed copies are kept in libraries and museums in many countries.

Audubon promised to show every bird life-size, but a flamingo is taller than his page. So he painted it with its long neck curved down, as if it were reaching to feed. It is one of the last plates in the book.

A flamingo eats with its head upside down in the water. Its bent bill has comb-like edges inside that strain tiny shrimp and algae out of the mud and water. Those foods even give the flamingo its pink color.

Look closely

- Find the bend in the flamingo’s bill. Which kind of beak in our lesson is it most like?
- Look at the feet. Can you see skin between the toes? What would that help the bird do?
- Follow the long neck from the body to the head. How did Audubon make the bird fit on the page?
- Find the smaller flamingos in the background. What are they doing?

Talk about it

1. Why does a bird that feeds in shallow water need long legs?
2. What do the beak and feet together tell you about where this bird finds its food?

> **Safety first.** Use the tweezers and clothespins carefully and point them away from eyes. Do not eat the test foods after they have been handled and dropped, and keep small seeds and beads away from younger brothers and sisters. Wipe up spilled water right away so no one slips.

EXPERIMENT: BEAK BUFFET: WHICH BEAK TOOL PICKS UP SEEDS BEST?

Birds with different beaks eat different foods. You will use household tools as “beaks” and run a fair test. **Question:** Which beak tool picks up the most sunflower seeds in 30 seconds? Write your **prediction** first.

You will need

- Four beak tools: tweezers, a spring clothespin, a spoon and a pair of chopsticks
- A shallow tray or plate with 50 unshelled sunflower seeds
- A small cup to be the bird’s “stomach”
- Timer and a helper
- Science notebook and pencil
- Optional second round: a cup of water and a drinking straw, or uncooked rice

Steps

1. **What we change:** the beak tool. **What we keep the same:** the same 50 seeds spread the same way, the same cup, the same 30 seconds, and the same person picking up. **What we measure:** the number of seeds in the cup.
2. Hold the cup in one hand. When your helper says go, pick up seeds with the first tool, one bite at a time, and drop them in the cup. Stop at 30 seconds.
3. Count the seeds in the cup and record the number. Put the seeds back on the tray and spread them out again.

4. Do three trials with each tool. Record a table with columns: Tool, Trial 1, Trial 2, Trial 3, Average.
5. Find each tool's average: add the three trials and divide by 3.
6. Make a bar graph of the averages. Which tool won? Which real bird's beak is it most like?
7. Optional: repeat with rice grains or with water and a straw, and see whether the winner changes.

Tips

- Use the tool the way a beak works: one "bite" at a time, no scooping with your free hand.
- If two trials are very different, think about why. Was your hand tired? Did seeds pile up?

Check your work

- I changed only the tool and kept everything else the same.
- I did three trials for each tool and found the averages.
- I wrote which tool worked best and matched it to a real beak shape.

NATURE NOTEBOOK

1. Draw six bird heads in a row, one for each beak shape in the lesson. Under each, write the beak's job and one real bird that has it.
2. Draw four bird feet: perching, talons, webbed and climbing. Label which toes point forward and which point back.
3. Watch one bird eat, at a feeder or in a video. Sketch its beak and write what food it was eating and how it used its beak.

> **From history.** When Charles Darwin visited the Galápagos Islands in 1835 on the ship *Beagle*, he collected small brown birds but did not carefully label which island each came from. Back in London in 1837, the bird expert John Gould examined them and found that the birds with such different beaks were all finches. Over a hundred years later, the Grants' careful leg bands and measurements filled in what Darwin had missed.

WORKED EXAMPLES

Example 1. In the Beak Buffet test, Sam did three trials with each tool. Clothespin: 12, 15 and 15 seeds. Tweezers: 8, 9 and 10 seeds. Find the average for each tool. How many more seeds did the clothespin pick up on average?

1. Clothespin total: 12 + 15 + 15 = 42. Average: 42 ÷ 3 = 14 seeds.
2. Tweezers total: 8 + 9 + 10 = 27. Average: 27 ÷ 3 = 9 seeds.
3. Difference: 14 − 9 = 5 seeds.
4. The clothespin grips hard like a cone-shaped seed-cracking beak. The tweezers are thin and pointed like an insect-eating warbler’s beak.

Answer: Clothespin average 14 seeds; tweezers average 9 seeds. The clothespin picked up 5 more seeds on average.

Example 2. Use this key to classify a mystery bird’s foot. The foot has two toes pointing forward and two pointing back.
1a. Skin joins the toes → webbed foot (swimmer)
1b. Toes are separate → go to 2
2a. Two toes forward, two back → climbing foot
2b. Three toes forward, one back → go to 3
3a. Thick toes with long, sharp, curved claws → talons (bird of prey)
3b. Thin toes with small claws → perching foot (songbird)

1. Step 1: Are the toes joined by skin? No, so choose 1b and go to 2.
2. Step 2: Two toes point forward and two point back, so choose 2a.
3. The key ends at “climbing foot.”
4. Birds with climbing feet include woodpeckers and parrots. If the bird also has a straight chisel beak, it is most likely a woodpecker.

Answer: A climbing foot, like a woodpecker’s or a parrot’s.

PRACTICE

1. EASY Match each beak to its food: (a) cone, (b) hook, (c) long tube, (d) spear. Foods: fish, nectar, seeds, meat.
2. EASY What kind of foot does a duck have, and how does it help?
3. EASY How many toes point forward and how many point back on a perching foot?
4. MEDIUM Practice data: a student measured the beak depth of five pretend finches: 9 mm, 10 mm, 8 mm, 11 mm and 12 mm. Find the average beak depth. Is that more or less than 1 cm?
5. MEDIUM A bird has a hooked beak and thick toes with long, sharp, curved claws. What does it most likely eat, and what group of birds is it in?

6. HARD Leo wants to test which beak tool moves the most water from one cup to another in 20 seconds: a spoon, a straw or tweezers. Name the variable he changes, three things he should keep the same, and what he should measure.
7. HARD After the 1977 drought on Daphne Major, the medium ground finches had slightly deeper beaks on average. Did the finches grow bigger beaks because they tried hard to crack the big seeds? Explain.
8. CHALLENGE A hummingbird has a long, thin beak. In two or three sentences, explain why it could not live on sunflower seeds, and what a Northern Cardinal's beak has that the hummingbird's lacks.

COMMON MISTAKES

- Thinking a bird can grow a new beak shape because it needs one. A bird is hatched with its beak shape; variation among birds of the same kind is what makes some do better when the food changes.
- Thinking all birds eat seeds. Birds eat seeds, insects, nectar, fruit, fish, worms and meat, and the beak shows which.
- Thinking a bigger beak is always better. In the dry year deeper beaks helped the Daphne finches, but in wet years with many small seeds, smaller beaks did well again.

> **Make it a game · Beak and Feet Detective.** A parent describes a bird in two clues: one about the beak and one about the feet, such as "a long spear beak and long spread-out toes." Name the food it eats and one bird that fits (heron!) to score a point. Then switch roles. After five rounds, invent a bird of your own and describe its beak and feet for the others to guess.

> **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 seed-cracker, a nectar-sipper and a fish-spearer each show the wisdom of the God who made them.

Practice answers

1. (a) cone: seeds. (b) hook: meat. (c) long tube: nectar. (d) spear: fish.
2. A webbed foot. The skin between the toes pushes against the water like a paddle so the duck can swim.
3. Three forward and one back.
4. 9 + 10 + 8 + 11 + 12 = 50; 50 ÷ 5 = 10 mm. Since 10 mm = 1 cm, the average is exactly 1 cm (about 0.4 in).
5. It eats meat, such as mice, fish or other animals. It is a bird of prey (a raptor), like a hawk, eagle or owl.
6. Variable he changes: the beak tool. Keep the same: the amount of water in the starting cup, the size of the cups, the 20 seconds, and the person using the tools (any three). Measure: the amount of water moved, in milliliters, using a measuring cup.

7. No. Each bird’s beak size was already set. Some finches already had slightly deeper beaks. Those birds could crack the big caltrop seeds, so more of them lived and had chicks, and the chicks had deeper beaks like their parents. The birds stayed finches; it was variation within their kind.
8. Sample answer: A hummingbird’s beak is a thin tube made for reaching nectar deep in flowers, and it is too thin and weak to crack a hard seed shell. A cardinal’s short, thick cone beak is strong at the base, so it can crush the shell to get the seed inside.

4.3 Backyard Bird Count

OBJECTIVES

- Tell how Frank Chapman started the Christmas Bird Count on Christmas Day 1900 and why counts by many ordinary people help scientists.
- Run a 15-minute bird count using tally marks and the “most seen at one time” rule, and record date, time and weather.
- Read and make a bar graph of bird-count data and compare counts from two different times.

Warm-up. Spill a handful of mixed buttons, beans or coins on the table and give yourself 20 seconds to count how many of each kind there are. Then have someone stir them while you count again. Was it harder when they moved? Birds move too, so bird counters need a smart rule to keep from counting the same bird twice.

Video. Coming soon. How to do a backyard bird count and the Great Backyard Bird Count for kids: search Cornell Lab of Ornithology (All About Birds, eBird), National Audubon Society, Birds Canada, and nature footage of common feeder birds such as chickadees, cardinals, sparrows and doves.

KEY TERMS

species
One particular kind of living thing whose members look alike and can have young together, such as the Northern Cardinal.

tally
A quick way to count with marks: four lines and a fifth line across them make a group of five.

data
Facts and measurements that are written down, such as how many birds of each species were seen.

citizen scientist
An ordinary person, of any age, who collects careful data that real scientists use.

migration
The regular trip some birds make each year between their summer and winter homes.

CORE IDEAS

The story. In the 1800s, many Americans kept a holiday custom called the “side hunt.” On Christmas Day, hunters chose sides and went out to see which team could shoot the most birds and animals. Frank Chapman, a bird scientist at the American Museum of Natural History in New York, had a better idea. In his magazine, *Bird-Lore*, he asked people to go out

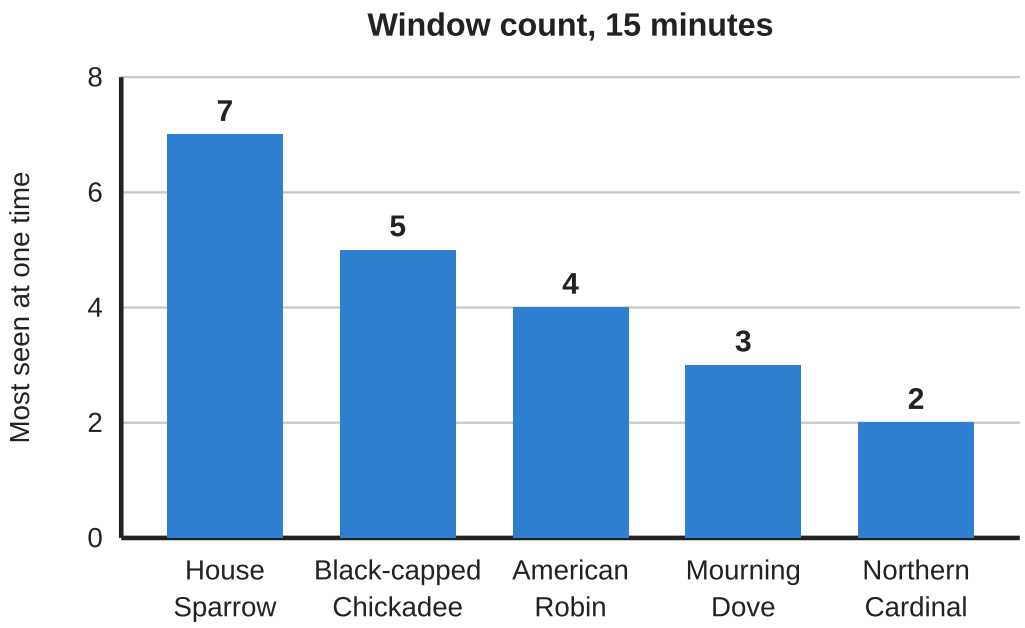
on Christmas Day and *count* birds instead of shooting them. On Christmas Day 1900, twenty-seven people did, in twenty-five places from Canada to California. Together they listed about ninety species. That was the first Christmas Bird Count, and it has been held every winter since.

How they figured it out. Counting birds sounds easy until you try it. Birds fly away, come back, and hide in bushes. If you add up every bird you see, you may count the same chickadee five times. So bird counters use a simple rule: for each species, write down only the **largest number you see at one time**. If you see 3 House Sparrows, then 5 together, then 2, you report 5. You can be sure at least five were there. Counters also write down the date, the time they started and stopped, the place, and the weather, because cold, wind and rain all change how many birds come out. Every count follows the same rules, so the numbers can be compared fairly from year to year and place to place.

The big idea. One person's count tells you about one yard on one morning. Thousands of counts, all done the same way, tell scientists where each species lives, when birds migrate, and which birds are becoming more or less common. That is why ordinary people make such good **citizen scientists**. In 1998 the Cornell Lab of Ornithology and the National Audubon Society began the **Great Backyard Bird Count**. For four days each February, anyone may watch birds for at least 15 minutes and send in the list. Now people around the world take part, and children's counts go into the same data as the experts'.

Try it and see. A good count is simple. Pick a spot where you can see a feeder, a tree or a patch of sky. Set a timer for 15 minutes. Make a list of the species you see, with tally marks beside each one, and circle the biggest group of each species you saw at one time. If you are not sure what a bird is, write "unknown sparrow" or "small brown bird" rather than guessing. Afterward, make a bar graph (see the figure) so you can see your data at a glance.

God's handiwork. Jesus said that not one sparrow falls to the ground without the Father (Matthew 10:29). God knows every bird, every day. When we count birds carefully, we are noticing a little of what He already sees, and we are learning how to care for His creatures well, as Adam was told to "dress" and "keep" the garden (Genesis 2:15).



One family's 15-minute window count. Each bar shows the most birds of that species seen at one time.

PICTURE STUDY



Cardinal Grosbeak (Northern Cardinal), Plate 159 of The Birds of America, John James Audubon; engraved and printed by Robert Havell Jr., Printed in the early 1830s · Hand-colored engraving with aquatint, from Audubon's watercolor · Audubon's original watercolor is at the New-York Historical Society, New York. Printed copies are kept in libraries and museums in many countries.

In Audubon's day the Northern Cardinal was called the "Cardinal Grosbeak," which means a cardinal with a big beak. It is one of the most common backyard birds in the eastern United States, and it stays all winter, so it shows up on many winter bird counts.

Audubon painted a male and a female together. A good bird counter has to know that both belong to the same species, even though they look different.

Look closely

- Compare the two birds. Which is the male and which is the female? How can you tell?
- Find the crest on each bird's head and the thick, cone-shaped beak. What food is that beak made for?
- Look at the feet gripping the branch. What kind of foot is this, from Lesson 4.2?
- Find the black patch around the beak. Is it the same on both birds?

Talk about it

1. If you saw these two birds at your feeder, how many species would you write down? How many birds?
2. Why is it important for a bird counter to know what the female of a species looks like?

> **Safety first.** Watch birds from a window or with an adult outdoors. Never touch wild birds, nests, eggs or droppings, and wash your hands with soap after filling a feeder or handling birdseed. Never look toward the sun, with your eyes or with binoculars.

EXPERIMENT: MY 15-MINUTE BIRD COUNT: MORNING OR AFTERNOON?

You will do real bird counts, the same way citizen scientists do, and use them to answer a question. **Question:** Do I see more birds in the morning or in the afternoon? Write your **prediction** before your first count.

You will need

- A window or outdoor spot with a view of a feeder, tree or bushes
- Timer or clock
- Science notebook and pencil
- A thermometer (optional)
- A bird guide: a library field guide, the free All About Birds website, or the free Merlin Bird ID app with a parent's help
- Binoculars (optional)

Steps

1. **What we change:** the time of day (morning, within two hours after sunrise, or afternoon). **What we keep the same:** the same spot, the same 15 minutes, and the same counting rule. **What we measure:** the total number of birds and the number of species.
2. At the top of a page write the date, start time, place, weather and temperature in °C (°F).

3. Count for 15 minutes. For each species, make tally marks every time you see a group, and circle the largest group you saw at one time.
4. At the end, add up the circled numbers to get your total birds. Count the species on your list.
5. Do three morning counts and three afternoon counts on different days.
6. Find the average total for mornings and for afternoons. Make a bar graph comparing the two.
7. Write your conclusion: Was your prediction right? Name one thing besides the time of day (such as the weather) that might have changed your counts.
8. Optional: in February, count with your parent during the Great Backyard Bird Count and send in your list on the official website.

Tips

- Fill the feeder the day before your first count and keep it filled, so the food is not the thing that changes.
- Sit still and quiet. Birds stay away from fast movements behind a window.

Check your work

- I used the “most seen at one time” rule for every species.
- I recorded the date, time, place and weather for every count.
- I compared morning and afternoon with averages and a bar graph.

NATURE NOTEBOOK

1. Draw a page for your first count: date, time, weather, a tally list, and a quick sketch of one bird you saw.
2. Make a bar graph of your first count, with one bar for each species and a title.
3. Draw a map of your counting spot from above. Mark the feeder, trees and window, and put a small X wherever you saw birds.

> **From history.** The Great Backyard Bird Count began in 1998, started by the Cornell Lab of Ornithology and the National Audubon Society. It was one of the first bird counts where people sent in their lists over the internet, so scientists could see the results quickly. Birds Canada later joined as a partner, and today people in many countries take part each February.

WORKED EXAMPLES

Example 1. During a 15-minute count, Ella saw 3 House Sparrows at 9:00, 5 House Sparrows together at 9:05, and 2 House Sparrows at 9:12. How many House Sparrows should she report? Why not 10?

1. Find the largest number seen at one time: 3, 5 and 2. The largest is 5.
2. Adding them, 3 + 5 + 2 = 10, would count some birds more than once. The 2 sparrows at 9:12 might be two of the same 5 she saw before.
3. She can be sure at least 5 sparrows were there, because she saw 5 at once.

Answer: She reports 5 House Sparrows, the most seen at one time. Reporting 10 might count the same birds twice.

Example 2. Use the bar graph of one family’s window count. (a) How many birds did they count in all? (b) How many more House Sparrows than Northern Cardinals? (c) Did sparrows and chickadees together make up more than half of the birds?

(Use the map or drawing “Read the height of each bar against the scale on the left.” shown earlier in this lesson.)

1. Read each bar: House Sparrow 7, Black-capped Chickadee 5, American Robin 4, Mourning Dove 3, Northern Cardinal 2.
2. (a) Total: 7 + 5 + 4 + 3 + 2 = 21 birds.
3. (b) 7 − 2 = 5 more House Sparrows.
4. (c) Sparrows and chickadees: 7 + 5 = 12. Half of 21 is 10.5. Since 12 is more than 10.5, yes.

Answer: (a) 21 birds of 5 species. (b) 5 more House Sparrows. (c) Yes: 12 of the 21 birds were sparrows or chickadees, which is more than half.

PRACTICE

1. EASY Who started the Christmas Bird Count, and in what year?
2. EASY How many birds do these tally marks show: |||| |||| |||?
3. EASY You see 2 Blue Jays, later 4 Blue Jays together, and later 1 Blue Jay. How many Blue Jays do you report?
4. MEDIUM Read the table of two counts at the same feeder.
   Black-capped Chickadee: Saturday 4, Sunday 3
   Northern Cardinal: Saturday 2, Sunday 2
   Mourning Dove: Saturday 6, Sunday 2
   Blue Jay: Saturday 1, Sunday 3
   (a) Find each day’s total. (b) Which species changed the most from Saturday to Sunday?

5. MEDIUM Why should a bird counter write down the weather and temperature with every count?
6. HARD Grace wants to test whether more birds visit a feeder with black-oil sunflower seed or a feeder with millet. Name the variable she changes, three things she should keep the same, and what she should measure.
7. HARD A family in Ohio counts birds in February and sees no hummingbirds, though hummingbirds visited their flowers all summer. Give the best explanation.
8. CHALLENGE In two or three sentences, explain why scientists want thousands of people counting birds the same way, instead of one expert counting very carefully.

COMMON MISTAKES

- Adding up every sighting of a species. Birds come and go, so this counts the same birds again. Use the most seen at one time.
- Guessing a name when you are not sure. A good scientist writes “unknown sparrow” rather than recording the wrong species.
- Thinking one low count means birds are disappearing. Weather, time of day and season all change counts; only many counts over many years show a real change.

> **Make it a game · Flash Count.** A parent drops a mix of small paper “birds” cut in three colors (red cardinals, brown sparrows, gray doves) onto the table in small groups, three times, and takes them away after 5 seconds each time. Write the most of each color you saw at one time. Score a point for each correct “most at once” number. Then trade places and make the parent count.

> **Scripture.** “Are not two sparrows sold for a farthing? and one of them shall not fall on the ground without your Father.” (Matthew 10:29, KJV)

A farthing was a very small coin. Sparrows seemed almost worthless, yet God watches over each one. The next verses tell us we are worth even more to Him.

Practice answers

1. Frank Chapman, on Christmas Day 1900.
2. 13 (two groups of five plus three).
3. 4, the most seen at one time.
4. (a) Saturday: 4 + 2 + 6 + 1 = 13 birds. Sunday: 3 + 2 + 2 + 3 = 10 birds. (b) The Mourning Dove, which went down by 4 (from 6 to 2).
5. Weather changes how many birds come out. On a cold, windy or rainy day the count might be lower even if the same birds live nearby, so scientists need the weather to compare counts fairly.
6. Variable she changes: the kind of seed. Keep the same: the same kind of feeder, the same amount of seed, the same place (or swap the two feeders’ places each day), the same time of day and the same length of count (any three). Measure: the number of birds that visit each feeder during the count.

7. Migration. Ruby-throated Hummingbirds fly south for the winter, to Mexico and Central America, and come back in spring. They were not in Ohio in February.
8. Sample answer: One expert can only be in one place at a time, but birds live across a whole continent. Thousands of counts done by the same rules show where birds are, when they migrate and how their numbers change, and the many counts help even out mistakes in any single one.

4.4 Drawing a Bird

OBJECTIVES

- Tell how Roger Tory Peterson's 1934 field guide used drawings and arrows to point out field marks.
- Draw a bird from a photo or from life using simple shapes and correct proportions, and label at least eight parts of a bird.
- Use scale and ratio to draw a bird at a chosen size, and test whether labeled field marks help others identify it.

Warm-up. Without looking at any picture, draw a robin from memory in one minute. Then look at a real photo of a robin for one minute and draw it again. Put the two drawings side by side. What did you get wrong from memory? Where are the eyes, how long is the tail, and where do the legs come out?

Video. Coming soon. How to draw a bird step by step for kids and how to use field marks to identify birds: search Cornell Lab of Ornithology (All About Birds, Bird Academy), National Audubon Society, the Roger Tory Peterson Institute, nature-journaling channels, and slow nature footage of songbirds perching.

KEY TERMS

field mark
A spot, stripe, bar or color pattern that helps you tell one species of bird from another.

field guide
A book or app with pictures and descriptions that helps you identify living things outdoors.

proportion
How big one part is compared with another, such as the size of a bird's head compared with its body.

wing bar
A pale stripe across a bird's folded wing, made by the light-colored tips of a row of feathers.

eye ring
A thin circle of pale or colored feathers around a bird's eye.

CORE IDEAS

The story. In 1934 a young art teacher named Roger Tory Peterson published a small book called *A Field Guide to the Birds*. Peterson had grown up in Jamestown, New York, and had loved birds since he was a boy. He knew how hard it was to name a bird flitting through the trees, because older bird books described every feather and were too big to carry. Several publishers turned his book down. One finally printed 2,000 copies, and they sold out in about

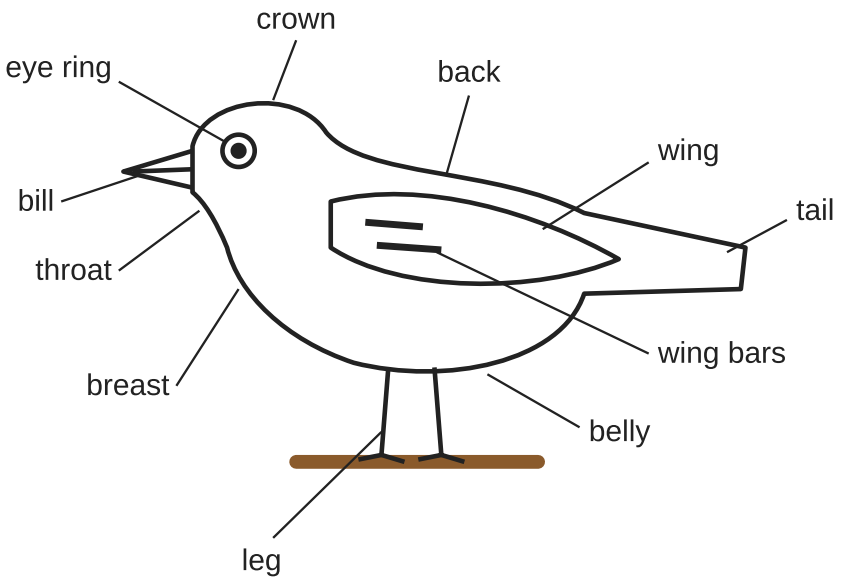
a week. Families everywhere could now slip a bird book into a pocket and name the birds they saw.

How they figured it out. Peterson's secret was in his drawings. He painted birds that look alike in the same pose, side by side on the same page, so you could compare them at a glance. Then he drew small arrows pointing to the one or two marks that tell each bird apart: a white **wing bar**, a pale **eye ring**, a dark eye stripe, white spots in the tail, a streaked breast. He called these **field marks**. Instead of trying to see everything, a bird watcher only had to look for the marks the arrows showed. Nearly every field guide since then, in books and apps, has used Peterson's idea.

The big idea. To draw a bird well, you must see it well, and to see it well you need names for its parts (see the figure). Start with the **shape and size**: is it smaller than a sparrow, about the size of a robin, or as big as a crow? Then draw two simple shapes: a small circle for the head and a bigger egg shape for the body, tilted the way the bird sits. Notice the **proportions**. On a robin, the head is about one third as long as the body. Add the bill, starting right where the face meets the head; the eye sits close to the base of the bill, not in the middle of the head. Then add the tail, the folded wing on the side of the body, and the legs. That bend in a bird's leg that looks like a backward knee is really its **ankle**. The knee is hidden up in the feathers.

Try it and see. Field guides give each bird's length from bill tip to tail tip. An American Robin is about 25 cm (10 in) long. If you want to draw it half size, make your drawing 12.5 cm (about 5 in) long. Draw lightly first, check your proportions with your pencil held at arm's length, and only then press harder and add field marks. Finish the way Peterson did: draw arrows to the field marks and label them. A drawing with labeled field marks is not just art. It is a scientific record that someone else can use.

God's handiwork. The Bible says, "ask now the beasts, and they shall teach thee; and the fowls of the air, and they shall tell thee" (Job 12:7). When you draw a bird slowly, it teaches you things you never noticed: the thin ring around its eye, the pattern of the wing feathers, the way its toes wrap a twig. Drawing is one of the best ways to learn to see what God has made.



The parts of a bird that field guides and bird artists name.

PICTURE STUDY



Wing of a European Roller, Albrecht Dürer, Dated 1512 (some experts think it was painted about 1500) · Watercolor and gouache on vellum · Albertina Museum, Vienna, Austria

Albrecht Dürer was a German artist who lived about five hundred years ago. He painted plants and animals with such care that scientists still admire his work. Here he painted just one thing, the wing of a European Roller, a bright blue bird of Europe, Asia and Africa.

Look at how Dürer painted every row of feathers, from the tiny ones near the shoulder to the long flight feathers at the tip. He did not draw a “bird shape.” He drew exactly what he saw.

Look closely

- Find the small feathers at the top. How are they arranged? Do they overlap like roof shingles?
- Find the long flight feathers. How many can you count?
- List all the colors you can find. Where does the color change?
- Find one tiny detail, such as the thin shaft down the middle of a feather.

Talk about it

1. Why do you think Dürer painted only one wing instead of a whole bird?
2. How could a careful drawing like this help a scientist?
3. Which part of a bird would you most like to draw in this much detail?

EXPERIMENT: THE ARROW TEST: DO LABELED FIELD MARKS HELP PEOPLE NAME A BIRD?

Peterson believed that arrows pointing to field marks help people name birds faster. You will test his idea. **Question:** Can people find the right bird faster from a drawing with labeled field-mark arrows than from a plain drawing? Write your **prediction** first.

You will need

- A clear photo of one backyard bird with easy field marks, such as a Black-capped Chickadee, Dark-eyed Junco or Northern Cardinal
- Photos of three other birds that look a little like it (from a field guide, library book or the All About Birds website), plus the photo of your bird
- Two sheets of drawing paper, pencil, eraser and colored pencils
- Ruler, timer, and at least four people to be testers
- Science notebook

Steps

1. Measure your bird’s real length in a field guide. Choose a size for your drawings (life-size or half size) and work out how long the drawing should be.
2. Draw the bird twice, the same size and the same pose, using a head circle and a body egg shape. Color both the same way.
3. On the second drawing only, add Peterson arrows pointing to two or three field marks and label them (for example, “black cap,” “white cheek,” “gray wing”).
4. **What we change:** plain drawing or arrow drawing. **What we keep the same:** the same bird, the same size and colors, and the same four photos laid out in the same order. **What we measure:** the seconds it takes a tester to point to the right photo.

5. Show half your testers only the plain drawing and the other half only the arrow drawing, so no one sees both. Time each tester with the timer.
6. Record a table: Tester, Drawing (plain or arrows), Seconds, Right or wrong. Find the average time for each kind of drawing.
7. Write your conclusion: Did the arrows help? With only a few testers, how sure can you be?

Tips

- Hold your pencil at arm’s length and line it up with the photo to check how long the tail is compared with the body.
- Shuffle which tester gets which drawing so that it is fair, for example by drawing names from a hat.

Check your work

- I drew my bird with correct proportions at a size I chose and measured.
- I changed only one thing (arrows or no arrows) and kept the rest the same.
- I timed each tester, found averages and wrote a conclusion.

NATURE NOTEBOOK

1. Copy the bird-parts figure and label all eleven parts from memory, then check your labels.
2. Draw one bird from life, at a window or feeder, for 10 minutes. It will move! Draw quick shapes first and add details when it sits still. Write the date, place and weather.
3. Draw two birds that look alike (such as a House Sparrow and a Song Sparrow) side by side in the same pose, and add Peterson arrows to the marks that tell them apart.

> **From history.** When Roger Tory Peterson was about eleven years old, his seventh-grade teacher in Jamestown, New York, started a Junior Audubon Club. Each member received bird leaflets with pictures to color, and Peterson carefully copied a painting of a Blue Jay by the bird artist Louis Agassiz Fuertes. That school club helped start the boy on the path to becoming one of the best-known bird artists in the world.

WORKED EXAMPLES

Example 1. An American Robin is about 25 cm (10 in) long from bill tip to tail tip. You want to draw it at half size. How long should your drawing be? How long would a half-size drawing of a 13 cm (5 in) Black-capped Chickadee be?

1. Half size means divide the real length by 2.
2. Robin: 25 cm ÷ 2 = 12.5 cm. In inches: 10 in ÷ 2 = 5 in.
3. Chickadee: 13 cm ÷ 2 = 6.5 cm. In inches: 5 in ÷ 2 = 2.5 in.
4. Check: the robin drawing should still be about twice as long as the chickadee drawing, just as the real birds are. 12.5 cm is about twice 6.5 cm.

Answer: The robin drawing should be 12.5 cm (5 in) long and the chickadee drawing 6.5 cm (2.5 in) long.

Example 2. In a photo of a robin, the head is 2 cm long and the body (without the tail) is 6 cm long. What is the ratio of head to body? If the body in your drawing is 9 cm long, how long should the head be?

1. Head to body: 2 cm to 6 cm. Divide both by 2: the ratio is 1 to 3. The head is one third as long as the body.
2. Your drawing's body is 9 cm. One third of 9 cm is 9 ÷ 3 = 3 cm.
3. Check: 3 to 9 is the same as 1 to 3.

Answer: The ratio is 1 to 3, so the head in your drawing should be 3 cm long.

PRACTICE

1. EASY What is a field mark? Give two examples.
2. EASY What year did Roger Tory Peterson publish *A Field Guide to the Birds*, and what did he add to his drawings to point out field marks?
3. EASY The joint in the middle of a bird's leg looks like a knee bending backward. What is it really?
4. MEDIUM A Blue Jay is about 28 cm (11 in) long. How long is a half-size drawing? How long is a double-size drawing of a 13 cm chickadee?
5. MEDIUM Read the Arrow Test results.
   Plain drawing testers: 14 seconds, 18 seconds, 16 seconds
   Arrow drawing testers: 9 seconds, 11 seconds, 10 seconds
   (a) Find the average time for each kind of drawing. (b) How many seconds faster were the arrow-drawing testers on average?
6. MEDIUM Name the parts of a bird: (a) the top of the head, (b) the front of the body below the throat, (c) the pale stripes across a folded wing.

7. HARD Noah wonders whether looking at a bird photo for 2 minutes before drawing makes his drawings more accurate than starting right away. Name the variable he changes, two things he should keep the same, and what he could measure.
8. CHALLENGE A House Sparrow and a Song Sparrow are both small and brown. In two or three sentences, explain how Peterson's method would help a beginner tell them apart, and name one field mark you might point an arrow to.

COMMON MISTAKES

- Drawing what you think a bird looks like (a "V" in the sky or a cartoon) instead of what you see. Look at the bird more than at your paper.
- Putting the eye in the middle of the head. On most birds the eye sits close to the base of the bill.
- Bending the bird's leg forward like a human knee. The joint that bends backward is the ankle; the knee is hidden in the feathers.

Make it a game · Field Mark Detective. A parent secretly picks a bird from a field guide and gives one field-mark clue at a time, such as "It has an eye ring," "It has two white wing bars," "It is smaller than a sparrow." After each clue, sketch what you think the bird looks like and make a guess. Guessing after one clue earns 3 points, after two clues 2 points, and after three clues 1 point. Then trade places.

Scripture. "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)

Job's friends thought they knew everything, but Job said even the birds could teach them about God's work. When you draw a bird slowly and carefully, it teaches you too.

Practice answers

1. A spot, stripe, bar or color pattern that helps you tell one bird species from another. Examples: wing bars, an eye ring, a black cap, a streaked breast, white spots in the tail.
2. 1934. He drew small arrows pointing to the field marks.
3. The ankle. The bird's knee is higher up, hidden in the feathers.
4. Blue Jay at half size: 28 ÷ 2 = 14 cm (about 5.5 in). Chickadee at double size: 13 × 2 = 26 cm (about 10 in).
5. (a) Plain: 14 + 18 + 16 = 48; 48 ÷ 3 = 16 seconds. Arrows: 9 + 11 + 10 = 30; 30 ÷ 3 = 10 seconds. (b) 16 − 10 = 6 seconds faster.
6. (a) crown, (b) breast, (c) wing bars.
7. Variable he changes: looking for 2 minutes first or starting right away. Keep the same: the bird photo (or birds of the same difficulty), the drawing time, the size of the drawing and the pencil (any two). Measure: how many millimeters the bill, tail and body lengths are off from the photo, or how many field marks he drew correctly.
8. Sample answer: Peterson would paint both sparrows side by side in the same pose and point arrows only at the marks that differ, so the beginner knows exactly where to look. For

example, an arrow could point to the Song Sparrow’s streaked breast with a dark central spot, or to the male House Sparrow’s gray crown and black bib.

Unit 4 review

Answer each question. Show your work for calculations and use complete sentences for explanations. The review is worth 50 points.

1. (5 pts) Name four traits that all birds share. Which one trait belongs only to birds?
2. (5 pts) What was special about the size of the birds in Audubon's *The Birds of America*, and how did he fit very tall birds like the flamingo onto the page?
3. (5 pts) *The Birds of America* had 435 plates sent out in sets of five. How many sets were there?
4. (5 pts) Match each bird to its beak shape: Northern Cardinal, Mallard, hummingbird, Red-tailed Hawk. Shapes: hook, cone, flat bill, long tube.
5. (5 pts) Describe a woodpecker's foot and a duck's foot, and tell how each one helps the bird.
6. (5 pts) During the 1977 drought on Daphne Major, why did more finches with deeper beaks survive? Were they still finches afterward?
7. (5 pts) In a 15-minute count you see 2 Mourning Doves, then 6 together, then 3. How many do you report, and why?
8. (5 pts) A count found: House Sparrow 8, Northern Cardinal 3, Black-capped Chickadee 4, Blue Jay 1. (a) How many birds in all? (b) How many species? (c) How many more sparrows than chickadees?
9. (5 pts) What are field marks, and how did Roger Tory Peterson show them in his 1934 field guide?
10. (5 pts) A Northern Cardinal is about 22 cm long. (a) How long is a half-size drawing? (b) Design a fair test of whether arrows help people identify your drawing: name the variable you change, one thing you keep the same, and what you measure.

Unit project: my backyard bird plate

Choose one bird you have counted in your own yard or neighborhood and make a full page about it, the way Audubon and Peterson would. Draw the bird at life size or half size (show your measuring), color it carefully, and add Peterson arrows to at least three field marks. Around the drawing, label its beak shape and foot type and tell what it eats, give its common name, its length in centimeters and inches, and the class it belongs to.

On the back or a second page, include the data from your bird counts: your tally sheets, the bar graph comparing morning and afternoon, and a short paragraph telling what you discovered about this bird and how it shows the wisdom of the God who made it.

- **Accuracy**: The drawing has correct proportions and size, the parts and field marks are labeled correctly, and the beak, feet and diet match the real bird.
- **Data**: The count records are dated, follow the "most seen at one time" rule, and the bar graph is titled, labeled and correct.

- **Explanation**: The paragraph explains what the beak and feet show about how the bird lives and what the counts revealed.
- **Care**: The page is neat, carefully colored and easy to read, like a plate from a real field guide.

Answer key

1. Any four of: feathers, a toothless beak, two wings, two scaly legs, a backbone, warm blood, hard-shelled eggs. Only birds have feathers.
2. He painted every bird life-size on very large pages (about 99 × 66 cm, or 39 × 26 in). For tall birds he bent the neck or slanted the body so the whole bird fit at full size.
3. 435 ÷ 5 = 87 sets.
4. Northern Cardinal: cone. Mallard: flat bill. Hummingbird: long tube. Red-tailed Hawk: hook.
5. A woodpecker has a climbing foot, with two toes forward and two back, to hold tight to tree bark. A duck has a webbed foot, with skin between the toes, that pushes water like a paddle for swimming.
6. Only big, hard caltrop seeds were left, and finches with slightly deeper, stronger beaks could crack them, so more of those birds lived and had chicks. Yes, they were still medium ground finches; this was variation within their kind.
7. 6, the most seen at one time. Adding them (11) might count the same doves more than once.
8. (a) 8 + 3 + 4 + 1 = 16 birds. (b) 4 species. (c) 8 − 4 = 4 more sparrows.
9. Field marks are spots, stripes, bars or color patterns that tell one species from another. Peterson painted look-alike birds side by side in the same pose and drew small arrows pointing to the field marks.
10. (a) 22 ÷ 2 = 11 cm. (b) Change: plain drawing or drawing with field-mark arrows. Keep the same: the same bird, size, colors or set of photos to choose from (any one). Measure: the seconds each tester takes to pick the right bird.

UNIT 5

Mammals in Depth

Mammals are the furry, milk-giving animals: dogs and deer, mice and whales, bats and bison. In Unit 2 you learned that mammals are one of the five classes of vertebrates. Now you will look closer, the way a museum scientist does. You will learn to read an animal's teeth to tell what it eats, sort mammals by how their babies begin life, and tell a monkey from an ape at a glance.

You will meet Georges Cuvier in Paris, who predicted hidden bones in a stone from the shape of a jaw; the crew of Captain Cook's *Endeavour*, who watched kangaroos bound across the grass of Australia; Jane Goodall, who sat quietly on a hillside at Gombe until wild chimpanzees showed her how they make tools; and William Hornaday, Mary Ann Goodnight and the friends of the bison, who saved the great beast of the plains when fewer than 1,100 were left. In every lesson you will observe, measure, sort and test like a real naturalist.

God made "the beast of the earth after his kind" (Genesis 1:25). As you study the chisel teeth of the beaver, the pouch of the kangaroo, the grasping hand of the chimpanzee and the snowplow head of the bison, you will see how each creature is fitted for its life, and how people made in God's image are called to care for them.

BEFORE YOU BEGIN

- Can name the five classes of vertebrates and tell what makes an animal a mammal (Unit 2)
- Can follow a simple dichotomous key (Unit 1)
- Can add, subtract, multiply by two-digit numbers and find a simple average
- Can read a thermometer and a ruler in metric units

MASTERY CHECKLIST

- I can name the four kinds of mammal teeth and use tooth shapes to tell a carnivore, a herbivore and an omnivore apart.
- I can sort mammals into monotremes, marsupials and placental mammals and explain how a joey grows in a pouch.
- I can list the features of primates and tell a prosimian, a monkey and an ape apart.
- I can tell how the bison was saved and name people who helped save it.
- I can design a fair test by changing one thing, keeping the rest the same and measuring the result.
- I can estimate a large number by counting a sample and multiplying.

OPTIONAL BOOKS AND RESOURCES

- **Smithsonian's National Zoo and Conservation Biology Institute** (https://nationalzoo.si.edu/): Free. Animal fact pages and live animal cameras. Look up

the American bison, which Hornaday helped bring to the zoo's beginnings (Lesson 5.4), as well as the zoo's primates and other mammals for Lessons 5.1–5.3.

- **Bison in Yellowstone, from the National Park Service** (https://www.nps.gov/yell/learn/nature/bison.htm): Free. Facts, photos and safety rules about the only place in the United States where wild bison have never died out, even in the worst years of the 1880s and 1890s. Good for Lesson 5.4 and for planning a family trip.
- **Smithsonian National Museum of Natural History** (https://naturalhistory.si.edu/): Free. Browse the museum's mammal collections and exhibits online, or visit in Washington, D.C., to see skulls and skeletons up close and test your tooth-reading skills from Lesson 5.1.

5.1 Teeth Tell Diet ★

OBJECTIVES

- Name the four kinds of mammal teeth (incisors, canines, premolars and molars) and tell the job of each.
- Use the shape of an animal's teeth to decide whether it is a carnivore, a herbivore or an omnivore.
- Tell how Georges Cuvier used the teeth in a jaw to predict hidden bones, and add up a tooth count from a tooth formula.

Warm-up. Take a slice of apple and a cracker and stand in front of a mirror. Bite the apple slice. Which teeth did the biting? Now chew the cracker slowly with your mouth closed and feel with your tongue: which teeth are doing the grinding? Run your tongue across your teeth from front to back. Do the front teeth feel like a knife edge, a point or a flat table? Write one word for each.

Video. Coming soon. Mammal teeth for kids: incisors, canines and molars, and how herbivore, carnivore and omnivore skulls differ; search Smithsonian National Museum of Natural History, natural history museum skull collections, SciShow Kids, Homeschool Pop (Alternate) and nature footage of animals eating.

KEY TERMS

incisor
A flat, sharp front tooth used for cutting and nipping food.

canine
A pointed tooth beside the incisors used for piercing and holding.

molar
A wide cheek tooth in the back of the mouth used for crushing and grinding. The premolars, just in front of the molars, help slice and crush.

carnivore
An animal that eats mostly meat, such as a cat or a wolf.

herbivore
An animal that eats mostly plants, such as a cow, a horse or a deer.

omnivore
An animal that eats both plants and animals, such as a bear, a pig or a person.

CORE IDEAS

The story. In 1804, in the great natural history museum in Paris, a scientist named Georges Cuvier sat down with a slab of white stone. Workers in the gypsum quarries of Montmartre, a hill at the edge of the city, had split the rock open and found the bones of a small animal

pressed inside. Only part of the skeleton showed. Cuvier looked hard at the jaw and the little teeth. They were shaped, he said, like the teeth of an opossum, a pouched animal from the Americas. Then he made a bold prediction. If this really was an opossum kind of animal, its hips should have two thin extra bones that opossums have near the pouch. Those bones were still hidden in the stone. Cuvier invited people to watch, and with a fine steel needle he scraped the stone away, grain by grain. There were the two thin bones, just where he said they would be. The teeth had told the truth.

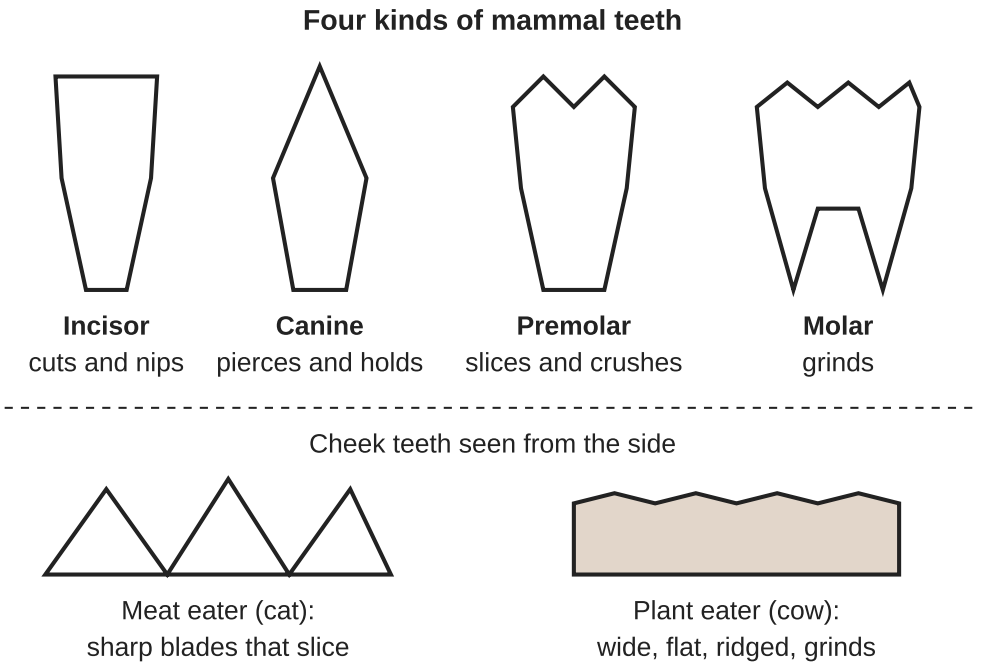
How they figured it out. Cuvier spent years comparing the skeletons of hundreds of animals in the museum's collection. He noticed that the parts of a body fit together like the parts of a well-made tool. An animal with sharp, blade-like cheek teeth also has claws, strong jaw muscles and a short gut for digesting meat. An animal with wide, flat, ridged cheek teeth usually has hooves and a long gut for digesting tough plants. So a scientist who knows teeth well can say a great deal about an animal from a single jaw. Museum workers, zoo vets and wildlife scientists still use this idea every day.

The big idea. Most mammals have four kinds of teeth, and each kind has a job. **Incisors** are the flat front teeth that cut and nip, as when you bite an apple. **Canines** are the pointed teeth beside them that pierce and hold. **Premolars** and **molars** are the cheek teeth in the back that slice, crush and grind. The shape of these teeth tells what an animal eats. A **carnivore**, or meat eater, like a cat or a wolf, has long canines and cheek teeth with sharp edges that slide past each other like the blades of scissors. A **herbivore**, or plant eater, like a cow, a horse or a deer, has wide, flat molars with hard ridges for grinding grass. A cow has no upper front teeth at all. It wraps its tongue around the grass and pinches it against a tough pad on its upper jaw. An **omnivore**, which eats both plants and animals, like a bear, a pig or a person, has a mix: front teeth for biting, canines that are not very long, and fairly flat molars for chewing.

Teeth that never stop growing. Some plant eaters carry a special tool. Rodents such as squirrels, mice and beavers have big front incisors that keep growing all their lives. The front face of each one has a hard orange or yellow coat, and the back is softer, so as the animal gnaws, the back wears away faster and the tooth stays sharp as a chisel. A pet rat or hamster needs hard things to chew, or its teeth grow too long. Behind a rodent's front teeth is a wide gap, and it has no canines at all.

Try it and see. Look in a mirror and count your own teeth. Children have 20 baby teeth, and most grown-ups have 32 adult teeth, counting the four wisdom teeth far in the back. At your age you probably have a mix of baby teeth and new adult teeth, so your number may be anything in between. Find your incisors, canines and molars. Which kind of eater do your teeth say you are?

God's handiwork. The psalmist wrote that the eyes of all wait upon the Lord, and He gives them their meat, which means their food, in due season (Psalm 145:15). Every jaw you study is fitted to the food that animal eats: the chisel of the beaver, the grinding mill of the cow and the scissors of the cat. When you read teeth like Cuvier, you are reading a little of the Creator's careful plan.



The four kinds of mammal teeth, and how the cheek teeth of a meat eater and a plant eater differ.

PICTURE STUDY



Plowing in the Nivernais, Rosa Bonheur, 1849 · Oil on canvas · Musée d'Orsay, Paris

Rosa Bonheur was a French painter who loved animals and studied them with the care of a scientist. She visited farms, markets and slaughterhouses to learn how cattle and horses were built, bone by bone and muscle by muscle. In this painting, teams of oxen turn over the autumn soil in the Nivernais, a farming region in the middle of France.

Oxen are cattle, and cattle are herbivores. All day long they eat grass and hay, and then they lie down and chew it again. The strength you see in these animals comes from plants ground up by wide, flat molars.

Look closely

- Count the oxen in each team. How many are pulling each plow?
- Look at the heads of the oxen. Can you see their mouths and noses? What do you think they eat when the work is done?
- Find the farmers. What is each one doing to guide the team?
- Look at the soil. How has the plow changed it? How can you tell which part of the field has already been plowed?

Talk about it

1. If you could look inside an ox's mouth, what kind of cheek teeth would you expect to see? Why?
2. Why might Rosa Bonheur have studied real animals so closely before she painted them?
3. How do the oxen in this picture serve the farmers, and how do the farmers care for the oxen?

> **Safety first.** Use scissors carefully with a grown-up nearby. Wash your hands and the tools before and after handling food, and do not eat the test food when you are done. Look at a pet's teeth only if the pet is calm and a parent is helping. Never touch a wild animal, and never pick up a skull or bones found outdoors without gloves and a grown-up.

EXPERIMENT: THE TOOTH TOOLS TEST

Your teeth are tools. In this experiment you will use kitchen tools as models of teeth: a fork for pointed canines, scissors for the sharp, sliding cheek teeth of a cat, and two spoons rubbed together for the flat, grinding molars of a cow. **Question:** Which kind of tooth works best on a soft plant food, and which works best on a tough, stringy food?

Write a **prediction** before you begin. **What we change:** the tooth tool. **What we keep the same:** the size of the food pieces and the way we count. **What we measure:** how many strokes it takes to break each piece into bits smaller than 1 cm (less than ½ in).

You will need

- A fork (model canines)
- Child-safe scissors (model meat eater's cheek teeth)
- Two metal spoons, rubbed back to back (model grinding molars)
- Three lettuce leaves (plant food)
- Three strips of string cheese or cooked deli meat (tough, stringy food)
- A ruler, a plate for each tool, a pencil and your lab notebook

Steps

1. Cut the lettuce and the cheese into squares about 5 cm (2 in) on each side. Make six of each so every tool gets a fair turn.
2. In your notebook, draw a table with three rows (fork, scissors, spoons) and two columns (lettuce, cheese).
3. Write your prediction: which tool will break the lettuce fastest? Which will break the cheese fastest?
4. Test the fork: poke and tear one lettuce square until every bit is smaller than 1 cm (less than ½ in). Count each poke as one stroke. Write the number.
5. Test the scissors the same way, counting each snip as one stroke. Then test the spoons, counting each back-and-forth rub as one stroke.
6. Repeat all three tools with the cheese squares.
7. Do a second round with fresh squares and find the average for each tool. Circle the winner for each food.
8. Write two sentences: Which tooth tool worked best on each food? Which kind of animal has teeth like that tool?

Tips

- Keep the count fair: use the same size squares and the same rule for “small enough” every time.
- Real cheek teeth work with strong jaw muscles and with the tongue moving food around, so your tools are only models. They still show why shape matters.

Check your work

- I made a prediction before testing.
- I changed only one thing, the tool, and kept the food size the same.
- I recorded my counts in a table and found the best tool for each food.
- I can explain which animals have teeth shaped like each tool.

NATURE NOTEBOOK

1. Draw your own top teeth as you see them in a mirror, one side at a time. Label the incisors, canines and molars. Write the date and how many teeth you counted.
2. Draw the side view of a cat’s cheek teeth and a cow’s cheek teeth from the figure. Under each, write the animal’s diet and one word for the tooth’s job.
3. Make a three-column chart titled “Teeth Tell Diet”: Carnivore, Herbivore, Omnivore. Write two animals and one tooth clue in each column.

> **From history.** Long before Cuvier, Carl Linnaeus also used teeth to sort mammals. In *Systema Naturae* he grouped mammals into orders largely by counting and comparing their front teeth, because teeth are hard, easy to see and match the way an animal lives.

> Teeth are also the part of an animal most often kept in museum drawers, since they are the hardest part of the body.

WORKED EXAMPLES

Example 1. Scientists write a dog's teeth as a tooth formula for *one side* of its mouth. Top: 3 incisors, 1 canine, 4 premolars, 2 molars. Bottom: 3 incisors, 1 canine, 4 premolars, 3 molars. How many teeth does a grown dog have in all?

1. Add the top teeth on one side: 3 + 1 + 4 + 2 = 10.
2. Add the bottom teeth on one side: 3 + 1 + 4 + 3 = 11.
3. One side of the mouth has 10 + 11 = 21 teeth.
4. The mouth has two sides that match, left and right: 21 × 2 = 42.

Answer: A grown dog has 42 teeth.

Example 2. A museum drawer holds a small skull with a label that has fallen off. It has two pairs of long, curved front teeth with orange fronts, a wide gap behind them, no canines, and flat cheek teeth. Use this key to classify its diet. 1a. Long canines and blade-like cheek teeth: go to "meat eater." 1b. Short or missing canines: go to 2. 2a. Big front teeth with a chisel edge and a gap behind: "gnawing plant eater (rodent)." 2b. Front teeth for biting and fairly flat, bumpy molars: "omnivore."

1. Step 1: The skull has no canines, so 1a does not fit. Go to 2.
2. Step 2: It has big, curved front teeth with orange fronts and a gap behind, which matches 2a.
3. Its flat cheek teeth agree with 2a: they grind plant food such as seeds, bark and nuts.

Answer: It is a gnawing plant eater, a rodent, such as a beaver or a squirrel.

PRACTICE

1. EASY Name the four kinds of mammal teeth in order from the front of the mouth to the back.
2. EASY Which teeth does a horse use most to grind its grass?
3. MEDIUM A cat's tooth formula for one side is: top 3 incisors, 1 canine, 3 premolars, 1 molar; bottom 3 incisors, 1 canine, 2 premolars, 1 molar. How many teeth does a grown cat have?
4. MEDIUM Read the table of adult tooth counts. Grown person: 32. Cat: 30. Dog: 42. Virginia opossum: 50. (a) Which animal has the most teeth? (b) How many more teeth does it have than a grown person? (c) Which animal has fewer teeth than a person?

5. MEDIUM A skull has long, pointed canines and cheek teeth with sharp edges like scissor blades. What does this animal mostly eat, and what do we call that kind of eater?
6. HARD A black bear skull has fairly large canines but wide, flat, bumpy molars. A friend says, “Big canines, so it only eats meat.” Is your friend right? Explain using both kinds of teeth.
7. HARD In the Tooth Tools Test, you want to know which tool breaks lettuce into small bits with the fewest strokes. (a) What is the one thing you change? (b) Name two things you must keep the same. (c) What do you measure?
8. CHALLENGE A beaver gnaws through tree trunks every day, yet its front teeth do not wear down to stumps. Explain why. Then tell what could happen to a pet hamster that had nothing hard to chew.

COMMON MISTAKES

- Thinking big canines always mean a meat eater. Gorillas have large canines but eat mostly leaves, stems and fruit. Look at the cheek teeth too.
- Thinking plant eaters have weak teeth. Grass is tough and gritty, so herbivores have some of the hardest-working teeth of all: big, ridged molars that grind all day.
- Thinking every animal’s teeth stop growing, as ours do. A rodent’s front teeth keep growing all its life.

Make it a game · Who Eats What?. A parent names an animal, such as a beaver, a lion, a sheep or a raccoon. You have ten seconds to say whether it is a carnivore, a herbivore or an omnivore and give one tooth clue (“long canines,” “flat molars,” “gnawing incisors”). One point for the diet and one point for the clue. Switch places and quiz your parent. First to ten points wins.

Scripture. “The eyes of all wait upon thee; and thou givest them their meat in due season. Thou openest thine hand, and satisfiest the desire of every living thing.” (Psalm 145:15–16, KJV)

In the King James Bible, “meat” means food of every kind. God feeds the grazing cow and the hunting fox alike, and He gave each one teeth suited to the food it eats.

Practice answers

1. Incisors, canines, premolars, molars.
2. Its molars (and premolars), the wide, flat cheek teeth in the back of the mouth.
3. Top one side: 3 + 1 + 3 + 1 = 8. Bottom one side: 3 + 1 + 2 + 1 = 7. One side: 8 + 7 = 15. Both sides: 15 × 2 = 30 teeth.
4. (a) The Virginia opossum. (b) 50 − 32 = 18 more teeth. (c) The cat, with 30.
5. It eats mostly meat. It is a carnivore, like a cat, a fox or a wolf.
6. No. The canines help with meat, but the wide, flat, bumpy molars are made for crushing and grinding plants such as berries, nuts and roots. A bear is an omnivore: it eats both plants and animals.

7. (a) The tool (fork, scissors or spoons). (b) Any two of: the size of the lettuce squares, the kind of lettuce, the rule for “small enough” (smaller than 1 cm), the way strokes are counted, the person doing the test. (c) The number of strokes it takes to break the square into small bits.
8. A rodent’s front incisors keep growing all its life, and the hard front face wears more slowly than the soft back, so gnawing keeps the tooth sharp and at the right length. A pet hamster with nothing hard to chew would not wear its teeth down, so they could grow too long and make it hard for the hamster to eat.

5.2 Marsupials: Mammals with Pouches

OBJECTIVES

- Explain what makes a marsupial a mammal and how a marsupial baby grows in its mother's pouch.
- Sort mammals into three groups (monotremes, marsupials and placental mammals) by how their babies begin life.
- Tell how the crew of Captain Cook's *Endeavour* met the kangaroo in 1770, and name the one marsupial that lives wild in the United States.

Warm-up. Find a jelly bean, a paper clip or a raisin and set it in your palm. A newborn kangaroo is about that small, about 2 cm (less than 1 in) long. Now picture a grown kangaroo taller than your kitchen table. Close your hand around the tiny thing. Where could such a small baby stay safe and warm? Write your guess.

Video. Coming soon. Marsupials for kids: kangaroo joeys in the pouch, koalas, wombats and the Virginia opossum carrying babies on her back; search Smithsonian's National Zoo, San Diego Zoo Wildlife Alliance, Australian zoo channels, SciShow Kids, Homeschool Pop (Alternate) and nature footage.

KEY TERMS

marsupial
A mammal whose baby is born very tiny and then grows in a pouch or fold of skin on its mother's belly, drinking her milk. Kangaroos, koalas, wombats and opossums are marsupials.

pouch
A pocket of skin on a marsupial mother's belly where her baby stays warm and nurses.

joey
A baby marsupial, especially a baby kangaroo, wallaby, koala or wombat.

monotreme
A mammal that lays eggs. The platypus and the echidnas are monotremes; the mothers make milk for the hatchlings.

placental mammal
A mammal whose baby grows much longer inside its mother before birth. Dogs, mice, bison and most other mammals are placental mammals.

CORE IDEAS

The story. In June 1770, the English ship *Endeavour*, under Captain James Cook, struck a coral reef off the northeast coast of Australia. The sailors worked the pumps day and night and finally brought the ship into the mouth of a river, where they pulled her up on the shore

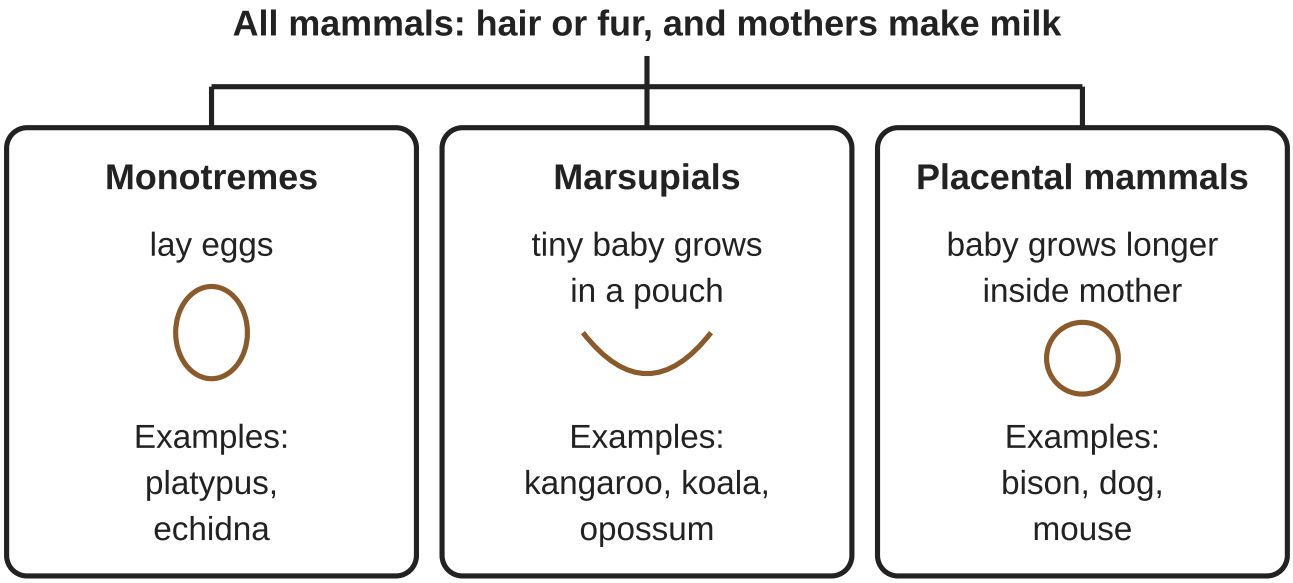
to mend the hole. They stayed there about seven weeks. While the carpenters worked, the ship's naturalist, Joseph Banks, explored the land. He and the crew saw a strange gray animal as big as a greyhound that did not run on four legs at all. It bounded across the grass on its two great back legs, holding its small front paws up to its chest, with a long, thick tail behind it. The people who lived there, the Guugu Yimithirr, called the animal something like *gangurru*. Cook wrote the name in his journal, and English speakers have called it the **kangaroo** ever since.

How they figured it out. Banks carried kangaroo skins and a skull home to England, and naturalists studied them closely. The kangaroo had fur and its mother made milk, so it was plainly a **mammal**. But like the opossum of the Americas, which Europeans already knew, the female had a **pouch** on her belly. As naturalists watched living kangaroos over the years, they learned the pouch's secret. A kangaroo baby is born after only about a month inside its mother, when it is the size of a jelly bean, pink, hairless and blind, with back legs that are only little buds. Using its strong front legs, it climbs up through its mother's fur into the pouch in just a few minutes. There it fastens onto a teat and drinks milk. This baby is called a **joey**. A red kangaroo joey first peeks out after about six months and leaves the pouch for good at about eight months, though it still pokes its head back in to nurse until it is about a year old. Remember the two thin hip bones Cuvier found in Lesson 5.1? Marsupials have them, near the pouch.

The big idea. All mammals have hair or fur, and all mammal mothers make milk for their young. Scientists sort mammals into three groups by how the babies begin life. **Monotremes**, the platypus and the echidnas, lay eggs. **Marsupials** give birth to tiny babies that grow in a pouch or a fold of skin. **Placental mammals**, which include dogs, bats, whales, bison and most other mammals, keep the baby growing inside the mother much longer, so it is born bigger and more ready for the world. There are more than 300 kinds of marsupials. Most live in Australia and on nearby islands: kangaroos and wallabies that hop, koalas that eat eucalyptus leaves, wombats that dig burrows, and the fierce little Tasmanian devil, a meat eater with very strong jaws. A wombat's pouch opens toward its back legs, so dirt does not fly in while it digs.

In the world today. You do not have to travel to Australia to see a marsupial. The **Virginia opossum** lives in backyards, woods and farms across much of the United States, and it is the only marsupial that lives wild north of Mexico. A newborn opossum is about the size of a honeybee. The babies stay in the pouch about two months, and then they ride on their mother's back as she hunts at night for insects, fruit, snails, eggs and scraps. The opossum is an omnivore with 50 teeth, more than any other land mammal in North America. When it is badly frightened, it may fall over, go limp and lie still, which people call "playing possum."

God's handiwork. Think of the newborn joey: no bigger than a bean, with eyes it cannot open and back legs that are only buds, yet it knows the way to its mother's pouch and makes the climb alone. Then the pouch keeps it warm, safe and fed for months. Every part of the plan, the strong little front legs, the warm pocket and the mother's milk, is ready at just the right time. This is the care of the God who made the beasts of the earth after their kind.



Mammals are sorted into three groups by how their babies begin life.

PICTURE STUDY



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

This is the first painting of a kangaroo ever shown in England. Joseph Banks asked George Stubbs, an English painter famous for his careful pictures of horses, to paint it after the *Endeavour* came home. Stubbs never saw a living kangaroo. He worked from the skin and skull that Banks brought back, and from the sketches and descriptions of the men who had seen the animals in Australia.

When the painting was shown in London, many people had never imagined such a creature. “New Holland” was an old name for Australia, and “kongouro” was one of the early ways of spelling kangaroo.

Look closely

- Look at the back legs and the tail. How do they help the kangaroo sit up?
- Compare the size of the front paws with the back legs. Why do you think they are so different?
- Find the ears and the eyes. Which way is the kangaroo looking?
- Look at the hills and plants behind it. Do you think Stubbs had seen this place, or did he imagine it?

Talk about it

1. Stubbs painted from a skin, not a live animal. What might be hard to get right that way?
2. If you had been in London in 1772, what questions would you have asked Joseph Banks about this animal?
3. What would you need to add to this painting to show that the kangaroo is a marsupial?

> **Safety first.** Use warm tap water only, never boiling or very hot water, and have a grown-up pour it. If you see a wild opossum or any wild animal, watch from a distance and never try to touch, feed or pick it up, even if it is lying still.

EXPERIMENT: DOES A POUCH KEEP A JOEY WARM?

A joey has almost no fur and cannot make enough heat to stay warm by itself. In this experiment, a small jar of warm water stands in for the joey, and a sock held against your body stands in for the pouch.

Question: Does a pouch keep a baby warmer? **Prediction:** write what you think will happen. **What we change:** pouch or no pouch. **What we keep the same:** the size of the jars, the amount of water, the starting temperature and the time. **What we measure:** the water temperature every 10 minutes.

You will need

- Two small, matching jars or plastic bottles with lids (baby food jars work well)
- Warm tap water and a measuring cup
- A kitchen or aquarium thermometer that reads in °C (or °F)
- A thick sock (the pouch) and a loose sweatshirt or apron with a front pocket
- A clock or timer, a pencil and your lab notebook

Steps

1. Ask a grown-up to fill both jars with the same amount of warm tap water, about 100 mL (about ½ cup) each.
2. Measure the water in each jar. Write the starting temperatures. They should be the same, or within 1 degree.
3. Put the lids on. Slip one jar into the sock and tuck it into your sweatshirt pocket or apron, close to your belly. This jar is the joey in the pouch.
4. Set the other jar on a table in the same room with no covering. This jar is the joey with no pouch.
5. After 10 minutes, quickly open each jar, measure the water and close it again. Do the same at 20 minutes and 30 minutes.
6. Record your numbers in a table with three columns: Time, Pouch jar, No-pouch jar.
7. Find how many degrees each jar cooled from the start to 30 minutes. Write a sentence that answers the question.

Tips

- Measure each jar the same way, holding the thermometer in the water for the same amount of time.
- If you have time, repeat the test and switch which jar goes in the pouch, to be sure the jars themselves are not different.

Check your work

- I wrote a prediction before starting.
- I changed only one thing: pouch or no pouch.
- I recorded temperatures in a table with units.
- I can explain how a pouch helps a tiny joey.

NATURE NOTEBOOK

1. Draw a mother kangaroo with a joey peeking out of her pouch. Label the pouch, the joey, the strong back legs and the tail.
2. Copy the three mammal groups from the figure into your notebook. Add one more animal of your own to each box.
3. If an opossum lives near you, look for its tracks in mud or snow: the back foot has a thumb that points sideways like a hand. Sketch a track from a field guide or from life, and write the date and place.

> **From history.** Long before Cook reached Australia, English settlers in Virginia met the opossum. Captain John Smith, writing about Virginia in 1612, described it as an animal with a head like a pig’s, a tail like a rat’s, about the size of a cat, with a bag under its belly where the mother carries and nurses her young. The word “opossum” itself comes from the language of the Algonquian-speaking people of the Virginia coast.

WORKED EXAMPLES

Example 1. Use this key to sort four mammals: a platypus, a Virginia opossum, a bison and a wombat. Key: 1a. The mother lays eggs: **monotreme**. 1b. The mother gives birth to live young: go to 2. 2a. The baby is born tiny and grows in a pouch: **marsupial**. 2b. The baby grows much longer inside the mother and is born bigger: **placental mammal**.

(Use the map or drawing "Use the three groups to check your sorting." shown earlier in this lesson.)

1. Platypus: the mother lays eggs, so step 1a. It is a monotreme.
2. Virginia opossum: live birth (1b), and the tiny babies grow in a pouch (2a). It is a marsupial.
3. Bison: live birth (1b), and the calf grows inside its mother for months and can stand soon after it is born (2b). It is a placental mammal.
4. Wombat: live birth (1b), and the tiny joey grows in a backward-opening pouch (2a). It is a marsupial.

Answer: Monotreme: platypus. Marsupials: Virginia opossum and wombat. Placental mammal: bison.

Example 2. A red kangaroo joey leaves the pouch for good at about 8 months. Virginia opossum babies leave the pouch at about 2 months. (a) How many times longer does the joey stay in the pouch? (b) Counting each month as about 30 days, about how many more days is that?

1. (a) Divide: 8 months ÷ 2 months = 4. The joey stays about 4 times as long.
2. (b) Change months to days: 8 × 30 = 240 days for the kangaroo, and 2 × 30 = 60 days for the opossum.
3. Subtract: 240 − 60 = 180 days.

Answer: (a) About 4 times as long. (b) About 180 more days.

PRACTICE

1. EASY Name two things that all mammals, including marsupials, have in common.
2. EASY What is a joey, and where does it live while it grows?
3. MEDIUM Many people call the koala a "koala bear." Is it a bear? Explain.
4. MEDIUM Which marsupial lives wild in the United States, and what does its family look like after the babies leave the pouch?
5. MEDIUM Read this sample data from the pouch experiment. Start: pouch jar 40 °C, no-pouch jar 40 °C. At 10 minutes: pouch 37 °C, no-pouch 34 °C. At 20 minutes: pouch 35 °C, no-pouch 30 °C. At 30 minutes: pouch 34 °C, no-pouch 27 °C. (a) How many degrees did each jar cool in 30 minutes? (b) Which jar stayed warmer?

6. HARD In the pouch experiment, (a) what is the one thing you change? (b) Name three things you keep the same. (c) Which jar is the control, the one you compare against?
7. HARD A newborn red kangaroo has a mass of less than 1 gram, about as much as a paper clip. A grown female can have a mass of about 25 kg (55 lb). There are 1,000 grams in 1 kilogram. About how many times heavier is the mother than her newborn?
8. CHALLENGE A kangaroo's pouch opens toward its head, but a wombat's pouch opens toward its back legs. Wombats dig burrows with their front claws. Explain why the backward pouch is a good design for a wombat.

COMMON MISTAKES

- Thinking the koala is a bear. It is a marsupial; "koala bear" is only a nickname.
- Thinking a joey is born inside the pouch. It is born from its mother's body like other mammals, then climbs up through her fur into the pouch by itself.
- Thinking marsupials live only in Australia. Opossums live in the Americas, and the Virginia opossum lives across much of the United States.

> **Make it a game · Egg, Pouch or Inside?.** A parent names a mammal: platypus, kangaroo, horse, koala, echidna, opossum, whale, wombat, mouse, Tasmanian devil. You answer "Egg!" for a monotreme, "Pouch!" for a marsupial or "Inside!" for a placental mammal, and act it out: tuck your arms in like an egg, hop like a kangaroo or rock a pretend baby. One point for each right answer. Take turns naming animals until you have each named five.

> **Scripture.** "Can a woman forget her sucking child, that she should not have compassion on the son of her womb? yea, they may forget, yet will I not forget thee." (Isaiah 49:15, KJV)

A kangaroo mother carries and feeds her joey for months. God says His care for His people is even more faithful than the love of a mother for the baby she nurses.

Practice answers

1. They have hair or fur, and the mothers make milk to feed their babies.
2. A joey is a baby marsupial, such as a baby kangaroo. It lives in its mother's pouch, where it stays warm and drinks her milk.
3. No. A koala is a marsupial: its baby is born tiny and grows in its mother's pouch. Bears are placental mammals.
4. The Virginia opossum. After about two months in the pouch, the babies ride on their mother's back.
5. (a) Pouch jar: $40 - 34 = 6$ degrees. No-pouch jar: $40 - 27 = 13$ degrees. (b) The pouch jar stayed warmer; it cooled less than half as much.
6. (a) Whether the jar is in the pouch or not. (b) Any three of: jar size, amount of water, starting temperature, the room, the length of time, the way you measure. (c) The no-pouch jar on the table is the control.

7. 25 kg = 25 × 1,000 = 25,000 grams. 25,000 ÷ 1 = 25,000, so the mother is at least 25,000 times heavier than her newborn joey.
8. When a wombat digs, its front claws throw dirt backward under its body. If the pouch opened forward, dirt would fly in on the joey. A pouch that opens toward the back legs keeps dirt out and the joey safe.

5.3 Primates: Hands That Grasp

OBJECTIVES

- List the features that mark a mammal as a primate: grasping hands, forward-facing eyes, nails instead of claws on most fingers, and a large brain for its body size.
- Sort primates into three groups (prosimians, monkeys and apes) and tell a monkey from an ape by its tail.
- Tell how Jane Goodall watched chimpanzees make and use tools at Gombe in 1960, and design a fair test of how much a thumb helps a hand.

Warm-up. Pick up a pencil, a coin and a button using your whole hand. Now try again without letting your thumb touch anything. Which object was hardest? Wiggle your thumb and watch how it can swing across to touch the tip of each finger. Write one sentence about what your thumb does that your fingers cannot.

Video. Coming soon. Primates for kids: lemurs, monkeys and apes, prehensile tails, and chimpanzees using tools to fish for termites; search Smithsonian's National Zoo, the Jane Goodall Institute, San Diego Zoo Wildlife Alliance, SciShow Kids, Homeschool Pop (Alternate) and nature footage.

KEY TERMS

primate
A mammal with grasping hands, forward-facing eyes, nails on most fingers and toes, and a large brain for its size. Lemurs, monkeys and apes are primates.

opposable thumb
A thumb that can swing across the palm to touch the tips of the other fingers, so the hand can pinch and grip.

prehensile tail
A tail that can grab and hold on to branches like an extra hand. Spider monkeys and howler monkeys have one.

monkey
A primate that usually has a tail and runs along the tops of branches on all fours. Baboons, capuchins and spider monkeys are monkeys.

ape
A primate with no tail, long arms and a large brain. Gibbons, orangutans, gorillas, chimpanzees and bonobos are apes.

prosimian
A small primate such as a lemur, loris or galago, often with big eyes for seeing at night and a wet nose like a dog's.

CORE IDEAS

The story. In July 1960, a young Englishwoman named Jane Goodall stepped off a boat onto the shore of Lake Tanganyika in East Africa. She had come to Gombe, a place of steep, forested valleys, to watch wild chimpanzees. At first the chimpanzees ran away whenever they saw her. So every day she climbed to the same high rocky spot with her binoculars and her notebook and simply sat, quietly, until they grew used to her. One morning that autumn she saw a chimpanzee with a gray beard on his chin, whom she named David Greybeard, crouched beside a termite mound. He picked a grass stem, poked it into a hole, waited, and drew it out covered with termites, which he ate. Later she watched chimpanzees pull the leaves off a twig to make it into a good probe. They were not just using tools. They were making them. That same year she saw chimpanzees eat meat as well as fruit and leaves, so she learned they were omnivores.

How they figured it out. Goodall's method was the naturalist's method: watch patiently, write down exactly what you see, and come back again and again. She learned to tell each chimpanzee apart by its face and ways, kept careful daily notes, and stayed at Gombe for many years. Her records showed how chimpanzee mothers care for their babies for years, how the young ones learn by watching, and how the group shares grooming and food. Scientists still study chimpanzees at Gombe today.

The big idea. Chimpanzees belong to the order **Primates**, a name Carl Linnaeus chose. Primates are mammals with several features that work together for life in the trees. They have **grasping hands**, and many have an **opposable thumb** that can swing across to touch the fingertips, so they can pinch a seed or wrap around a branch. Apes can grasp with their feet as well. Most primates have flat **nails** instead of claws, and soft, sensitive fingertip pads for feeling. Their **eyes face forward**, so both eyes see the same thing from slightly different places, which helps a primate judge how far away the next branch is before it leaps. And primates have **large brains** for the size of their bodies.

Three groups. Primates are usually sorted into three groups. **Prosimians**, such as the ring-tailed lemurs of Madagascar and the slow lorises of Asia, are small, often have huge eyes for night, and have a wet nose like a dog's. **Monkeys** usually have tails and run along the tops of branches on all fours. Monkeys of Central and South America, such as spider monkeys and howler monkeys, can have a **prehensile tail** that grips like a fifth hand. Monkeys of Africa and Asia, such as baboons and macaques, have tails too, but cannot hang by them. **Apes** have no tail at all, and their arms are long and strong. Gibbons swing hand over hand through the treetops, orangutans climb slowly through the forests of Borneo and Sumatra, and gorillas, the largest primates, spend much of their day on the ground eating leaves and stems. Here is the quick test: a tail means a monkey (or a prosimian); no tail means an ape.

Try it and see. Tape your thumb to the side of your hand and try to button a shirt, tie a shoe or pick up a pencil and write your name. You will discover how much work your thumb does every minute. In this lesson's project you will turn that into a fair test with a timer.

God's handiwork. Linnaeus placed people beside the apes in his chart because he sorted by body parts he could see and count: hands, eyes, teeth. Our bodies do share many features with theirs, and the same Maker designed them all. But the Bible teaches that only people were made in the image of God (Genesis 1:27). A chimpanzee can strip a twig to fish for termites, but only a person writes down what she sees, asks why, gives thanks and prays. Jane Goodall's notebook is itself a sign of that difference.

PICTURE STUDY



Tropical Forest with Monkeys, Henri Rousseau, 1910 · Oil on canvas · National Gallery of Art, Washington, D.C.

Henri Rousseau was a French painter who worked many years as a tax collector in Paris and taught himself to paint. He never traveled to a jungle. Instead, he walked through the great glass greenhouses of the Jardin des Plantes, the botanical garden of Paris, and studied pictures of animals in books, then built his own imaginary forests leaf by leaf.

He painted this picture in the last year of his life. The leaves are bigger and neater than real ones, and the monkeys look like characters in a story, but the painting is full of the feeling of a crowded, living forest.

Look closely

- Count the monkeys. Where is each one, and what is it holding?
- Look at how the monkeys hold on. Are they using hands, feet or tails?
- Find the leaves of different shapes. How many kinds of green can you see?
- Rousseau never saw a real jungle. Which parts look true to life, and which look made up?

Talk about it

1. Are these animals monkeys or apes? What clue in the painting helps you decide?
2. Which primate features from the lesson would help a real monkey live in a forest like this one?
3. How is studying a greenhouse in Paris different from what Jane Goodall did at Gombe?

> **Safety first.** Tape the thumb loosely with masking or painter's tape, not so tight that it hurts or turns colors, and take the tape off right after each trial. At a zoo, never put hands or food through a fence; monkeys and apes are very strong and can bite.

EXPERIMENT: HOW MUCH DOES A THUMB HELP?

Question: How much longer does it take to do an everyday job without using your thumb? **Prediction:** write your guess, in seconds.

What we change: thumb free or thumb taped. **What we keep the same:** the same person, the same shirt and buttons, the same hand and the same starting position. **What we measure:** the time, in seconds, to fasten five buttons. Doing three trials each way and finding the average makes the result more trustworthy.

You will need

- A button-up shirt with at least five buttons (a parent's shirt laid on a table works well)
- Masking tape or painter's tape
- A stopwatch or a phone timer, and a helper
- A pencil and your lab notebook

Steps

1. Lay the shirt flat on a table, unbuttoned. In your notebook, draw a table with two columns, Thumb free and Thumb taped, and three rows for Trials 1, 2 and 3.
2. Write your prediction.
3. Thumb free, Trial 1: with your hands flat on the table, wait for your helper to say "Go." Fasten all five buttons. Your helper stops the timer when the fifth button is done. Record the time.
4. Unbutton the shirt and do Trials 2 and 3 the same way.
5. Have your helper tape the thumb of each hand loosely against the side of the hand, so the thumb cannot move across the palm.
6. Do three thumb-taped trials in exactly the same way. Remove the tape between trials if it feels tight.
7. Find the average for each column: add the three times and divide by 3.
8. Draw a bar graph with two bars, like the one in this lesson, and write a sentence that answers the question.

Tips

- Practice once before you start timing, so that learning the task does not change your results.
- Try other tasks too: picking up ten coins, tying a shoe, writing your name. Which task needs the thumb most?

Check your work

- I changed only one thing: thumb free or thumb taped.
- I did three trials each way and found the averages.
- I made a bar graph of my results.
- I can explain why an opposable thumb helps a primate.

NATURE NOTEBOOK

1. Trace your hand in your notebook. Draw arrows to show how your thumb moves across your palm. Label the thumb, fingers, nails and fingertip pads.
2. Draw a monkey with a prehensile tail and an ape with no tail side by side. Under each, write its group and two features.
3. At a zoo, in a book or in a nature film, watch a primate for five minutes. Write down every time it uses its hands, feet or tail, and what it was doing.

> **From history.** Carl Linnaeus first used the name *Primates* for this order in the 10th edition of *Systema Naturae* in 1758. The Latin word means “of the first rank,” because he placed the order first in his list of mammals. Like his other groups, he defined it by features he could see and count, including the front teeth and the hands.

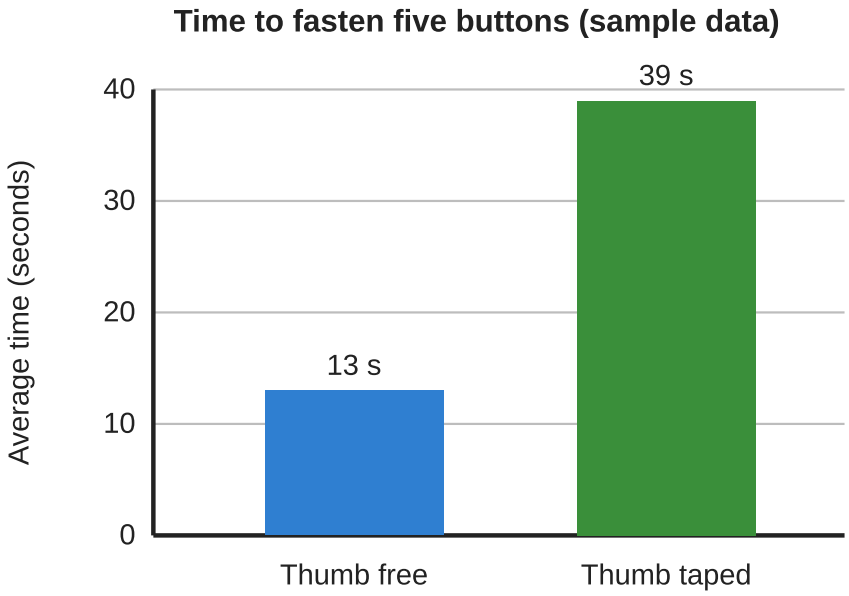
WORKED EXAMPLES

Example 1. Use this key to sort four primates: a ring-tailed lemur, a spider monkey, a baboon and a gorilla. Key: 1a. Big eyes, wet nose, small body: **prosimian**. 1b. Dry nose: go to 2. 2a. No tail: **ape**. 2b. Has a tail: go to 3. 3a. Tail can grab branches: **monkey of the Americas**. 3b. Tail cannot grab: **monkey of Africa or Asia**.

1. Ring-tailed lemur: big eyes and a wet nose (1a). It is a prosimian.
2. Spider monkey: dry nose (1b), a tail (2b), and the tail grabs branches (3a). It is a monkey of the Americas.
3. Baboon: dry nose (1b), a tail (2b), but the tail cannot grab (3b). It is a monkey of Africa.
4. Gorilla: dry nose (1b) and no tail (2a). It is an ape.

Answer: Prosimian: ring-tailed lemur. Monkeys: spider monkey (Americas) and baboon (Africa). Ape: gorilla.

Example 2. A student timed how long it took to fasten five buttons. Thumb free: 12, 14 and 13 seconds. Thumb taped: 36, 39 and 42 seconds. Find each average. How many seconds longer did it take with the thumb taped, and how many times as long?



Sample data: average time to fasten five buttons.

1. Thumb free: 12 + 14 + 13 = 39 seconds. 39 ÷ 3 = 13 seconds.
2. Thumb taped: 36 + 39 + 42 = 117 seconds. 117 ÷ 3 = 39 seconds.
3. Difference: 39 − 13 = 26 seconds longer.
4. Times as long: 39 ÷ 13 = 3.

Answer: Averages: 13 seconds with the thumb free and 39 seconds with it taped. Taping the thumb took 26 seconds longer, 3 times as long.

PRACTICE

1. EASY Name three features that most primates share.
2. EASY What is the quickest way to tell a monkey from an ape?
3. MEDIUM What did Jane Goodall see David Greybeard do at the termite mound, and why was it important?
4. MEDIUM Why do forward-facing eyes help a primate that leaps from branch to branch?
5. MEDIUM Read the table. Ring-tailed lemur: long tail, cannot grab, Madagascar. Spider monkey: long tail, can grab, South and Central America. Baboon: tail, cannot grab, Africa. Gibbon: no tail, Asia. Orangutan: no tail, Borneo and Sumatra. (a) Which animals have no tail? What group are they? (b) Which animal could hang from a branch by its tail? (c) How many of the five live in Asia, counting Borneo and Sumatra as Asia?

6. HARD A student wants to test whether taping the thumb slows a person down when picking up ten coins from a table. (a) What is the one thing the student changes? (b) What is the control? (c) Name two things that must stay the same. (d) What is measured?
7. HARD Gorillas have large canine teeth. Does that mean gorillas are meat eaters? Use what you learned about teeth in Lesson 5.1.
8. CHALLENGE Linnaeus put people in the same order as apes because of hands, eyes and teeth. Write two or three sentences explaining how a person is like a chimpanzee in body, and how the Bible says a person is different.

COMMON MISTAKES

- Calling apes “monkeys.” Gorillas, chimpanzees, orangutans and gibbons are apes, and they have no tails.
- Thinking every primate lives high in the trees. Baboons and gorillas spend much of their time on the ground.
- Thinking all primates are big and fierce. Many are small and gentle; some lemurs and galagos would fit in your hands.

> **Make it a game · Monkey or Ape?.** A parent calls out a primate: gorilla, capuchin, gibbon, baboon, orangutan, spider monkey, chimpanzee, lemur, howler monkey, bonobo. If it is an ape, stand tall and swing your arms over your head. If it is a monkey, curl one arm behind you like a tail. If it is a prosimian, make big round eyes with your fingers. One point for each right move. Bonus point if you can name one place where that animal lives.

> **Scripture.** “So God created man in his own image, in the image of God created he him; male and female created he them.” (Genesis 1:27, KJV)

Primates are wonderful creatures with clever hands and bright eyes. Yet only man and woman were made in God’s own image, to know Him, to rule over the creatures with care and to study His works as Jane Goodall did.

Practice answers

1. Any three of: grasping hands (often with an opposable thumb), forward-facing eyes, nails instead of claws on most fingers and toes, and a large brain for their body size.
2. Look for a tail. Monkeys usually have tails; apes have no tail.
3. He poked a grass stem into a termite mound and pulled it out covered with termites to eat. Later chimpanzees were seen stripping leaves off twigs to make probes. It showed that wild chimpanzees use and even make simple tools.
4. Both eyes look at the same thing from slightly different places, which helps the animal judge how far away a branch is before it jumps.
5. (a) The gibbon and the orangutan; they are apes. (b) The spider monkey. (c) Two: the gibbon and the orangutan.
6. (a) Whether the thumb is free or taped. (b) The thumb-free trials are the control, the ones to compare against. (c) Any two of: the same person, the same ten coins, the same table, the

same hand, the same starting position, the same timer. (d) The time, in seconds, to pick up all ten coins.

7. No. Gorillas eat mostly leaves, stems, shoots and fruit. Their wide, flat molars are made for grinding plants. Big canines alone do not prove a meat diet; you must look at the cheek teeth and at what the animal is seen eating.
8. Sample answer: Like a chimpanzee, a person has grasping hands with an opposable thumb, forward-facing eyes, nails and a large brain. But Genesis 1:27 teaches that only people are made in the image of God. People can reason about right and wrong, write, worship and pray, which no animal does.

5.4 The Bison Saved (1880s–1900s)

OBJECTIVES

- Classify the American bison (*Bison bison*) as a hoofed, cud-chewing herbivore in the cattle family and describe how its body fits life on the plains.
- Tell how William Hornaday, Mary Ann Goodnight, the people of Yellowstone and the American Bison Society saved the bison from vanishing in the 1880s–1900s.
- Estimate a large number by counting a sample, the way naturalists estimate the size of a herd.

Warm-up. Spill a handful of dried beans or rice onto a plate. Without counting one by one, guess how many there are and write your guess. Now count a small corner of the plate and think: could that help you make a better guess for the whole plate? Keep your guess for later in the lesson.

Video. Coming soon. American bison for kids: how the bison were saved, Yellowstone's wild herd, William Hornaday and the American Bison Society; search National Park Service (Yellowstone), U.S. Fish and Wildlife Service, Smithsonian, Smithsonian's National Zoo, nature footage of bison herds, and Homeschool Pop (Alternate).

KEY TERMS

bison
A large, shaggy, hoofed mammal of the cattle family, *Bison bison*, often called the buffalo. It is the largest land mammal in North America.

ruminant
A hoofed plant eater with a stomach of four parts that brings swallowed food back up to chew again. Cattle, bison, sheep and deer are ruminants.

herd
A large group of animals of one kind that live, feed and travel together.

estimate
A careful guess of a number, made by measuring or counting part of something and figuring out the rest.

conservation
Wise care and protection of living things and the land, so they last for future generations.

CORE IDEAS

The story. In 1886, William Temple Hornaday, the chief taxidermist of the United States National Museum in Washington (part of the Smithsonian), went to look at the museum's bison specimens. He found that it had almost none worth showing, and he set out for the plains of Montana to collect some while he still could. Not many years before, travelers had

described herds so large that they took days to pass. Now Hornaday and his men searched the hills for weeks and found only small, scattered bands. He brought back skins and skeletons and made a lifelike group of bison for the museum, but he never forgot that empty land. In 1889 he wrote a book reporting his count: fewer than 1,100 bison were left in all of North America, counting the wild ones in Canada and the ones kept in zoos and on ranches.

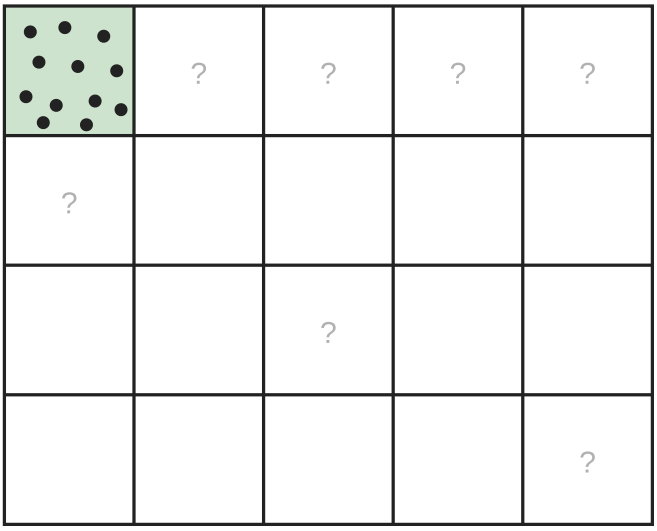
What happened to the herds. Bison had fed the Lakota, Cheyenne, Comanche, Blackfeet and other Plains nations for generations, giving them meat, robes, tools and lodge covers. In the 1870s, new ways of tanning made bison hides valuable as tough leather, including for the belts that turned machines in factories. Railroads now crossed the plains, so hunters could ship hides east by the trainload. Hide hunters shot bison by the thousands, often leaving the meat to rot, and farms, ranches and fences spread across the grassland. In a few short years the great herds were gone.

How they saved them. The rescue came from ordinary people as well as famous ones. A Pend d'Oreille man named Samuel Walking Coyote brought a few orphaned calves across the mountains to the Flathead country of Montana, and from them grew one of the largest herds of the time. In the Texas Panhandle, Mary Ann Goodnight, a rancher's wife, begged her husband Charles to help save orphaned calves, and their herd grew; its offspring still roam a Texas state park. In Yellowstone, the first national park, a few wild bison, about two dozen, hid in the high valleys. A law of 1894 made killing them a crime, soldiers guarded them, and in 1902 the park added bison bought from the Goodnight herd and from a Montana herd. In 1905 Hornaday started the American Bison Society, with President Theodore Roosevelt as its honorary president. In 1907 the Bronx Zoo in New York sent 15 bison by train to the Wichita Mountains of Oklahoma, where Comanche people, among them the leader Quanah Parker, came to see the bison return. In 1908 Congress set aside the National Bison Range in Montana.

The big idea. The bison, *Bison bison*, is a mammal in the same family as cattle, sheep and goats. Use what you learned in Lesson 5.1: like a cow, it has no upper front teeth, and it grinds grass with wide, ridged molars. It is a **ruminant**. It swallows grass, later brings it back up as cud and chews it again, and its four-part stomach breaks the tough grass down. A grown bull can stand about 1.8 m (6 ft) tall at the shoulder and weigh about 900 kg (2,000 lb), yet it can run about 55 km per hour (35 mph). The big hump is muscle, held up by long spines on the backbone. It lets the bison swing its huge head from side to side like a snowplow to sweep snow off the grass in winter. Its winter coat is so thick that snow can rest on its back without melting.

In the world today. Bison now number in the hundreds of thousands, most of them on private ranches, with herds on public lands such as Yellowstone, where thousands roam free. In 2016 the bison became the national mammal of the United States. When naturalists want to know how many bison are in a herd too big to count one by one, they **estimate**: they count the animals in one part of the area, from the ground or from the air, and multiply. You will try that in this lesson's project. The bison story shows biblical stewardship at work, good people who cared for creatures God made and gave them room to grow.

Estimating a herd by counting one square



20 squares in all

Counted: 12 beans in 1 square

Estimate:
12 × 20 = 240

To estimate a big herd, count one square and multiply by the number of squares.

PICTURE STUDY



The Last of the Buffalo, Albert Bierstadt, 1888 · Oil on canvas · National Gallery of Art, Washington, D.C. (Corcoran Collection)

Albert Bierstadt was born in Germany and grew up in Massachusetts. He traveled west many times and became famous for enormous paintings of the Rocky Mountains and the Yosemite Valley. By 1888 he knew that the great bison herds he had seen on his early journeys were nearly gone.

In this painting he did not show one real day. He gathered many scenes into one canvas: the hunt, the herds, the bones, the open land. It is a picture of remembering, made at the very time when Hornaday and others were starting to save the last bison.

Look closely

- Find the rider on the white horse. What is happening between the rider and the bison?
- Look at the ground in front. What lies in the grass? What do these things tell you?
- Look far back toward the mountains. How many herds of animals can you find?
- Find a bison up close. How does Bierstadt show its hump, its shaggy coat and its horns?

Talk about it

1. Why do you think Bierstadt called this painting *The Last of the Buffalo*?
2. The painting shows the herds as they had been, but it was made when only a few bison were left. How does it make you feel about the people who saved them?
3. If you could paint the next chapter of the bison story, what would you show?

> **Safety first.** Bison are wild animals, not pets. In a park, stay in your car or at least 25 yards (about 23 m) away from bison, as the National Park Service asks; they can run fast and charge without warning. Keep dried beans away from little brothers and sisters, who might put them in their mouths or noses.

EXPERIMENT: COUNT THE HERD: HOW GOOD IS AN ESTIMATE?

Hornaday could not line up every bison to count it, and neither can park scientists today. They count part of an area and multiply. In this experiment, dried beans spread on a grid are your herd.

Question: Does counting more sample squares give a better estimate? **Prediction:** write your guess. **What we change:** the number of squares we count (1 square or 4 squares). **What we keep the same:** the same beans, the same grid and the same spreading. **What we measure:** how far each estimate is from the true count.

You will need

- A large sheet of paper or poster board, about 50 cm by 40 cm (20 in by 16 in)
- A ruler and a marker
- Two or three big handfuls of dried beans (the herd)
- A small cup
- A pencil and your lab notebook

Steps

1. Use the ruler to draw a grid of 20 equal squares on the paper: 5 across and 4 down, each 10 cm (4 in) on a side.

2. Have a helper scatter the beans evenly over the whole grid, as a herd spreads across a valley. Do not count them yet.
3. Estimate with 1 square: pick one square without looking, count the beans in it, and multiply by 20. Write the estimate.
4. Estimate with 4 squares: pick four squares in different parts of the grid, count the beans in all four, divide by 4 to find the average per square, and multiply by 20. Write the estimate.
5. Now find the true count. Scoop the beans into the cup a few at a time, counting carefully in groups of ten.
6. For each estimate, subtract to find how far it was from the true count.
7. Spread the beans again and repeat the whole test once more. Which method came closer both times? Write your answer to the question.

Tips

- Pick squares from different parts of the grid. Real herds bunch up near water and good grass, so counting only one spot can fool you.
- If a bean sits on a line, decide on a rule before you start, such as “count it in the square to its left or above it,” and use the same rule every time.

Check your work

- I wrote a prediction.
- I made a 1-square estimate and a 4-square estimate the same way each time.
- I found the true count and how far off each estimate was.
- I can explain why counting more samples usually gives a better estimate.

NATURE NOTEBOOK

1. Draw a bison from the side. Label the hump, the horns, the shaggy winter coat, the hooves and the beard. Next to it, write its scientific name, *Bison bison*.
2. Make a timeline of the bison rescue from 1886 to 1908. Put at least five events on it, with a small picture for each.
3. Draw a bison’s head and teeth from a picture. Label the place where the upper front teeth are missing, and write: “herbivore, ruminant.”

> **From history.** After his trip to Montana, Hornaday kept a few live bison on the grounds of the Smithsonian in Washington, starting in 1887. Crowds came to see them, and his idea of a living collection of American animals helped lead to the founding of the National Zoo by Congress in 1889. In 2014, for its 125th birthday, the National Zoo brought American bison back to honor that beginning.

WORKED EXAMPLES

Example 1. A grid of 20 equal squares is covered with beans spread evenly. You count one square and find 12 beans. Estimate the number of beans on the whole grid.

(Use the map or drawing "Count one square, then multiply by 20." shown earlier in this lesson.)

1. Each square should hold about the same number of beans, because they are spread evenly.
2. Multiply the beans in one square by the number of squares: 12 × 20.
3. 12 × 20 = 12 × 2 × 10 = 24 × 10 = 240.

Answer: About 240 beans.

Example 2. A grown bison bull can weigh about 900 kg (2,000 lb). A 10-year-old child weighs about 30 kg (66 lb). About how many children would it take to balance one bull on a giant seesaw?

1. Divide the bull's mass by one child's mass: 900 kg ÷ 30 kg.
2. Think of it as 90 ÷ 3 = 30, so 900 ÷ 30 = 30.
3. Check with pounds: 66 × 30 = 1,980 lb, which is close to 2,000 lb.

Answer: About 30 children.

PRACTICE

1. EASY What did William Hornaday find when he went looking for bison in Montana in 1886?
2. EASY Is the bison a carnivore, a herbivore or an omnivore? Name one tooth clue.
3. MEDIUM What is a ruminant? Name the bison and two other ruminants.
4. MEDIUM Name three people or groups who helped save the bison, and tell one thing each one did.
5. MEDIUM Read this sample data from the bean experiment. Trial 1: true count 300; 1-square estimate 220; 4-square estimate 290. Trial 2: true count 300; 1-square estimate 380; 4-square estimate 310. (a) How far off was each estimate? (b) Which method was closer both times?
6. HARD In the bean experiment, (a) what is the one thing you change? (b) Name two things that must stay the same. (c) What do you compare each estimate against?
7. HARD A park scientist flying over a valley divides it into 25 equal sections. She counts 16 bison in one section. Estimate the herd. Then tell why she might count several sections instead of one.
8. CHALLENGE Explain how a bison's hump, its winter coat and its teeth each help it live on cold, grassy plains.

COMMON MISTAKES

- Thinking the bison and the buffalo are two different animals in America. In North America “buffalo” is a common nickname for the bison; true buffalo are the water buffalo of Asia and the Cape buffalo of Africa.
- Thinking the hump is fat or stored water, like a camel’s is often wrongly said to be. A bison’s hump is muscle held up by long spines on its backbone.
- Thinking an estimate is just a wild guess. A good estimate is built from a careful count of a sample and some arithmetic.

Make it a game · Save the Herd. Put 5 dried beans in a bowl: that is your little herd. Take turns with a parent answering questions from this unit. For each right answer, add 2 beans to the herd, as calves born in spring. For a wrong answer, take 1 bean away. After ten questions, count your herd. Can you grow it to 25 beans, more than 15 bison sent to Oklahoma in 1907?

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

The bison of the plains belong to God, who made them. When people like Hornaday and the Goodnights cared for the last few bison, they were doing what God asked of Adam: to dress the garden and to keep it (Genesis 2:15).

Practice answers

1. He found only small, scattered bands where huge herds had once lived. By 1889 he reported fewer than 1,100 bison left in all of North America.
2. A herbivore. Like a cow, it has no upper front teeth, and it has wide, ridged molars for grinding grass.
3. A ruminant is a hoofed plant eater with a four-part stomach that brings swallowed food back up as cud to chew again. Examples: bison, and any two of cattle, sheep, goats or deer.
4. Any three, for example: William Hornaday reported how few were left and started the American Bison Society in 1905. Mary Ann and Charles Goodnight raised a herd from orphaned calves in Texas. Samuel Walking Coyote brought orphaned calves to Montana. Theodore Roosevelt was honorary president of the American Bison Society. The Bronx Zoo sent 15 bison to the Wichita Mountains in Oklahoma in 1907. Yellowstone protected its last wild bison and added more in 1902.
5. (a) Trial 1: 1-square was 300 − 220 = 80 off; 4-square was 300 − 290 = 10 off. Trial 2: 1-square was 380 − 300 = 80 off; 4-square was 310 − 300 = 10 off. (b) The 4-square method was closer both times.
6. (a) The number of squares counted (1 or 4). (b) Any two of: the same beans, the same grid, the same way of spreading, the same rule for beans on a line, the same multiplier of 20. (c) The true count, found by counting every bean.
7. 16 × 25 = 400 bison. Bison bunch up near water and good grass, so one section might have many more or many fewer than the rest. Counting several sections and averaging gives a better estimate.

8. The hump is strong muscle on long backbone spines that lets the bison swing its head like a snowplow to clear snow off the grass. The thick winter coat holds in body heat so well that snow can rest on its back without melting. Its wide, ridged molars and four-part stomach let it grind and digest tough grass, the main food of the plains.

Unit 5 review

Answer each question. Show your work for calculations and use complete sentences for explanations. The review is worth 50 points.

1. (5 pts) Name the four kinds of mammal teeth and give the job of each.
2. (5 pts) Animal A has long canines and cheek teeth with sharp edges like scissors. Animal B has no upper front teeth and wide, flat, ridged molars. What does each animal eat? Name one animal that could be A and one that could be B.
3. (5 pts) A grown person’s tooth formula for one side is: top 2 incisors, 1 canine, 2 premolars, 3 molars; bottom the same. How many teeth does a grown person have in all? Show your work.
4. (5 pts) Name the three groups of mammals sorted by how their babies begin life. Give one example of each.
5. (5 pts) Describe a newborn kangaroo and how it gets to the pouch. Then name the only marsupial that lives wild in the United States.
6. (5 pts) In the pouch experiment, one jar of warm water went into a sock pouch and one stayed on the table. Name the one thing that was changed, two things that were kept the same, and what was measured.
7. (5 pts) List three features of primates and explain how one of them helps a primate live in the trees.
8. (5 pts) Classify each as a prosimian, a monkey or an ape: gorilla, spider monkey, ring-tailed lemur, orangutan. What did Jane Goodall see chimpanzees do at Gombe in 1960?
9. (5 pts) Tell the story of how the bison was saved. Include William Hornaday, at least one other person or group, and one place where bison were protected.
10. (5 pts) A valley is divided into 25 equal sections. A scientist counts 8 bison in one section. Estimate the whole herd. Then tell what kind of eater the bison is and what “ruminant” means.

Unit project: my mammal field book

Make a small field book of eight mammals, at least one from each lesson’s group: a carnivore, a herbivore, an omnivore, a marsupial, a monotreme, a monkey, an ape and the bison. Give each mammal its own page with a careful drawing, its common name and scientific name, a sketch of its teeth with its diet labeled, its mammal group (monotreme, marsupial or placental), where it lives and one amazing fact.

At the back, add your lab pages from the unit (the Tooth Tools Test, the pouch experiment, the thumb test bar graph and the bean-count estimate) and a timeline of how the bison was saved from 1886 to 1908. Finish with a short paragraph on how people can care wisely for the animals God made.

- **Accuracy**: Each mammal is classified correctly by diet and by group, with correct names and true facts.

- **Observation**: Drawings are careful and labeled, including the teeth, and show the features that place each mammal in its group.
- **Lab records**: All four experiments include a question, a prediction, what was changed and kept the same, a data table with units, and a conclusion.
- **Care and explanation**: The book is neat and complete, the bison timeline is correct, and the closing paragraph explains stewardship with real examples.

Answer key

1. Incisors cut and nip; canines pierce and hold; premolars slice and crush; molars grind.
2. Animal A is a carnivore (meat eater), such as a cat or a wolf. Animal B is a herbivore (plant eater), such as a cow or a bison.
3. Top one side: 2 + 1 + 2 + 3 = 8. Bottom one side: 8. One side: 8 + 8 = 16. Both sides: 16 × 2 = 32 teeth.
4. Monotremes lay eggs (platypus or echidna). Marsupials have tiny babies that grow in a pouch (kangaroo, koala, wombat or opossum). Placental mammals grow longer inside the mother (bison, dog, mouse or many others).
5. A newborn kangaroo is about the size of a jelly bean, pink, hairless and blind, with tiny back legs. It climbs up through its mother's fur with its strong front legs into the pouch by itself, fastens onto a teat and drinks milk. The only wild marsupial in the United States is the Virginia opossum.
6. Changed: pouch or no pouch. Kept the same (any two): jar size, amount of water, starting temperature, room, length of time, way of measuring. Measured: the water temperature every 10 minutes.
7. Any three of: grasping hands (often with an opposable thumb), forward-facing eyes, nails instead of claws, a large brain for its size. Example: forward-facing eyes help it judge how far away a branch is before it leaps; grasping hands hold on to branches.
8. Gorilla: ape. Spider monkey: monkey. Ring-tailed lemur: prosimian. Orangutan: ape. Goodall saw chimpanzees poke grass stems and stripped twigs into termite mounds to fish out termites, so they make and use tools. She also saw them eat meat.
9. Sample answer: In 1886 Hornaday found only a few bison left in Montana, and by 1889 he reported fewer than 1,100 in all of North America. Mary Ann and Charles Goodnight raised a herd in Texas from orphaned calves, and Samuel Walking Coyote brought calves to Montana. Yellowstone protected its last wild bison by law in 1894. In 1905 Hornaday started the American Bison Society with Theodore Roosevelt as honorary president, and in 1907 the Bronx Zoo sent 15 bison to the Wichita Mountains of Oklahoma. The National Bison Range in Montana followed in 1908.
10. 8 × 25 = 200 bison. The bison is a herbivore. A ruminant is a hoofed plant eater with a four-part stomach that brings food back up as cud to chew again.

UNIT 6

Plants Classified

On the third day of creation God said, “Let the earth bring forth grass, the herb yielding seed, and the fruit tree yielding fruit after his kind, whose seed is in itself, upon the earth: and it was so” (Genesis 1:11). In this unit you will sort the green world the way botanists do, by asking a few careful questions. Does the plant have tubes inside? Does it make spores or seeds? Do its seeds lie bare on a cone, or are they wrapped inside a fruit? Those questions divide plants into four big groups: **mosses**, **ferns**, **conifers** and **flowering plants**.

You will meet a London doctor who found a fern growing in a sealed bottle, a Scottish explorer who shot giant cones out of the tallest pines in Oregon, and a German schoolteacher who discovered why a wild geranium has hairs over its nectar. You will measure how much water moss can hold, watch a pine cone close in water, take a flower apart, and count petals and leaf veins to tell monocots from dicots.

Finally you will learn to press plants the way botanists have done since Luca Ghini in the 1500s, and build a small herbarium of your own, with every specimen carefully labeled. By the end, a walk outdoors will never look the same: you will see spores, cones, flowers and fruits everywhere, each made by God “after his kind.”

BEFORE YOU BEGIN

- Can use a simple dichotomous key (Unit 1, Lesson 1.4)
- Knows the main parts of a plant: root, stem, leaf and flower
- Can measure length in centimeters and mass in grams
- Can add, subtract and find a simple average

MASTERY CHECKLIST

- I can sort plants into mosses, ferns, conifers and flowering plants using a key.
- I can explain the difference between a spore and a seed, and between a nonvascular and a vascular plant.
- I can tell a pine, a spruce and a fir apart by their needles, and explain how a conifer’s seeds grow on cones.
- I can name the parts of a flower, explain pollination, and tell how a flower’s ovary becomes a fruit.
- I can classify a flowering plant as a monocot or a dicot by its flower parts and leaf veins.
- I can press, mount and label a plant specimen and run a fair test with a variable and a control.

OPTIONAL BOOKS AND RESOURCES

- **USDA PLANTS Database** (https://plants.usda.gov/): Free. Look up any plant growing in the United States by its common or scientific name, see where it grows, and find its family. Helpful for writing collection labels (Lesson 6.4).
- **Smithsonian National Museum of Natural History, Department of Botany** (https://naturalhistory.si.edu/research/botany): Free. Learn about the U.S. National Herbarium and see how real botanists collect, press and store plant specimens.
- **iNaturalist** (https://www.inaturalist.org/): Free. A parent can photograph a plant on your walk and get help identifying it. Children under 13 need a parent's permission to have an account, so a parent should run the account and post the observations.

6.1 Mosses and Ferns: Plants with Spores ★

OBJECTIVES

- Tell how Nathaniel Bagshaw Ward found a fern growing in a closed glass bottle and how his discovery led to the Wardian case.
- Explain the difference between nonvascular plants (mosses) and vascular plants (ferns), and explain how both make new plants from spores instead of seeds.
- Use a simple key to sort plants into four groups, and run a fair test measuring how much water moss can hold.

Warm-up. Find a clump of moss in a sidewalk crack, on a shady rock or at the base of a tree (or use a pinch of dried moss from a garden center). Look at it with a magnifying glass. Can you find roots? Flowers? Seeds? Now press it gently with your finger. Is it dry or damp? Write down three things you notice, and one question you have.

Video. Coming soon. Mosses and ferns for kids, spores, fern fiddleheads unrolling and moss spore capsules: search Smithsonian, SciShow Kids, Homeschool Pop (Alternate), Moody Science classics, botanical garden channels, and time-lapse nature footage of fiddleheads uncurling.

KEY TERMS

spore
A tiny speck, usually a single cell, that can grow into a new moss or fern. Unlike a seed, it has no baby plant and no stored food inside.

nonvascular plant
A plant with no tubes inside to carry water and food. Mosses are nonvascular, so they stay small and soak up water like a sponge.

vascular plant
A plant with tiny tubes inside its roots, stems and leaves that carry water and food. Ferns, conifers and flowering plants are vascular.

rhizoid
A thin, hairlike thread that holds a moss to soil, bark or rock. It is not a true root.

frond
The leaf of a fern. A young frond comes up rolled tight and is called a fiddlehead.

sorus (plural sori)
A small cluster of spore cases, seen as a brown or orange dot on the underside of a fern frond.

CORE IDEAS

The story. In London around 1829, a doctor named Nathaniel Bagshaw Ward had a sad hobby. He loved ferns, but the smoky city air killed every fern he tried to grow on an old wall in his garden. Ward also collected insects. One day he buried the chrysalis of a sphinx moth in damp soil inside a glass bottle and closed the lid, so he could watch the moth come out. Before the moth appeared, something else did. A tiny green fern and a little grass sprouted from the soil. Ward set the bottle on his windowsill and left it shut. The fern kept growing, healthy and green, for years, without a single drop of new water.

How they figured it out. Ward watched closely. In the warmth of the day, water rose from the damp soil and the leaves, beaded up on the inside of the glass, and ran back down into the soil. The closed bottle made its own little rain, and the glass kept out the city's soot. Ward built bigger glass boxes, now called **Wardian cases**. In 1833 he packed plants into two of them and sent them on the long voyage from England to Australia. The plants arrived alive. In 1842 he wrote a book about growing plants in closed glass cases, and soon families all over Britain kept ferns in glass cases in their parlors. And where had Ward's fern come from? It grew from a speck too small to see, a **spore**, that had been waiting in the soil.

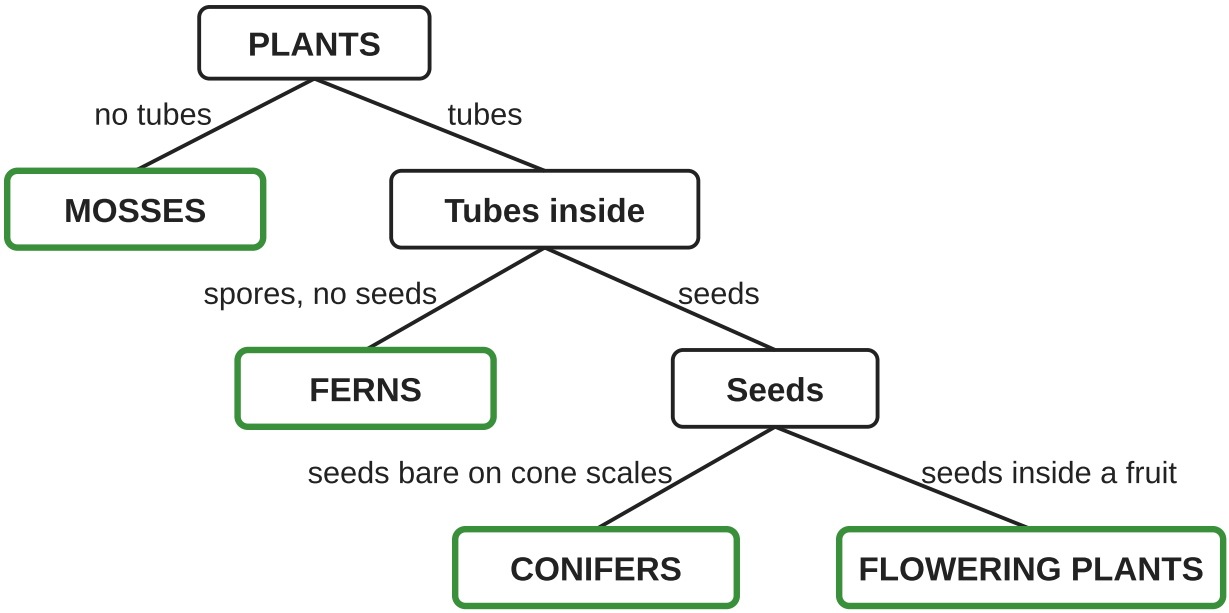
The big idea. Botanists sort plants first by asking, "Does it have tubes inside?" (see the key in the figure). **Mosses** are **nonvascular plants**. They have no tubes to carry water, so they soak it up through their thin leaves like a sponge. They have no true roots, only hairlike **rhizoids** that hold them to rock, bark or soil. Because water cannot travel far inside them, mosses stay short and grow packed together in soft green carpets. **Ferns** are **vascular plants**. Tubes run through their roots, stems and leaves, so ferns can grow much taller; some tropical tree ferns grow taller than a two-story house. A fern's leaf is called a **frond**. A new frond comes up rolled tight like the top of a violin, so we call it a **fiddlehead**.

Spores, not seeds. Mosses and ferns never make flowers or seeds. Instead they make spores. A moss holds its spores in a tiny capsule on top of a thin stalk. A fern carries them in brown dots called **sori** on the underside of its fronds. Many people think those dots are bugs or a disease, but they are the fern's spore cases. A spore is not a seed. It has no baby plant and no packed lunch of stored food inside. The wind carries spores far, and where one lands on damp ground it can grow into a new plant. Mosses and ferns also need a film of water to make new plants, which is why you find them in wet woods, beside streams and on the shady side of rocks.

Try it and see. Lay a fern frond with brown dots face-down on a sheet of white paper, cover it with a bowl, and leave it overnight. In the morning, lift the frond. A fine brown dust, thousands of spores, will be printed on the paper in the shape of the dots. One kind of moss, sphagnum or peat moss, can hold many times its own weight in water, which is why gardeners use it. In this lesson's project you will measure just how much.

God's handiwork. King Solomon studied plants "from the cedar tree that is in Lebanon even unto the hyssop that springeth out of the wall" (1 Kings 4:33). The smallest plants were worth a wise king's attention. Mosses are often among the first plants to grow on bare rock,

where they catch dust, hold water and help make a thin layer of soil for other plants. Even the green fuzz in a sidewalk crack has a job in God's world.



A simple key to the four big groups of plants in this unit.

PICTURE STUDY



Muscinae (Mosses), Plate 72 of Kunstformen der Natur, Ernst Haeckel; printed by Adolf Giltsch, 1904 · Color lithograph from Haeckel's drawings · Published in Leipzig and Vienna in the book *Kunstformen der Natur* ("Art Forms in Nature"). Printed copies are kept in libraries in many countries.

Ernst Haeckel was a German zoologist who drew living things with great care, often under a microscope. His book *Art Forms in Nature* came out in parts and was finished in 1904. Each of its hundred plates shows one group of living things arranged like a beautiful pattern.

In this plate Haeckel drew mosses, plants most people step on without a glance. He made the tiny spore capsules big enough to study, so you can see how the top of a capsule is built. When a capsule is ripe, its lid falls off and the spores drift out.

Look closely

- Find a whole moss plant. Can you see the leafy part at the bottom and the thin stalk rising above it?
- Find a spore capsule. Where on the plant does it grow?
- Look for a capsule drawn very large. What shapes do you see around its top?
- Notice how Haeckel arranged the drawings. Is the page balanced, with matching shapes on each side?

Talk about it

1. Why would a scientist draw a capsule much bigger than it really is?
2. Haeckel found beauty in a plant most people ignore. What small living thing near your home deserves a closer look?

> **Safety first.** Collect moss only with permission and take only a small piece, or use dried sphagnum moss from a garden center. Wear garden gloves when handling dried sphagnum moss, because it can carry a fungus that infects scratches on the skin, and wash your hands afterward. Never eat any part of a moss or fern. Wipe up spilled water right away so no one slips.

EXPERIMENT: THE MOSS SPONGE TEST: WHICH HOLDS THE MOST WATER?

Mosses have no tubes, so they hold water in and between their thin leaves. Gardeners say sphagnum moss holds water better than almost anything. You will test that claim like a real scientist. **Question:** Which holds the most water for its weight: dried sphagnum moss, cotton balls or paper towels? Write your **prediction** first.

You will need

- Dried sphagnum moss (sold in garden centers for lining hanging baskets), with garden gloves
- Cotton balls and paper towels
- A kitchen scale that measures in grams
- Three bowls of water and a kitchen strainer
- A timer, a towel for spills, and your science notebook

Steps

1. **What we change:** the material. **What we keep the same:** the dry mass of each sample (10 g), the soaking time (5 minutes), the dripping time (1 minute) and the water. **What we measure:** the mass of each sample after soaking.
2. Weigh out 10 g of dry moss, 10 g of cotton balls and 10 g of paper towels. Record each dry mass.
3. Put each sample in its own bowl of water. Push it under so it soaks completely. Wait 5 minutes.
4. Lift the first sample out with the strainer and let it drip for exactly 1 minute. Then weigh it at once and record the wet mass. Do the same with the other two.
5. For each sample, find the water held: wet mass minus dry mass.
6. Find how many times its own weight each sample held: water held ÷ dry mass.
7. Make a bar graph of the water held by each material. Was your prediction right?

Tips

- Weigh quickly after dripping, because water keeps draining out.
- If you can, repeat the test two more times and find the average for each material.

Check your work

- I changed only the material and kept the mass, soak time and drip time the same.
- I subtracted to find the water held and divided to find how many times its weight.
- I can explain why a plant with no tubes needs to hold water like a sponge.

NATURE NOTEBOOK

1. Draw a moss plant large on your page. Label the leafy part, the rhizoids, the stalk and the spore capsule.
2. Draw a fern frond and turn it over in a second drawing to show the sori. Draw one fiddlehead beside it.
3. Make a spore print from a fern frond (see “Try it and see”). Tape a piece of it in your notebook, or draw its pattern, and write the date and where you found the fern.

> **From history.** When Carl Linnaeus sorted plants in the 1700s, he could see how flowering plants made seeds, but he could not see how mosses and ferns made new plants. So he put them in a group he called *Cryptogamia*, meaning “hidden marriage.” In 1851 the German botanist Wilhelm Hofmeister, who studied plants under the microscope, finally showed step by step how mosses and ferns grow from spores and form new plants. A fern spore first grows into a tiny, flat, green, heart-shaped plant smaller than a fingernail, and the new fern grows out of that little heart.

WORKED EXAMPLES

Example 1. One family did the Moss Sponge Test. Each sample started at 10 g dry.
Sphagnum moss: wet mass 160 g
Cotton balls: wet mass 130 g
Paper towels: wet mass 70 g
How much water did each hold, and how many times its own dry weight is that? Which held the most?

1. Water held = wet mass − dry mass.
2. Moss: 160 g − 10 g = 150 g of water. 150 ÷ 10 = 15 times its dry weight.
3. Cotton: 130 g − 10 g = 120 g of water. 120 ÷ 10 = 12 times its dry weight.
4. Paper towels: 70 g − 10 g = 60 g of water. 60 ÷ 10 = 6 times its dry weight.
5. Compare: 150 g is the most. The moss held 2 and a half times as much water as the paper towels (150 ÷ 60 = 2.5).

Answer: Moss held 150 g (15 times its weight), cotton 120 g (12 times) and paper towels 60 g (6 times). The sphagnum moss held the most water. Your own numbers may be different, which is why scientists repeat tests.

Example 2. On a walk in a shady woods you find a plant about knee-high. Its leaves have veins, so it has tubes inside. It has no flowers anywhere, and there are rows of brown dots on the underside of its leaves. Use the key in the figure to classify it.

1. Start at the top: Does it have tubes inside? Yes, the veins show tubes, so it is not a moss. Go down the “tubes” branch.
2. Does it make spores or seeds? The brown dots are sori, clusters of spore cases, and there are no flowers, fruits or cones. Go down the “spores” branch.
3. The key ends at “Ferns.”
4. Check: ferns have fronds, tubes and sori. Everything fits.

Answer: It is a fern. The brown dots are its spore cases (sori), not insects or a disease.

PRACTICE

1. EASY Mosses are called nonvascular plants. What does that mean? What holds a moss onto a rock?
2. EASY Where would you look on a fern to find its spores? What are the spore clusters called?
3. EASY What is a fiddlehead, and why does it have that name?
4. MEDIUM A student counted moss clumps on the four sides of a large oak tree in a northern state.
   North side: 12

East side: 7
South side: 3
West side: 5
Which side had the most moss? How many clumps were there in all? Give one reason the north side might have more moss.

5. MEDIUM A pinch of dry sphagnum moss has a mass of 5 g. After soaking and dripping, it has a mass of 105 g. How much water did it hold? How many times its own dry weight is that?
6. MEDIUM Spanish moss hangs in gray curtains from oak trees in the American South. It has tubes inside and makes tiny flowers and seeds. Is it a true moss? Which group does it belong to?
7. HARD Design an experiment: Does moss stay greener if it is misted with water every day? Name the variable you change, what your control is, three things you keep the same, and what you observe or measure.
8. CHALLENGE In two or three sentences, explain why mosses stay short while some ferns can grow as tall as a house.

COMMON MISTAKES

- Thinking every plant called a “moss” is a moss. Spanish moss is a flowering plant, Irish moss is a seaweed, and reindeer moss is a lichen. Scientists classify by the plant’s parts, not its common name.
- Thinking the brown dots under a fern frond are insects or a disease. They are sori, the clusters of spore cases.
- Thinking moss always grows on the north side of trees, so it can be used as a compass. Moss grows wherever it stays damp and shady, which can be any side.

> **Make it a game · Spore or Seed?.** A parent names a plant or a plant part: moss, oak tree, fern, sunflower, pine tree, fiddlehead, apple, Spanish moss. You call out “Spore!” or “Seed!” and then name its group from the key: moss, fern, conifer or flowering plant. Score one point for the right call and one for the right group. Trick plants with “moss” in the name are worth double.

> **Scripture.** “And he spake of trees, from the cedar tree that is in Lebanon even unto the hyssop that springeth out of the wall: he spake also of beasts, and of fowl, and of creeping things, and of fishes.” (1 Kings 4:33, KJV)

Solomon studied the tall cedar and the little plant growing out of a wall. A wise naturalist looks closely at the small things too, like the moss in a crack and the fern on a shady bank.

Practice answers

1. Nonvascular means the moss has no tubes inside to carry water and food. Thin, hairlike rhizoids hold it onto the rock.
2. On the underside of the fronds (leaves). The clusters are called sori (one is a sorus).

3. A fiddlehead is a young fern frond that comes up rolled tight. It looks like the curled top of a fiddle (violin).
4. The north side had the most (12). Total: 12 + 7 + 3 + 5 = 27 clumps. In the northern half of the world, the north side of a tree gets the least direct sun, so it stays shadier and damper, and mosses need damp places. (Moss can grow on any side that stays damp, so it is not a reliable compass.)
5. 105 g − 5 g = 100 g of water. 100 ÷ 5 = 20 times its dry weight.
6. No. True mosses have no tubes and never make flowers or seeds. Spanish moss is a flowering plant (it belongs to the pineapple family), even though its name says “moss.”
7. Variable changed: misting (misted every day or not misted). Control: an identical tray of moss that is not misted. Keep the same: the kind of moss, the size of each piece, the containers, the amount of light and the temperature (any three). Observe: the color of each moss each day for two weeks (for example, rate it bright green, dull green or brown), and you could also weigh each tray.
8. Sample answer: Mosses have no tubes, so water has to soak slowly from cell to cell and cannot reach very far up. Ferns have tubes in their roots, stems and fronds that carry water from the ground up through the whole plant, so a fern can grow much taller and still get water to its top leaves.

6.2 Conifers: Seeds on Cones

OBJECTIVES

- Tell how the Scottish plant collector David Douglas found and recorded the Douglas fir and the sugar pine in the Pacific Northwest in 1825 and 1826.
- Explain what makes a plant a conifer: seeds lying bare on the scales of cones, pollen carried by the wind, and needles or scales for leaves.
- Use a key to tell pines, spruces and firs apart by their needles, and measure how a pine cone closes in water in a fair test.

Warm-up. Hold a dry, open pine cone. Count how many scales you can see around the bottom row. Shake it over a sheet of paper: does anything fall out? Now sniff a pine needle or a sprig from an evergreen (or a pine-scented candle if you have no tree nearby). Write down three things you notice about the cone and one question about it.

Video. Coming soon. Conifers for kids, how pine cones open and close, pine pollen clouds and seed wings, and giant sequoias and coast redwoods: search Smithsonian, U.S. Forest Service, National Park Service (Sequoia and Kings Canyon, Redwood), SciShow Kids, Homeschool Pop (Alternate), Science Max, and time-lapse footage of pine cones opening.

KEY TERMS

conifer
A plant that makes its seeds on cones. The word means “cone-bearer.” Pines, spruces, firs, cedars, junipers and redwoods are conifers.

gymnosperm
A seed plant whose seeds lie bare on a scale or stalk instead of inside a fruit. The word means “naked seed.” Conifers are gymnosperms.

cone
The part of a conifer that makes pollen or seeds. Seed cones are larger and usually woody; pollen cones are small and soft.

pollen
Fine dust made by a plant’s male parts. A conifer’s pollen is carried by the wind to its seed cones so seeds can form.

needle
A long, narrow, waxy leaf, like those of pines, spruces and firs.

evergreen
Keeping green leaves all year round. Most conifers are evergreen.

CORE IDEAS

The story. In April 1825 a young Scottish plant collector named David Douglas sailed into the mouth of the Columbia River in the Pacific Northwest. The Horticultural Society of London had sent him to find new plants that could be grown in Britain. All around him rose dark forests of giant evergreen trees. One of the most common had soft needles and hanging cones with little three-pointed tongues sticking out between the scales, like the back legs and tails of mice hiding inside. Douglas gathered its seeds and shipped them home, and soon these trees were growing in Britain. Today we call it the **Douglas fir**.

How they figured it out. The next year Douglas heard about a pine with huge cones and sweet seeds. He traveled south into what is now Oregon, and in October 1826 he found it: the **sugar pine**. The trees were so tall and straight that he could not climb them, so he shot the cones down with his gun. Sugar pine cones are the longest cones of any conifer, often 25 to 50 cm (10 to 20 in) long. Douglas did not just grab cones. He wrote down where each tree grew and how tall it was, and he described its bark, its needles, its cones and its seeds. Those are exactly the things botanists still use to classify a conifer.

The big idea. Conifer means “cone-bearer.” Conifers make seeds, but they never make flowers or fruit. Their seeds lie on the scales of woody cones, not shut up inside a fruit, so scientists call them **gymnosperms**, from Greek words meaning “naked seed.” A conifer makes two kinds of cones. In spring, small, soft **pollen cones** release clouds of yellow **pollen**, and the wind carries it to the larger **seed cones**. Inside a pine’s seed cone, two seeds form on each scale, each with a papery wing. When the cone dries, its scales open and the seeds spin away on the wind like little helicopters.

Needles tell the kind. Most conifers have **needles** or tiny scales instead of broad, flat leaves. A needle is narrow and coated with wax, so it loses little water, even in winter when the ground is frozen. That is why most conifers are **evergreen**. A few, like the larch (also called tamarack) and the bald cypress, turn gold and drop their needles each fall. To tell common conifers apart, look closely (see the figure). **Pines** have needles in bundles of 2, 3 or 5. **Spruces** have single needles that are four-sided and sharp, so they roll between your fingers. **Firs** have single needles that are flat and soft and will not roll. Remember: “flat, friendly fir.” Cedars and junipers have tiny overlapping scales. Cones help too: a true fir’s cones stand straight up on the branch, while pine and spruce cones hang down.

In the world today. Conifers include the tallest and the largest living trees on earth. Coast redwoods in California grow more than 110 m (360 ft) tall, and the giant sequoia called the General Sherman Tree is the largest single tree by volume. Most of the lumber that frames American houses comes from conifers, and so does much of our paper. Pine nuts are conifer seeds, and the blue “berries” of a juniper are really tiny cones with soft, fleshy scales.

God’s handiwork. “The trees of the LORD are full of sap; the cedars of Lebanon, which he hath planted” (Psalm 104:16). The great cedars of Lebanon in the Bible are conifers too. A pine cone is built so that it stays shut in wet weather and opens in dry, windy weather, just when its winged seeds can fly farthest.

PICTURE STUDY



Morning in a Pine Forest, Ivan Shishkin, with the bears painted by Konstantin Savitsky, 1889 · Oil on canvas · State Tretyakov Gallery, Moscow, Russia

Ivan Shishkin was a Russian painter who loved forests more than any other subject. He studied trees so carefully that people said you could tell the kind of every tree in his paintings. His friend Konstantin Savitsky, who was good at painting animals, added the bears. Later the gallery owner, Pavel Tretyakov, decided that Shishkin had done most of the work, and only Shishkin's name was left on the painting.

The scene shows an old pine forest at dawn, with mist still hanging between the trunks. A tall pine has snapped and fallen, and a bear family has found it.

Look closely

- Find the tall trunks rising into the mist. Are their lower branches thick or bare? Why might the lower branches of a crowded pine die?
- Find the fallen pine. Can you see where it broke?
- Count the bears. Which one is the mother?
- Look at the light. Where is the sun coming from, and how can you tell it is morning?

Talk about it

1. How would this forest look different if it were a forest of oaks and maples in autumn?
2. What might happen to the fallen pine over the next few years? What living things might use it?

> **Safety first.** Do not climb tall trees to reach cones; collect cones that have fallen to the ground. Pine sap is very sticky and hard to wash off, and cone scales can be prickly, so

> wear gloves if you like. Never eat needles, cones or seeds you find. The yew, a common hedge conifer with soft red berry-like cups, is poisonous: its needles and seeds can make people and pets very sick. Wash your hands after handling conifers. Use only warm tap water in any experiment, never hot water.

EXPERIMENT: PINE CONE WEATHER STATION: DOES WATER MAKE A CONE CLOSE?

People have long said a pine cone can tell the weather. Is it true? **Question:** What happens to an open pine cone when it is soaked in water, and what happens when it dries again? Write your **prediction** first.

You will need

- Two open pine cones of about the same size and kind
- A bowl of room-temperature water, deep enough to cover one cone
- A ruler marked in centimeters
- A timer, a towel and a plate
- Your science notebook

Steps

1. **What we change:** whether the cone is soaked in water. **The control:** the second cone, which stays dry on a plate beside the bowl. **What we keep the same:** the kind and size of the cones, the room and the times we measure. **What we measure:** the width of each cone across its widest part, in centimeters.
2. Measure the width of both cones before you start and record them.
3. Put one cone in the bowl of water and hold it under for a moment so it is soaked. Leave the other cone dry on the plate.
4. Measure both cones again after 30 minutes, 1 hour and 2 hours. Pat the wet cone gently with a towel before measuring.
5. Take the wet cone out and let it dry on the plate overnight. Measure both cones in the morning.
6. Make a table with columns: Time, Wet cone width, Dry cone width. Draw a line graph of the wet cone’s width over time.
7. Write a sentence answering the question. How could closing in wet weather help a pine tree?

Tips

- Measure the same way each time: across the widest part, with the ruler held straight.
- Mark the spot you measure with a tiny dab of paint or a twist tie so you measure the same place every time.

Check your work

- I kept a dry cone as a control and changed only the water.

- I measured in centimeters at the same times and recorded every number.
- I can explain why a cone that opens in dry weather helps its seeds travel.

NATURE NOTEBOOK

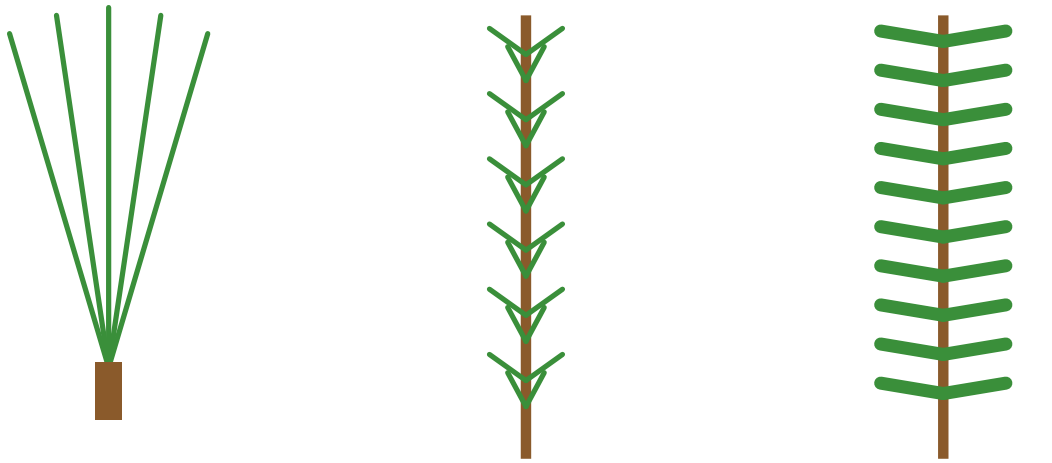
1. Draw a pine needle bundle, a spruce twig and a fir twig side by side. Label how many needles grow together and whether they are flat or four-sided.
2. Draw a pine cone large on your page. Pull out one scale (or find a loose one) and draw it, showing where the two winged seeds sat.
3. Find one conifer near your home. Draw its outline, one twig and one cone. Use the key from the worked example to name it, and write the date and place.

From history. The Douglas fir carries two men’s names. Its common name honors David Douglas, who sent its seeds to Britain in 1827. Its scientific name, *Pseudotsuga menziesii*, honors Archibald Menzies, a Scottish ship’s doctor and naturalist who first collected the tree in the early 1790s at Nootka Sound on Vancouver Island, during Captain George Vancouver’s voyage. *Pseudotsuga* means “false hemlock,” because botanists saw that the tree was not a true fir, a true hemlock or a true spruce, and needed a group of its own.

WORKED EXAMPLES

Example 1. You pick a twig from an evergreen. Its needles grow one at a time along the twig. Each needle is flat and soft, and when you try to roll it between your fingers, it will not roll. Use this key to name the tree.

1a. Leaves are tiny overlapping scales → cedar or juniper
1b. Leaves are needles → go to 2
2a. Needles grow in bundles of 2, 3 or 5 → pine
2b. Needles grow one at a time → go to 3
3a. Needles are four-sided and sharp, and roll between your fingers → spruce
3b. Needles are flat and soft, and will not roll → fir



Pine, spruce and fir needles. Look at how the needles are attached and what shape they are.

1. Step 1: The leaves are needles, not scales. Choose 1b and go to 2.
2. Step 2: The needles grow one at a time, not in bundles. Choose 2b and go to 3.
3. Step 3: The needles are flat and soft and will not roll. Choose 3b.
4. The key ends at “fir.” To check, look for cones: a true fir’s cones stand upright on the top branches.

Answer: The tree is a fir.

Example 2. In the Pine Cone Weather Station, one student recorded these widths:
Start: wet cone 7.0 cm, dry cone 7.0 cm
30 minutes: wet cone 5.5 cm, dry cone 7.0 cm
1 hour: wet cone 4.5 cm, dry cone 7.0 cm
2 hours: wet cone 4.0 cm, dry cone 7.0 cm
Next morning (after drying): wet cone 7.0 cm, dry cone 7.0 cm
How much did the wet cone close in 2 hours? In which time period did it close the most? What does the dry cone tell us?

1. Total change: 7.0 cm − 4.0 cm = 3.0 cm.
2. First 30 minutes: 7.0 − 5.5 = 1.5 cm. From 30 minutes to 1 hour: 5.5 − 4.5 = 1.0 cm. From 1 hour to 2 hours: 4.5 − 4.0 = 0.5 cm.
3. The biggest change, 1.5 cm, came in the first 30 minutes.
4. The dry cone stayed at 7.0 cm the whole time, so the change was caused by the water, not by time or the room.
5. The next morning the wet cone was back to 7.0 cm, so the cone opens again when it dries.

Answer: The wet cone closed 3.0 cm (from 7.0 cm to 4.0 cm, about 2.8 in to 1.6 in). It closed most in the first 30 minutes. The dry control cone did not change, which shows the water made the cone close.

PRACTICE

1. EASY What does the word “conifer” mean? Where do a conifer’s seeds grow?
2. EASY A conifer has two kinds of cones. Name them and tell what each one does.
3. EASY You find needles growing in bundles of five. What kind of tree is it?
4. MEDIUM A sugar pine cone is 50 cm long. About how many inches is that (1 in is about 2.5 cm)? A small pine cone from a backyard is 5 cm long. How many times longer is the sugar pine cone?
5. MEDIUM A student measured three needles from each of three trees.
   Tree A: 8 cm, 9 cm, 10 cm (in bundles of 5)
   Tree B: 2 cm, 2 cm, 2 cm (single, four-sided, sharp)
   Tree C: 13 cm, 14 cm, 15 cm (in bundles of 2)
   Find the average needle length for each tree. Which trees are pines, and what is Tree B?
6. HARD Design an experiment: Does a pine cone close faster in warm water or in cold water? Name the variable you change, three things you keep the same, what you measure, and your control.
7. HARD The Douglas fir has “fir” in its name, but its cones hang down from the branches and have three-pointed bracts sticking out. Is it a true fir? Explain how you know.
8. CHALLENGE A pine tree sends out huge yellow clouds of pollen in spring, but an apple tree makes much less pollen. In two or three sentences, explain why the pine needs so

much more.

COMMON MISTAKES

- Thinking every evergreen tree is a pine. Spruces, firs, cedars, junipers, hemlocks and redwoods are conifers too, and the needles and cones tell them apart.
- Thinking all conifers keep their needles all year. Larches (tamaracks) and bald cypresses turn gold and drop their needles every fall.
- Thinking the whole pine cone is a seed. The cone holds the seeds; each scale of a pine's seed cone carries two small winged seeds.

Make it a game · Pine, Spruce or Fir?. A parent gathers twigs from evergreens (or draws needles on cards). Close your eyes, take one, and use only your fingers: count the needles in a bundle, feel whether they are flat or four-sided, and try to roll one. Call out "Pine!", "Spruce!" or "Fir!" and then open your eyes to check. Score a point for each right answer, and a bonus point if you can name the clue that told you.

Scripture. "The trees of the LORD are full of sap; the cedars of Lebanon, which he hath planted; Where the birds make their nests: as for the stork, the fir trees are her house." (Psalm 104:16–17, KJV)

The psalm writer noticed that the great conifers are full of sap and are homes for birds. God planted them, and He planned their use for the creatures that live in them.

Practice answers

1. Conifer means "cone-bearer." Its seeds grow bare on the scales of its seed cones, not inside a fruit.
2. Pollen cones are small and soft and release pollen into the wind. Seed cones are larger and usually woody; they catch the pollen and grow the seeds.
3. A pine (a white pine has needles in bundles of five).
4. 50 ÷ 2.5 = 20 inches. 50 ÷ 5 = 10, so the sugar pine cone is 10 times longer.
5. Tree A: (8 + 9 + 10) ÷ 3 = 9 cm. Tree B: (2 + 2 + 2) ÷ 3 = 2 cm. Tree C: (13 + 14 + 15) ÷ 3 = 14 cm. Trees A and C are pines because their needles grow in bundles. Tree B is a spruce: single, four-sided, sharp needles.
6. Variable changed: the water temperature (warm tap water or cold water). Keep the same: the kind and size of cones, the amount of water, the size of the bowls and the measuring times (any three). Measure: the width of each cone in centimeters every 10 minutes, or the minutes until each is fully closed. Control: a third, matching cone kept dry, to show that the cones do not change on their own.
7. No. A true fir's cones stand straight up on the branch and fall apart there, so you rarely find a whole fir cone on the ground. The Douglas fir's cones hang down and fall whole, so it is not a true fir. Botanists put it in a different group of conifers, even though its common name says fir.
8. Sample answer: Pine pollen is carried by the wind, which blows it in every direction, so most grains never land on a seed cone. The tree must make enormous amounts so that a few reach

the right place. Apple blossoms are visited by bees that carry pollen straight from one flower to the next, so far less is wasted.

6.3 Flowering Plants: Seeds Inside Fruit

OBJECTIVES

- Tell how Christian Konrad Sprengel studied a wild geranium in 1787 and discovered how flowers and insects work together in pollination.
- Name the parts of a flower (sepal, petal, stamen, pistil, ovary) and explain how pollination leads to seeds inside a fruit.
- Classify flowering plants as monocots or dicots by counting flower parts and looking at leaf veins, and read and graph data on insect visits.

Warm-up. Look at three foods from your kitchen: a tomato, a green bean or pea pod, and an apple. Which of them do you think are fruits? Write your guesses. Now cut the apple across its middle (with a parent's help) and look at the core. What shape do the seed chambers make? Count them.

Video. Coming soon. Parts of a flower and pollination for kids, bees and hummingbirds visiting flowers, monocots and dicots, and seeds becoming fruit: search Smithsonian, U.S. Forest Service pollinator pages, SciShow Kids, Homeschool Pop (Alternate), Science Max, Moody Science classics, and slow-motion nature footage of bees collecting pollen.

KEY TERMS

flowering plant
A plant that makes flowers and grows its seeds inside a fruit. Scientists also call flowering plants angiosperms. They are the largest group of plants.

stamen
The male part of a flower that makes pollen. It has a stalk called the filament with a pollen box called the anther on top.

pistil
The female part in the center of a flower. It has a sticky top (stigma), a neck (style) and a swollen base (ovary) that holds the ovules, which become seeds.

pollination
Carrying pollen from an anther to a stigma. Insects, birds, bats or the wind can do it.

fruit
To a botanist, the ripened ovary of a flower that holds the seeds. Apples, tomatoes, pea pods, acorns and cucumbers are all fruits.

seed leaf
The first leaf or leaves packed inside a seed, also called a cotyledon. Monocots have one seed leaf; dicots have two.

CORE IDEAS

The story. In the summer of 1787, a schoolteacher named Christian Konrad Sprengel, the head of a school in Spandau near Berlin in Germany, was looking closely at a wild flower. It was a wood cranesbill, a purple wild geranium. At the base of each petal, Sprengel noticed a fringe of fine hairs, and just below the hairs, tiny drops of sweet nectar. Why would a flower have hairs there? Sprengel guessed that the hairs worked like a roof: they kept raindrops from washing away or spoiling the nectar, but an insect's thin tongue could still slip through to drink it.

How they figured it out. That one guess led to a bigger question: why do flowers make nectar at all? For several summers Sprengel watched flowers and the insects that visited them. He saw bees, flies and butterflies push into flowers to drink nectar, and he saw pollen dust their bodies and rub off on the next flower they visited. He noticed spots and lines on many petals that point the way to the nectar, which we now call nectar guides. In 1793 he published a book whose title means *The Secret of Nature Discovered in the Structure and Fertilization of Flowers*. A flower's shape, color, scent and nectar, he showed, all work together with the creatures that visit it.

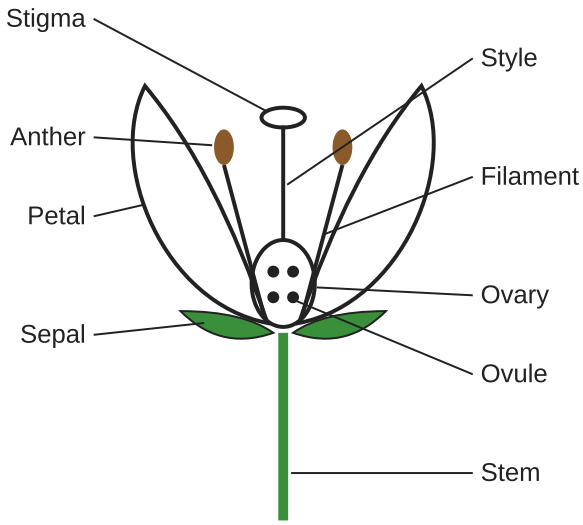
The big idea. Flowering plants are the largest group of plants, with about 300,000 known kinds. They include roses and daisies, but also grasses, wheat and corn, oak and maple trees, cactuses and almost all our vegetables. Every one makes flowers, and every one grows its seeds inside a fruit. Look at the figure. Green **sepals** wrap the bud. Colored **petals** invite visitors. **Stamens** make pollen in their anthers. In the center stands the **pistil**, with a sticky stigma on top and an ovary at the bottom holding tiny ovules. **Pollination** happens when pollen reaches the stigma. Bees, butterflies, hummingbirds and even bats carry pollen, and grasses, corn and oaks let the wind carry it. Then the ovules grow into seeds, and the ovary swells into the **fruit**. So to a botanist, a tomato, a pea pod, an acorn and a grain of wheat are all fruits.

Two big groups. Botanists sort flowering plants into two main groups. **Monocots** have one seed leaf, leaves with long parallel veins, and flower parts in threes or sixes. Lilies, tulips, onions, grasses and corn are monocots. **Dicots** have two seed leaves, leaves with branching, net-like veins, and flower parts usually in fours or fives. Beans, roses, maples, apples and sunflowers are dicots. You can see the difference in a seed: a soaked bean splits into two halves, its two seed leaves, but a corn kernel does not.

Try it and see. Soak a dry bean in water overnight. In the morning, rub off its skin and gently split it open. You will see the two seed leaves, packed with food, and a tiny baby plant tucked between them. Then look at the apple you cut in the warm-up. The five-pointed star of seed chambers is what is left of the flower's five-part ovary. The apple blossom had five petals too.

God's handiwork. On the third day of creation God said, "Let the earth bring forth grass, the herb yielding seed, and the fruit tree yielding fruit after his kind, whose seed is in itself" (Genesis 1:11). Every apple you cut open shows it: the seed is in the fruit, and an apple seed

grows an apple tree, after its kind. Jesus told His followers to “consider the lilies of the field” (Matthew 6:28). Sprengel did just that, and found a secret hidden in plain sight.



Stamen = anther + filament (makes pollen)
Pistil = stigma + style + ovary (ovules become seeds)

The parts of a flower. Stamens make pollen; the ovary of the pistil becomes the fruit, and its ovules become the seeds.

PICTURE STUDY



White Lily (Lilium candidum), from Les Liliacées, Pierre-Joseph Redouté, Published 1802–1816 · Color-printed stipple engraving, finished by hand, from Redouté’s watercolor · Printed copies of *Les Liliacées* are kept in botanical libraries and museums in many countries.

Pierre-Joseph Redouté was a French botanical painter who worked in Paris in the time of Napoleon. In *Les Liliacées* he painted lilies and their relatives, such as irises, tulips and amaryllis, in hundreds of life-size plates, printed in color and finished by hand.

The white lily is a monocot. Its flower has six white parts, three outer and three inner, with six stamens around one pistil, and its long, narrow leaves have parallel veins. Jesus told His followers to “consider the lilies of the field.” Redouté spent his life doing just that.

Look closely

- Count the white parts of one open flower. Do they come in threes?
- Find the stamens inside a flower. What color are the anthers at their tips?
- Look along the stalk at the leaves. Are they wide with branching veins, or long and narrow?
- Find a flower that has not opened yet. How is it different from the open ones?

Talk about it

1. Is this lily a monocot or a dicot? Which two clues from the lesson tell you?
2. Why would a botanist want a picture that shows the leaves and buds as well as the open flowers?
3. If a bee visited this flower, where would it pick up pollen, and where might that pollen land?

> **Safety first.** Have a parent do any cutting with a knife. Lilies are very poisonous to cats, so keep lily flowers, leaves and even pollen away from pet cats, and wash your hands after handling them. Lily pollen also stains clothes. Do not eat flowers from a bouquet or garden. Watch bees and wasps from a polite distance and do not swat at them; tell a parent first if you are allergic to stings.

EXPERIMENT: FLOWER TAKE-APART AND MONOCOT OR DICOT SURVEY

You will take a flower apart like a botanist and then survey several plants. **Question:** Do plants whose flowers have parts in threes also have leaves with parallel veins? Write your **prediction** first.

You will need

- One simple flower to take apart, such as an alstroemeria or lily from a grocery bouquet
- At least four other flowering plants with their leaves, from a garden, yard or bouquet (for example: tulip, daffodil, petunia, pansy, geranium, buttercup, apple blossom)
- A magnifying glass, tweezers and a sheet of white paper
- Clear tape and your science notebook
- A parent with a small knife

Steps

1. **What we change:** the kind of plant. **What we keep the same:** how we count (only the petals and stamens of one single flower) and how we look at the leaves. **What we measure:** the number of petals, the number of stamens, and whether the leaf veins are parallel or net-like.
2. Take apart your first flower from the outside in. Lay the sepals in a row on the paper, then the petals, then the stamens. Leave the pistil for last.
3. Count each kind of part and tape one of each into your notebook with a label.
4. Ask a parent to cut the ovary across the middle. Use the magnifying glass to find the ovules inside. These would have become seeds.
5. Now survey your other plants. For each one, count the petals and stamens of one flower and look at a leaf’s veins.
6. Record a table with columns: Plant, Petals, Stamens, Leaf veins, Monocot or dicot.
7. Answer the question: did every plant with parts in threes have parallel veins?

Tips

- Choose simple, single flowers. Florist roses and carnations have been bred with extra petals and are hard to count.
- In lilies and tulips, the sepals look just like the petals, so you will count six colored parts: three outer and three inner.

Check your work

- I named and taped down a sepal, a petal, a stamen and the pistil.
- I found the ovules inside the ovary.
- I recorded my survey in a table and classified each plant as a monocot or a dicot.

NATURE NOTEBOOK

1. Draw your take-apart flower large and label the sepal, petal, stamen (anther and filament) and pistil (stigma, style and ovary).
2. Draw a monocot leaf and a dicot leaf side by side. Draw the veins carefully so the difference is easy to see.
3. Sit by a flower bed for 10 minutes. Draw each kind of insect that visits and make a tally mark for every visit.

> **From history.** Sprengel’s book was mostly ignored while he lived. Many readers thought it was strange to say that flowers were built for insects. Decades later, Charles Darwin read it, praised Sprengel’s careful watching, and built on it in his own book on how orchids are pollinated, published in 1862. Today Sprengel is honored as one of the first scientists to study pollination by patiently watching real flowers and insects in the field.

WORKED EXAMPLES

Example 1. A student surveyed three plants.
Plant A: 6 petals, 6 stamens, long parallel leaf veins
Plant B: 5 petals, 10 stamens, net-like leaf veins
Plant C: 3 petals, 6 stamens, long parallel leaf veins
Classify each plant as a monocot or a dicot.

1. Monocots have flower parts in threes or sixes and parallel veins. Dicots have parts in fours or fives and net-like veins.
2. Plant A: 6 and 6 are multiples of 3, and the veins are parallel. Monocot.
3. Plant B: 5 petals and 10 stamens are multiples of 5, and the veins are net-like. Dicot.
4. Plant C: 3 and 6 are multiples of 3, and the veins are parallel. Monocot.
5. Each plant's two clues agree, so we can be confident.

Answer: Plant A: monocot. Plant B: dicot. Plant C: monocot.

Example 2. A family watched a flower bed for 15 minutes and tallied bee visits to flowers of each color.
Yellow: 18 visits
Blue: 14 visits
White: 6 visits
Red: 2 visits
How many visits were there in all? How many more visits did yellow get than red? What fraction of all the visits went to yellow and blue flowers together?

1. Total: 18 + 14 + 6 + 2 = 40 visits.
2. Yellow minus red: 18 − 2 = 16 more visits.
3. Yellow and blue together: 18 + 14 = 32 visits.
4. Fraction: 32 out of 40. Divide top and bottom by 8: 32/40 = 4/5.
5. This fits what scientists have found: bees see yellow and blue well, but they see red poorly. Many red flowers are pollinated by hummingbirds instead.

Answer: 40 visits in all. Yellow got 16 more visits than red. Yellow and blue together got 32 of 40 visits, which is 4/5.

PRACTICE

1. EASY Which part of a flower makes pollen? Which part becomes the fruit?
2. EASY To a botanist, which of these are fruits: tomato, carrot, pea pod, potato, cucumber?
3. EASY A plant has a flower with 3 petals and leaves with long parallel veins. Is it a monocot or a dicot?

4. MEDIUM Grass and corn flowers are small and green, with no bright petals and no sweet nectar. How are they pollinated? Explain how their flowers fit that job.
5. MEDIUM A student opened five pea pods and counted the peas: 6, 7, 5, 8 and 4. Find the average number of peas per pod. Each pea is a seed. What part of the flower was the pod?
6. HARD Design an experiment: Do bees visit blue paper flowers or yellow paper flowers more often? Name the variable you change, four things you keep the same, and what you measure.
7. HARD A pine tree and an apple tree both make seeds. Explain the difference in where their seeds grow, and name the group each tree belongs to.
8. CHALLENGE A cherry tree bloomed in spring, but a hard frost that night killed all of its flowers. In two or three sentences, explain why the tree will have no cherries that summer, even though its leaves grow back fine.

COMMON MISTAKES

- Thinking a fruit must be sweet. To a botanist a fruit is any ripened ovary with seeds, so tomatoes, cucumbers, bean pods, acorns and even grains of wheat are fruits.
- Thinking grasses and big trees like oaks and maples are not flowering plants. They make small flowers, often green and easy to miss, and they are pollinated by the wind.
- Thinking only bees pollinate flowers. Butterflies, moths, flies, beetles, hummingbirds, bats and the wind all carry pollen.

> **Make it a game · Botanist’s Grocery Sort.** Gather ten foods from the kitchen: for example a tomato, carrot, apple, asparagus spear, lettuce, pea pod, potato, cucumber, shelled peanut and dry bean. Race to sort them into piles: fruit, root, stem, leaf or seed. Score one point for each food in the right pile. Bonus point: for each fruit, name the flower part it came from (the ovary!).

> **Scripture.** “And why take ye thought for raiment? Consider the lilies of the field, how they grow; they toil not, neither do they spin: And yet I say unto you, That even Solomon in all his glory was not arrayed like one of these.” (Matthew 6:28–29, KJV)

Jesus tells us to look carefully at flowers. Their beauty is a gift from God, who clothes even the wild flowers, and He cares for His people even more.

Practice answers

1. The stamen (in its anther) makes pollen. The ovary of the pistil becomes the fruit.
2. The tomato, pea pod and cucumber are fruits, because each grew from a flower’s ovary and holds seeds. The carrot is a root, and the potato is an underground stem.
3. A monocot.
4. By the wind. They do not need bright petals, scent or nectar to call insects. Instead they make lots of light, dusty pollen that the wind can carry, and their stigmas are often feathery to catch it.

5. 6 + 7 + 5 + 8 + 4 = 30; 30 ÷ 5 = 6 peas per pod. The pod was the flower’s ovary, so the pod is the fruit.
6. Variable changed: the color of the paper flower (blue or yellow). Keep the same: the size and shape of the flowers, the amount of sugar water in each, the place in the garden (side by side), the time of day and the length of watching (any four). Measure: the number of bee visits to each color in, for example, 20 minutes, repeated on several days.
7. The pine’s seeds lie bare on the scales of a cone, so it is a conifer (a gymnosperm). The apple’s seeds grow inside a fruit that came from a flower’s ovary, so it is a flowering plant (an angiosperm).
8. Sample answer: Cherries are fruits, and fruits grow only from the ovaries of pollinated flowers. When the frost killed the flowers, there were no pistils left to be pollinated, so no ovules could become seeds and no ovaries could swell into cherries. The leaves can make food for the tree, but they cannot make fruit.

6.4 Pressing Plants: Making a Herbarium

OBJECTIVES

- Tell how Luca Ghini of Bologna began pressing and drying plants on paper in the 1500s, and explain why a herbarium is still a tool of science today.
- Press, dry, mount and label plant specimens the way botanists do, including a complete collection label.
- Measure how much water a plant loses as it dries, and run a fair test on what makes pressed plants dry faster.

Warm-up. Pick two leaves of the same kind (with permission). Leave one lying on a windowsill. Put the other flat between two paper towels inside a heavy book. Predict: after two days, how will each one look? Draw both leaves now, and check them again at the start of the next session.

Video. Coming soon. How to press plants and make herbarium specimens, and tours of museum herbarium collections: search Smithsonian National Museum of Natural History (Botany), Royal Botanic Gardens Kew, university herbarium channels, botanical garden education channels, SciShow Kids and Homeschool Pop (Alternate).

KEY TERMS

herbarium
A collection of dried, pressed plants mounted on paper, labeled and kept for study. The word is also used for the building or room where they are kept.

specimen
One real plant (or animal) collected and saved so that scientists can study it.

plant press
A stack of boards, cardboard and absorbent paper strapped tight, used to flatten and dry plants.

blotting paper
Thick, soft paper that soaks up water. In a plant press it draws water out of the plant. Paper towels or extra newspaper can take its place.

collection label
The note on a specimen sheet that tells the plant’s name, the place and habitat where it grew, the date it was collected and the collector’s name.

CORE IDEAS

The story. At the University of Bologna in Italy, in the first half of the 1500s, a teacher of medicine named Luca Ghini had a problem. His students had to learn the plants used to make medicines, but fresh plants wither in a few days, and in winter the meadows were

bare. So Ghini tried something new. He laid fresh plants flat between sheets of paper and pressed them until they were dry. Then he glued them onto pages and bound the pages into a book. Such a book came to be called a *hortus siccus*, Latin for “dry garden.” In 1544 Ghini moved to Pisa, where he started a botanical garden for the university, one of the first in Europe.

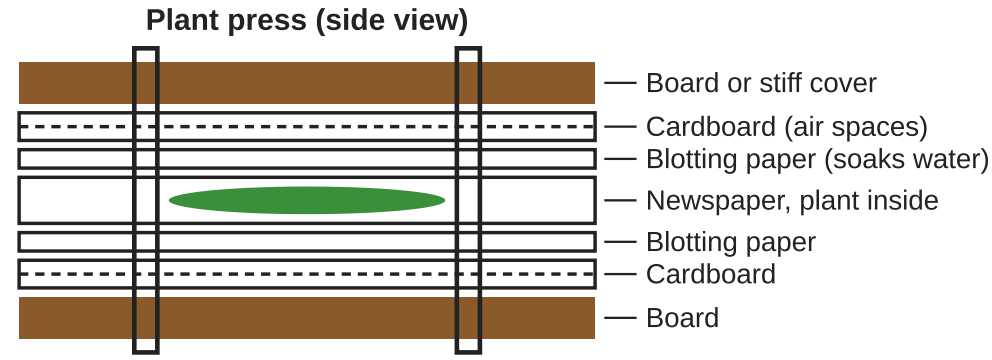
How they figured it out. Pressing works because it takes away a plant’s water slowly and evenly while holding the plant flat. A fresh leaf is mostly water. Left lying in the air, it curls, wrinkles and may mold. Pressed between absorbent paper under weight, the water moves out of the plant into the paper, and the plant dries flat, keeping its shape and often much of its color. Ghini’s students carried the method all over Europe. Some of their dried-plant books still survive in Italian collections, more than four hundred years later, and botanists can still study them.

The big idea. A collection of pressed plants is called a **herbarium**. Each pressed plant mounted on heavy paper is a **specimen**. A specimen is useful to science only if it has a **collection label** that tells the plant’s name, the exact place and habitat where it grew, the date, and who collected it. With labels, a herbarium becomes a library of real plants. Botanists compare a new plant with labeled specimens to classify it, check which plants grow in which places, and see how one kind varies from place to place. Great herbaria, like the one at the Smithsonian in Washington, D.C., hold millions of specimen sheets.

Try it and see. Collect on a dry day, after the dew is gone, because wet plants mold. Take the whole plant, or a good piece of it, with leaves, stem, flowers and, if you can, fruit or seeds, since botanists need all of these to identify it. Lay it inside a folded sheet of newspaper, spread out the leaves, and turn one leaf over to show its underside. Sandwich the newspaper between blotting paper, then cardboard, and stack it between two boards (see the figure). Strap it tight or pile heavy books on top. Change the blotting paper every day or two for the first week. Most plants are dry and stiff in one to two weeks. Then glue or tape the plant to heavy paper and write the label in the lower right corner, where botanists put it.

Collect with care. A good naturalist takes only what is needed. Always ask the landowner first, and never pick plants in parks or nature preserves. A good rule many botanists use: pick a plant only if you can see at least twenty more of the same kind growing nearby. That way the plant you take will hardly be missed.

God’s handiwork. A pressed flower keeps its shape for hundreds of years, but it is no longer alive. Isaiah wrote, “The grass withereth, the flower fadeth: but the word of our God shall stand for ever” (Isaiah 40:8). Our best efforts can only slow the fading. God’s word does not fade at all.



Two straps (or heavy books) press the stack tight.

COLLECTION LABEL

Name: dandelion (Taraxacum officinale)
Place: edge of back yard, Mill Road farm
Habitat: sunny lawn, damp soil
Date: May 3
Collector: (your name), specimen no. 1

The layers of a simple plant press, and a sample collection label.

PICTURE STUDY



Dictyota dichotoma, in the young state and in fruit, from Photographs of British Algae: Cyanotype Impressions, Anna Atkins, 1843 · Cyanotype (a blue sun print made on chemically treated paper) · Copies of Atkins's hand-made book are kept in a few libraries, including the British Library in London and the New York Public Library.

Anna Atkins was an English botanist who pressed and collected seaweeds. In 1842 the scientist John Herschel invented the cyanotype, a way of making pictures with sunlight on paper coated with iron chemicals. Atkins laid her pressed seaweeds right on the coated

paper and set it in the sun. Where the plant blocked the light, the paper stayed white. Everywhere else it turned a deep blue.

Starting in 1843 she made a book of these prints, one of the first books ever illustrated with photographs. Seaweeds are algae, not true plants, but collectors press them just the way you press a fern or a flower.

Look closely

- Follow one ribbon of the seaweed from its base. How many times does it split in two?
- Why is the seaweed white and the background blue?
- Look for the label. Why would a scientist put the name right on the picture?
- Can you see thin parts and thick parts? Which would be easier to press flat?

Talk about it

1. Atkins did not draw this seaweed; the seaweed made its own picture. Why might a scientist trust a print like this more than a drawing?
2. How is Atkins’s book like a herbarium? How is it different?

> **Safety first.** Ask permission before picking any plant, and never pick in parks, nature preserves or other people’s gardens. Learn to recognize poison ivy and poison oak (“Leaves of three, let it be”) and never collect them. Do not touch giant hogweed or wild parsnip, whose sap can burn skin in sunlight. Wash your hands after collecting. Never taste any plant. Let a parent handle scissors or clippers, and stack heavy books on a low, steady surface so they cannot fall on anyone.

EXPERIMENT: MY FIRST PLANT PRESS, AND A FAIR TEST OF DRYING

You will build a plant press, press plants like a botanist, and run a fair test at the same time. **Question:** Do plants dry faster if the blotting paper is changed every two days? Write your **prediction** first.

You will need

- Newspaper, blotting paper or paper towels, and corrugated cardboard cut to the same size (about 30 by 45 cm, or 12 by 18 in)
- Two flat boards or two very thick books for each press, plus belts, straps or more heavy books
- Six pairs of matching plants or leaves (for example, two clover stems, two fern fronds, two dandelions)
- A kitchen scale in grams, a pencil and your science notebook
- Heavy white paper or card stock, white glue or narrow strips of tape, and labels

Steps

1. **What we change:** whether the blotting paper is changed. **What we keep the same:** the kinds of plants (one of each pair goes in each press), the layers, the weight on top and the place we keep the presses. **What we measure:** how many days until each plant is dry and stiff, and its mass before and after.
2. Collect your plants on a dry day. Weigh each one and write its fresh mass on the newspaper sheet it goes in.
3. Build two presses with the same layers: board, cardboard, blotter, newspaper with plant, blotter, cardboard, and so on, with a board on top.
4. Strap both presses tight or put the same pile of books on each. Mark one press “Changed” and the other “Not changed.”
5. Every two days, open the “Changed” press and put in fresh, dry blotters. Open the other press too, so both get the same handling, but put the same blotters back.
6. Each time, test each plant: a dry plant is stiff and does not feel cool against your cheek. Record the day each plant becomes dry.
7. When all are dry, weigh them again. Mount the best ones on heavy paper and add a full collection label to each.

Tips

- Thick, juicy plants dry slowly. Slice a thick flower head or stem in half with a parent’s help before pressing.
- If a plant is longer than your paper, bend its stem into a V, N or W shape, the way botanists do.

Check your work

- I changed only the blotting paper and kept everything else the same.
- I recorded fresh mass, dry mass and the number of days to dry.
- Every mounted specimen has a label with name, place, habitat, date and collector.

NATURE NOTEBOOK

1. Before you press a plant, draw it alive and write its colors, its height in centimeters and its smell. After it dries, compare your drawing with the specimen. What changed?
2. Draw the layers of your plant press from the side and label each layer.
3. Write a complete collection label for one of your specimens in your notebook, then copy it neatly onto the specimen sheet.

> **From history.** Carl Linnaeus had a new idea about storing pressed plants. Instead of gluing them into bound books, as Ghini’s students had done, he kept each specimen on its own loose sheet of paper and stored the sheets flat in a cabinet. That way he could add new specimens in the right place and move sheets around as he learned more. Herbaria all over the world still store their specimens this way. After Linnaeus died, a young English naturalist named James Edward Smith bought his collections in 1784, and Linnaeus’s own herbarium is kept today by the Linnean Society of London.

WORKED EXAMPLES

Example 1. A fresh dandelion plant had a mass of 25 g. After two weeks in the press, its mass was 5 g. How much water did it lose? What fraction of the fresh plant was water?

1. Water lost = fresh mass − dry mass = 25 g − 5 g = 20 g.
2. Fraction that was water = water lost ÷ fresh mass = 20/25.
3. Simplify: divide the top and bottom by 5. 20/25 = 4/5.
4. 4/5 is the same as 80 out of 100, or 80 percent.

Answer: The plant lost 20 g of water. 4/5 (80 percent) of the fresh plant was water, so only 1/5 was the dry stuff that the plant is built from.

Example 2. A student's pressing log shows how many days each plant took to dry:
Fern frond: 4 days
Maple leaf: 6 days
Daisy: 8 days
Dandelion flower head: 10 days
Which dried fastest? How many more days did the dandelion take than the fern? What was the average drying time? Why might the dandelion take longest?

1. Fastest: the fern frond, at 4 days.
2. Difference: 10 − 4 = 6 more days for the dandelion.
3. Average: (4 + 6 + 8 + 10) ÷ 4 = 28 ÷ 4 = 7 days.
4. The dandelion flower head is thick and juicy, so it holds much more water than a thin fern frond, and the water takes longer to move out into the paper.

Answer: The fern dried fastest. The dandelion took 6 more days. The average was 7 days. Thick, juicy plant parts hold more water, so they take longer to dry.

PRACTICE

1. EASY What is a herbarium?
2. EASY Name four things that belong on a collection label.
3. EASY Why should you change the blotting paper in a plant press during the first week?
4. MEDIUM A student weighed three plants before and after pressing.
   Clover: fresh 12 g, dry 3 g
   Fern: fresh 8 g, dry 2 g
   Dandelion: fresh 30 g, dry 3 g
   How much water did each lose? Which lost the most water?
5. MEDIUM Your specimen paper is 28 cm wide and 43 cm long (11 by 17 in). Your fern frond is 35 cm long. Will it fit lengthwise? How much room is left? What could you do with a plant that is 60 cm long?

6. HARD Design an experiment: Do thin leaves dry faster than thick leaves in a plant press? Name the variable you change, three things you keep the same, and what you measure.
7. HARD Many botanists follow the rule: pick a plant only if you can see at least twenty more of the same kind nearby. Explain why this is a good rule.
8. CHALLENGE A museum finds an old, beautiful pressed flower with no label at all. In two or three sentences, explain why scientists say it is nearly useless for science.

COMMON MISTAKES

- Pressing plants that are wet from rain or dew. Wet plants turn brown or grow mold before they dry.
- Pressing only the flower. Botanists often need the leaves, stem, and fruit or seeds to identify a plant, so press as much of the plant as you can.
- Waiting to write the label. Write the place, habitat and date at once, on the newspaper sheet, before you forget. A specimen without a label is nearly useless to science.

> **Make it a game · Label Detective.** A parent writes five pretend collection labels, each with one mistake or missing part (no date, no place, a habitat that does not fit the plant, and so on). Read each label and find the problem. Score a point for each one you catch and fix. Then write a label for a real plant in your yard and see if your parent can find anything missing.

> **Scripture.** “The grass withereth, the flower fadeth: but the word of our God shall stand for ever.” (Isaiah 40:8, KJV)

A herbarium can keep the shape of a flower for centuries, but the flower is no longer alive. God’s word never withers or fades.

Practice answers

1. A collection of dried, pressed plants mounted on paper, labeled and kept for scientists to study.
2. Any four of: the plant’s name, the place where it was found, the habitat (such as a shady woods or a sunny lawn), the date, and the collector’s name.
3. The blotting paper fills with water from the plants. Fresh, dry paper keeps pulling water out, so the plants dry faster and do not mold.
4. Clover: $12 - 3 = 9$ g. Fern: $8 - 2 = 6$ g. Dandelion: $30 - 3 = 27$ g. The dandelion lost the most water (27 g, which is 9/10 of its fresh mass).
5. Yes. $43 - 35 = 8$ cm left over. A 60 cm plant is too long, so you would bend its stem into a V, N or W shape before pressing, the way botanists do (or press it in two labeled parts).
6. Variable changed: the thickness of the leaf (for example, thin maple leaves and thick jade-plant leaves). Keep the same: the press, the layers of paper, the weight on top, how often the blotters are changed and the room where the press sits (any three). Measure: the number of days until each leaf is dry and stiff, and the mass of each leaf before and after.
7. If there are many plants of that kind, taking one will not hurt the group, and the rest can still make seeds and keep growing there. If there are only a few, taking one could make that plant

disappear from the place. It is a way of caring for what God made while still learning from it.

8. Sample answer: Without a label, no one knows where the plant grew, when it was collected or what its habitat was like. Scientists cannot use it to learn which plants grew in which places, or to compare it with the same kind of plant from other places. It is still lovely to look at, but it has lost most of its value as a record.

Unit 6 review

Answer each question. Show your work for calculations and use complete sentences for explanations. The review is worth 50 points.

1. (5 pts) Mosses are nonvascular plants and ferns are vascular plants. What is the difference, and how does it affect how tall each can grow?
2. (5 pts) Name two ways a spore is different from a seed. Which two plant groups in this unit make spores?
3. (5 pts) A sample of dry sphagnum moss has a mass of 8 g. After soaking and dripping, its mass is 128 g. How much water does it hold? How many times its own dry weight is that?
4. (5 pts) What does “conifer” mean? Where do a conifer’s seeds grow, and how does its pollen travel?
5. (5 pts) Classify each tree: (a) needles grow in bundles of three; (b) single needles that are flat and soft and will not roll between your fingers; (c) single needles that are four-sided and sharp and roll easily.
6. (5 pts) In the pine cone experiment, one cone was soaked in water and one was left dry. What was the variable, what was the control, and what result showed that water made the cone close?
7. (5 pts) Name the flower part that makes pollen and the part that becomes the fruit. What is pollination, and what happens after it?
8. (5 pts) Corn has leaves with long parallel veins and one seed leaf. A bean has net-like veins and splits into two halves. Classify each as a monocot or a dicot, and give one more clue you could check in their flowers.
9. (5 pts) List four things that belong on a herbarium collection label, and explain why a specimen without a label is nearly useless to science.
10. (5 pts) A fresh fern frond has a mass of 20 g. After pressing, its mass is 4 g. How much water did it lose, and what fraction of the fresh frond was water? Then name the plant group a fern belongs to and one group that makes seeds.

Unit project: my herbarium of the four plant groups

Make a small herbarium of at least eight pressed specimens: one moss, one fern, two conifers (a twig with needles, plus a cone or a drawing of one), two monocots and two dicots. Mount each on heavy paper with a complete collection label in the lower right corner. Add a cover page with your own dichotomous key that leads to the four plant groups, and a table of contents listing every specimen.

Include your data from the Moss Sponge Test, the Pine Cone Weather Station and the drying test, with one graph, and write a paragraph explaining what makes each of the four groups different.

- **Accuracy**: Each specimen is placed in the correct group, and monocots and dicots are correctly identified with the clues that show it.

- **Labels and records**: Every specimen has a full label (name, place, habitat, date, collector), and the experiment data are complete, in tables, with units.
- **Explanation**: The paragraph and the key clearly explain tubes, spores and seeds, cones and fruits, using the unit's key terms correctly.
- **Care**: Specimens are flat, dry and neatly mounted; plants were collected with permission and by the rule of twenty.

Answer key

1. Vascular plants have tubes inside to carry water and food; nonvascular plants do not. Mosses have no tubes, so water cannot travel far inside them and they stay short. Ferns have tubes in their roots, stems and fronds, so they can grow much taller.
2. A spore is usually a single cell, with no baby plant and no stored food inside; a seed has a tiny baby plant and stored food. Mosses and ferns make spores.
3. 128 g − 8 g = 120 g of water. 120 ÷ 8 = 15 times its dry weight.
4. Conifer means "cone-bearer." Its seeds grow bare on the scales of its seed cones (not inside a fruit), and its pollen is carried by the wind from the small pollen cones to the seed cones.
5. (a) Pine. (b) Fir. (c) Spruce.
6. The variable was whether the cone was soaked in water. The control was the dry cone. The soaked cone got narrower (for example, from 7.0 cm to 4.0 cm) while the dry cone stayed the same width, so the change was caused by the water.
7. The stamen (its anther) makes pollen. The ovary of the pistil becomes the fruit. Pollination is carrying pollen to the stigma. After it, the ovules grow into seeds and the ovary swells into a fruit around them.
8. Corn is a monocot; the bean is a dicot. Monocot flower parts come in threes or sixes, while dicot flower parts usually come in fours or fives.
9. Any four of: plant name, place, habitat, date, collector. Without a label, no one knows where or when the plant grew, so scientists cannot use it as a record or compare it with plants from other places.
10. 20 g − 4 g = 16 g of water lost. 16/20 = 4/5 (80 percent) was water. A fern belongs to the ferns, the vascular plants that make spores. Conifers and flowering plants make seeds.

UNIT 7

Dinosaur Classification

On the sixth day “God made the beast of the earth after his kind” (Genesis 1:25), and among those land animals were the dinosaurs. No one alive has seen a living dinosaur, but we can hold their bones, measure their footprints and compare their teeth, just as the first dinosaur scientists did. In this unit you will use everything you learned about classification from Linnaeus to sort the dinosaurs into their groups by the features you can see in their skeletons.

You will meet Richard Owen, who named the **Dinosauria** in 1842 because of their upright legs and strong hips. You will follow William Buckland to the jaw of *Megalosaurus* and Barnum Brown to the first *Tyrannosaurus rex*, climb the sandstone ridge in Utah where Earl Douglass found a wall of sauropod bones, and watch Gideon Mantell puzzle over the teeth of *Iguanodon*. Along the way you will learn the two great branches of the dinosaur tree: the **lizard-hipped** theropods and sauropods, and the **bird-hipped** ornithischians.

Like a real paleontologist, you will measure and test as you go: upright and sprawling legs, the footprint rule for hip height, the strength of pillar-shaped columns and the grinding power of rough teeth. In each lesson the “⏳ Thinking About Time” box will help you tell the difference between what we observe in the rocks and the ideas people use to explain it.

BEFORE YOU BEGIN

- Can use a simple dichotomous key (Lesson 1.4)
- Knows the five classes of vertebrates and that reptiles are one of them (Lesson 2.1)
- Knows that teeth tell diet: sharp slicing teeth for meat, flat grinding teeth for plants (Lesson 5.1)
- Can measure in centimeters and meters and multiply and divide whole numbers

MASTERY CHECKLIST

- I can tell how Richard Owen named the Dinosauria in 1842 and what features set dinosaurs apart from lizards and from flying and swimming reptiles.
- I can explain the difference between a lizard hip and a bird hip and place a dinosaur on the classification tree.
- I can name the features of theropods and use the footprint rule to estimate a dinosaur’s hip height.
- I can name the features of sauropods and explain why pillar-like legs help a giant animal.
- I can sort ornithischians into armored, horned, duck-billed, bone-headed and two-legged plant-eater groups.
- I can tell the difference between what we observe in fossils and how people interpret their ages.

OPTIONAL BOOKS AND RESOURCES

- **Dinosaur National Monument (National Park Service)** (https://www.nps.gov/dino/index.htm): Free. Photos and information about the Carnegie Quarry wall of dinosaur bones that Earl Douglass found in 1909 (Lesson 7.3). If your family visits Utah or Colorado, children can earn a Junior Ranger badge.
- **Smithsonian National Museum of Natural History** (https://naturalhistory.si.edu/): Free to visit in Washington, D.C., and online. Browse the fossil hall's dinosaur skeletons and practice spotting theropods, sauropods and ornithischians by their hips, teeth and legs. Remember that museum signs give mainstream ages; read them with the "⏳ Thinking About Time" questions.
- **Natural History Museum, London** (https://www.nhm.ac.uk/): Free. The museum Richard Owen helped found. Its website has pages and pictures about dinosaurs, Mantell's *Iguanodon* and the history of the museum's first fossil finds.

7.1 Owen Names "Dinosauria" (1842) ★

OBJECTIVES

- Tell how Richard Owen studied the bones of *Megalosaurus*, *Iguanodon* and *Hylaeosaurus* and named a new group, the Dinosauria, in 1842.
- List the features that make an animal a dinosaur (upright legs under the body, a strong hip joined to the backbone, life on land) and explain why flying and swimming reptiles such as pterosaurs and plesiosaurs are not dinosaurs.
- Place dinosaurs in a classification tree with the two big groups, the "lizard-hipped" saurischians and the "bird-hipped" ornithischians, and run a fair test of upright and sprawling legs.

Warm-up. Get down on the floor and try to walk on your hands and feet with your elbows and knees sticking out to the sides, like a lizard doing push-ups. Then walk on hands and feet with your arms and legs straight under you, like a horse. Which way was easier to hold up your body? Write one sentence about what you felt in your arms.

Video. Coming soon. Richard Owen and the naming of the dinosaurs, the Crystal Palace dinosaurs in London, and what makes a dinosaur a dinosaur (upright legs, hip bones): search Natural History Museum London, Smithsonian National Museum of Natural History, Homeschool Pop (Alternate), SciShow Kids, and museum fossil-hall tours.

KEY TERMS

dinosaur
A land-living reptile, known from fossils, whose legs stood straight under its body and whose hip bones were joined firmly to the backbone. The name means "terrible lizard" or "fearfully great lizard."

fossil
The hardened remains or traces of a living thing, such as a bone, tooth, shell, footprint or leaf print, preserved in rock.

paleontologist
A scientist who studies fossils to learn about plants and animals of the past.

sacrum
The group of vertebrae joined together where the backbone meets the hip bones. Owen noticed that his dinosaurs had five of them fused into one strong piece.

upright posture
Standing with the legs straight under the body like pillars, as a horse or an elephant does, instead of sprawling out to the sides like a lizard.

Saurischia and Ornithischia
The two big groups of dinosaurs, named by Harry Seeley in 1887. Saurischians are "lizard-hipped" and ornithischians are "bird-hipped," named for the shape of their hip bones.

CORE IDEAS

The story. In the summer of 1841 an English anatomist named **Richard Owen** stood before a meeting of scientists in Plymouth, England, and spoke for more than two hours about the fossil reptiles of Britain. Owen worked at the Royal College of Surgeons in London, where he cared for a great collection of skeletons, and he knew bones better than almost anyone alive. In 1842 his talk was printed as a long report. In it Owen gave a new name to three strange animals whose bones had been dug up in southern England: *Megalosaurus*, *Iguanodon* and *Hylaeosaurus*. He called them the **Dinosauria**, from two Greek words, *deinos*, "terrible" or "fearfully great," and *sauros*, "lizard."

How they figured it out. Other men had already named each of the three animals. William Buckland named *Megalosaurus* in 1824 from a jaw and some bones found near Oxford. Gideon Mantell, a country doctor in Sussex, named *Iguanodon* in 1825 and *Hylaeosaurus* in 1833. Most people pictured them as giant lizards. Owen compared their bones with the lizards and crocodiles in his collection and saw that they did not fit. In all three, **five vertebrae were fused together in the sacrum**, making an extra-strong hip, while lizards have only two. Their leg bones showed that the legs stood **straight under the body**, like the legs of an elephant or a rhinoceros, not sprawled out to the sides. Animals so different, Owen reasoned, deserved a group of their own. That is classification at work: sorting living things by the features they share, just as Linnaeus taught.

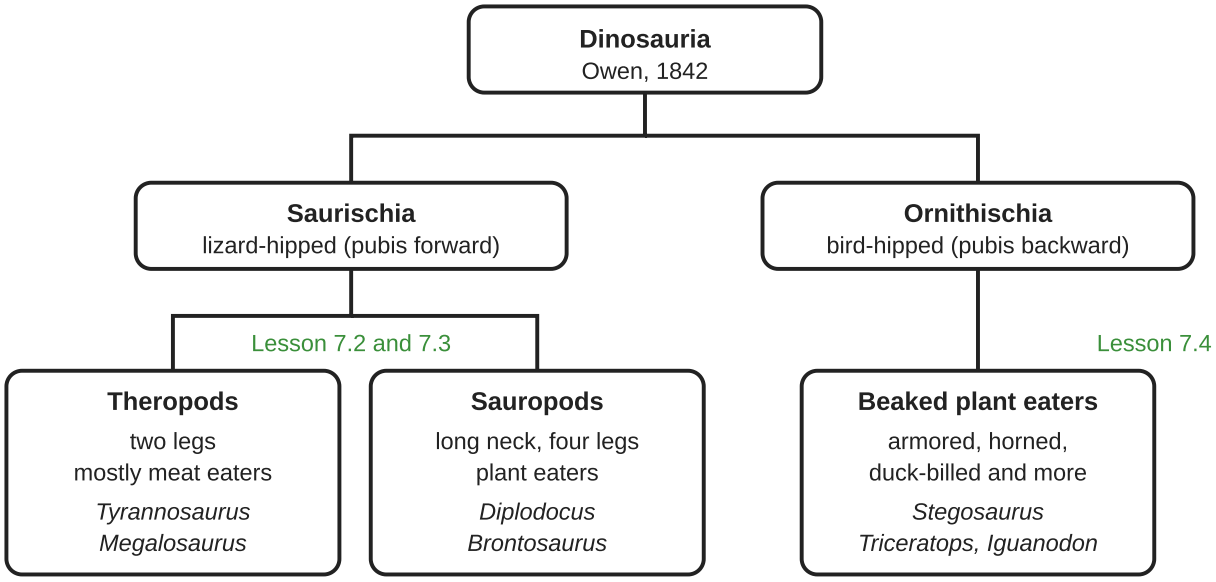
The big idea. Today a **dinosaur** is still known by its legs and hips. Every dinosaur lived on land and stood with its legs under its body. Its hip socket was open in the middle, like a ring, so the top of the thigh bone fit snugly into it. Many famous animals of the fossil record are *not* dinosaurs, even though books and toy sets put them together. **Pterosaurs** were flying reptiles. **Plesiosaurs**, **ichthyosaurs** and **mosasaurs** were swimming reptiles of the sea. *Dimetrodon*, with the sail on its back, had sprawling legs. None of these is a dinosaur.

Sorting the dinosaurs. As more skeletons were found, scientists needed smaller groups. In 1887 the English paleontologist **Harry Seeley** looked closely at the **pubis**, one of the three bones on each side of the hip. In some dinosaurs it pointed forward, as in a lizard; he called them **Saurischia**, "lizard-hipped." In others it pointed backward; he called them **Ornithischia**, "bird-hipped." The lizard-hipped group holds the meat-eating **theropods** (Lesson 7.2) and the long-necked **sauropods** (Lesson 7.3). The bird-hipped group holds the plant eaters with beaks, such as *Stegosaurus* and *Triceratops* (Lesson 7.4). Like a dichotomous key, each split asks one clear question about the bones.

God's handiwork. Owen was a churchgoing man who believed the wonderful design of animals pointed to a wise Creator. Scripture tells us that on the sixth day "God made the beast of the earth after his kind" (Genesis 1:25). The dinosaurs were among those land animals. We cannot watch a living *Iguanodon*, but we can observe its bones carefully, measure them, compare them and sort them, just as Owen did.

Try it and see. Why does it matter whether legs stand straight down or sprawl out to the sides? In the project you will build two model animals, one with upright legs and one with

sprawling legs, and add weight until each one sags. Then you will see why the heaviest land animals God made, from elephants to the giant dinosaurs, stand on legs like pillars.



Owen named the whole group in 1842. Seeley split it into two branches by the shape of the hip in 1887.

⏳ Thinking About Time

What the sign says. Museum signs say dinosaurs lived during a long stretch of time called the Mesozoic Era, divided into the Triassic, Jurassic and Cretaceous periods, and that they died out many millions of years before the first people.

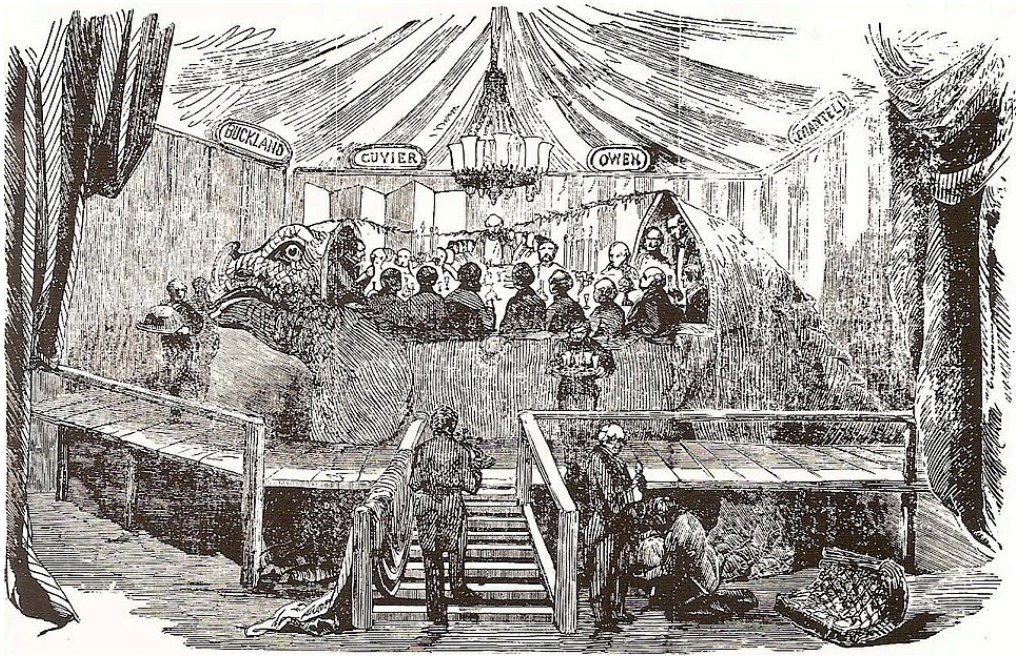
What we observe. What we can actually see is bones and footprints buried in layers of rock, often in sandstone and mudstone laid down by water. The bones do not come with dates written on them. Scientists measure the rocks and bones today and then use ideas about the past to work out ages.

How Christians read it. Many Christians read Genesis to mean that God made the land animals, dinosaurs included, on the sixth day, the same day He made Adam and Eve. On that reading, dinosaurs lived alongside people, and many of them were buried quickly in mud and sand during the worldwide Flood of Noah’s day, which is why we find so many of their bones in water-laid rock.

Try it. Next time you visit a museum or read a dinosaur book, find one sentence that gives an age and copy it into your notebook. Then underline the part that is an observation and circle the part that is an interpretation.

Genesis 1:24–25

PICTURE STUDY



Dinner in the Iguanodon Model at the Crystal Palace, Sydenham, Unknown engraver for *The Illustrated London News*, 1854 · Wood engraving printed in a newspaper · Published in *The Illustrated London News*, January 7, 1854; copies are kept in libraries

Twelve years after Owen named the Dinosauria, the sculptor Benjamin Waterhouse Hawkins was building life-size models of the dinosaurs for a new park around the Crystal Palace in south London. Owen advised him on how the animals should look. Before the *Iguanodon* model was finished, Hawkins held a New Year's Eve dinner for scientists and friends inside its mold, and Owen sat at the head of the table. A newspaper artist drew the scene for the readers of London.

The dinner was a joke and a celebration at the same time, but it showed how excited people were about these newly classified animals.

Look closely

- Find the curved body of the *Iguanodon* model around the table. Where is the head?
- Look at the banners on the tent. Newspaper readers of the time said they carried the names of naturalists such as Buckland, Mantell and Owen. Why would the guests honor them?
- Count about how many people you can see. How big must the model have been?
- Compare this *Iguanodon* with a picture in a modern dinosaur book. What is different about its legs and body?

Talk about it

1. Owen and Hawkins made the *Iguanodon* stand on four thick legs like a rhinoceros. Later finds showed it could walk on two legs or four. Why do scientists sometimes have

to change their pictures of an animal?
2. Why might a scientist want ordinary people to see what dinosaurs looked like, and not only read about them in reports?

EXPERIMENT: UPRIGHT OR SPRAWLING? A LEG TEST

Question: Does a model animal with legs straight under its body hold more weight than one with legs sprawled out to the sides? Owen noticed that dinosaurs stood with upright legs. You will build two models that differ in only one way and test them.

You will need

- 2 paper or plastic cups (the bodies), or 2 small boxes of the same size
- 8 unsharpened pencils or 8 craft sticks of the same length (the legs)
- Modeling clay or play dough
- Masking tape
- Pennies, washers or other small equal weights, and a small bag or dish to hold them
- Ruler marked in centimeters, notebook and pencil

Steps

1. Write your prediction: Which model will hold more pennies before it sags, the upright one or the sprawling one?
2. Model A (upright): turn a cup upside down. Tape four pencils to its sides so they point straight down, like table legs. Press a small ball of clay under each pencil tip for a foot.
3. Model B (sprawling): tape four pencils to the second cup so they slant out to the sides at about the angle of a lizard’s legs. Use the same amount of clay for each foot.
4. Measure the height of each body above the table and record it.
5. Set a dish on top of Model A. Add pennies one at a time. Stop when the body sinks 1 cm (about ½ inch) or the model tips. Record the number of pennies.
6. Do the same with Model B.
7. Repeat each test two more times and record all your numbers in a table with columns Trial, Model A, Model B.
8. Find the middle number (the median) for each model. Write your conclusion: Which posture held more weight? Was your prediction right?

Tips

- What we change: the angle of the legs. What we keep the same: the cup, the kind and length of the legs, the amount of clay, the tape and the kind of weights. What we measure: the number of pennies each model holds before it sinks 1 cm.
- Tape every leg the same way, with the same number of wraps, so the tape is not the thing being tested.
- Doing three trials helps you see whether one strange result was just bad luck.

Check your work

- I built two models that differ in only one way, the angle of the legs.
- I tested each model three times and recorded my numbers in a table.
- I can explain why upright legs help a large, heavy animal.
- I can name the two features Owen used to set dinosaurs apart.

NATURE NOTEBOOK

1. Draw a front view of a lizard and a front view of a dinosaur (or an elephant) standing still. Show where the legs come out of the body. Label one “sprawling” and one “upright.”
2. Copy the dinosaur classification tree from this lesson into your notebook. Leave room under each branch to add three dinosaurs as you learn them in Lessons 7.2 to 7.4.
3. Make a two-column chart titled “Dinosaur or Not?” Sort these animals: *Iguanodon*, *Pteranodon*, *Megalosaurus*, plesiosaur, *Triceratops*, *Dimetrodon*. Write one reason for each choice.

> **From history.** Richard Owen later led the building of a great new home for the fossils, minerals and specimens of the British Museum. He believed ordinary working people should be able to see God’s creatures for themselves, and he planned a grand building with long, well-lit galleries. The Natural History Museum in South Kensington, London, opened its doors in 1881, with Owen still in charge of its collections. Its walls and arches are covered with carved animals and plants, and it still holds some of the first dinosaur bones ever studied.

WORKED EXAMPLES

Example 1. Use the classification tree. A fossil skeleton has an open ring-shaped hip socket, legs straight under the body and a pubis bone that points forward. It also has a long neck, a small head and four thick legs. Name its group at each level of the tree.

(Use the map or drawing “Follow the tree one question at a time, just as you would a dichotomous key.” shown earlier in this lesson.)

1. Open hip socket and upright legs on land: it is a dinosaur (Dinosauria).
2. The pubis points forward: it is lizard-hipped (Saurischia).
3. Among the lizard-hipped dinosaurs, theropods walk on two legs and have sharp teeth; sauropods have long necks, small heads and four pillar-like legs. This skeleton matches the sauropods.

Answer: Dinosauria, then Saurischia (lizard-hipped), then sauropods.

Example 2. Owen said dinosaurs had 5 vertebrae fused in the sacrum, while lizards have 2. A museum shows the hips of 4 dinosaurs and 3 lizards. How many sacral vertebrae are there in all? How many more does one dinosaur hip have than one lizard hip?

1. Dinosaur hips: $4 \times 5 = 20$ sacral vertebrae.
2. Lizard hips: $3 \times 2 = 6$ sacral vertebrae.
3. In all: $20 + 6 = 26$.
4. Difference for one hip: $5 - 2 = 3$.

Answer: 26 sacral vertebrae in all. One dinosaur hip has 3 more than one lizard hip, which made it much stronger for carrying a heavy body on upright legs.

PRACTICE

1. EASY Who named the Dinosauria, and in what year was the name published?
2. EASY What does the word “dinosaur” mean?
3. EASY Name the three animals Owen placed in his new group.
4. MEDIUM A *Pteranodon* is a large flying reptile known from fossils. Is it a dinosaur? Explain.
5. MEDIUM Read the table of results from a leg test (pennies held before sinking 1 cm). Upright model: Trial 1, 42; Trial 2, 38; Trial 3, 40. Sprawling model: Trial 1, 11; Trial 2, 14; Trial 3, 12. (a) What is the median for each model? (b) About how many times as much did the upright model hold?
6. MEDIUM What did Harry Seeley look at to split the dinosaurs into two groups, and what are the two groups called?
7. HARD Maria wants to test whether the length of the legs changes how much weight a model animal can hold. (a) What should she change? (b) Name three things she should keep the same. (c) What should she measure?
8. CHALLENGE Write two or three sentences explaining why Owen decided that Megalosaurus, Iguanodon and Hylaeosaurus were not just giant lizards.

COMMON MISTAKES

- Thinking every large animal known from fossils is a dinosaur. Pterosaurs, plesiosaurs, mosasaurs, ichthyosaurs, mammoths and *Dimetrodon* are not dinosaurs.
- Thinking dinosaurs were just very big lizards. Lizards sprawl; dinosaurs stood on upright legs with a strong, many-boned sacrum.
- Thinking Owen found the first dinosaur. Buckland and Mantell had already found and named *Megalosaurus*, *Iguanodon* and *Hylaeosaurus*. Owen’s work was to compare them and name the whole group.

Make it a game · Dinosaur or Not?. A parent calls out an animal: Iguanodon, Pteranodon, Tyrannosaurus, plesiosaur, Stegosaurus, mammoth, Dimetrodon, Diplodocus,

mosasaur, Triceratops, crocodile. If it is a dinosaur, stand up tall with your arms straight down like pillars. If it is not, sprawl your arms out to the sides. Give one reason to earn a point. Play until you score ten points.

Scripture. “And God said, Let the earth bring forth the living creature after his kind, cattle, and creeping thing, and beast of the earth after his kind: and it was so.” (Genesis 1:24, KJV)

God made the land animals “after his kind.” When we sort animals into groups by the features they share, we are noticing the order God built into His creation.

Practice answers

1. Richard Owen, in 1842.
2. “Terrible lizard” or “fearfully great lizard,” from the Greek words *deinos* and *sauros*.
3. *Megalosaurus*, *Iguanodon* and *Hylaeosaurus*.
4. No. Pteranodon is a pterosaur, a flying reptile. Dinosaurs lived on land and stood on upright legs; pterosaurs are a separate group.
5. (a) Upright: the numbers in order are 38, 40, 42, so the median is 40. Sprawling: 11, 12, 14, so the median is 12. (b) 40 ÷ 12 is a little more than 3, so the upright model held a little more than 3 times as much.
6. He looked at the hip bones, especially which way the pubis bone points. Forward: Saurischia (lizard-hipped). Backward: Ornithischia (bird-hipped).
7. (a) The length of the legs. (b) Any three of: the leg angle (all upright), the body (same cup), the kind of leg material, the amount of clay for feet, the tape, the kind of weights. (c) The number of weights each model holds before it sinks a set distance or falls.
8. Owen compared their bones with real lizards and found real differences. The dinosaurs had five vertebrae fused into a strong sacrum instead of two, and their legs stood straight under the body like an elephant’s instead of sprawling out to the sides. Because they shared these features with each other and not with lizards, he put them in a new group.

7.2 Theropods

OBJECTIVES

- Tell how William Buckland named *Megalosaurus*, the first dinosaur to be named, and how Barnum Brown and Henry Fairfield Osborn found and named *Tyrannosaurus rex*.
- List the features of a theropod (two legs, three-toed feet, hollow bones, sharp saw-edged teeth, clawed hands, a long tail for balance) and sort theropods by size using a data table.
- Use the footprint rule (hip height is about 4 times footprint length) to estimate the size of a track-maker, and test the rule on real people.

Warm-up. Walk across the room on tiptoe, then walk normally, then run a few steps. Look at the floor where you stepped: if you have a damp towel, step on it and then on a paper bag to see your print. Which way of walking left the longest gap between your steps? Write down one thing a footprint could tell a scientist about the animal that made it.

Video. Coming soon. Theropod dinosaurs for kids, Tyrannosaurus rex skeletons, SUE the T. rex at the Field Museum, Megalosaurus at the Oxford University Museum of Natural History, and dinosaur trackways: search Field Museum, Smithsonian National Museum of Natural History, American Museum of Natural History, Homeschool Pop (Alternate), SciShow Kids and museum fossil-hall tours.

KEY TERMS

theropod
A lizard-hipped dinosaur that walked on two legs and had three main toes on each foot. Most were meat eaters. The name means “beast foot.”

bipedal
Walking on two legs.

predator
An animal that hunts and eats other animals.

serrated
Having a saw-like edge of tiny points, like a steak knife. Most theropod teeth were serrated.

trackway
A line of fossil footprints made by one animal as it walked.

hollow bones
Bones with air spaces inside, which are strong but light. Theropods and birds both have them.

CORE IDEAS

The story. On February 20, 1824, the Reverend **William Buckland**, a professor at Oxford University in England, rose before the Geological Society of London to describe some huge bones from a quarry at Stonesfield, near Oxford. The most striking was a piece of lower jaw with curved, blade-like teeth still standing in it, their edges finely notched like a saw. Buckland named the animal *Megalosaurus*, "great lizard." It was the very first dinosaur ever given a scientific name, eighteen years before Owen invented the word "dinosaur." You can still see Buckland's jaw at the Oxford University Museum of Natural History.

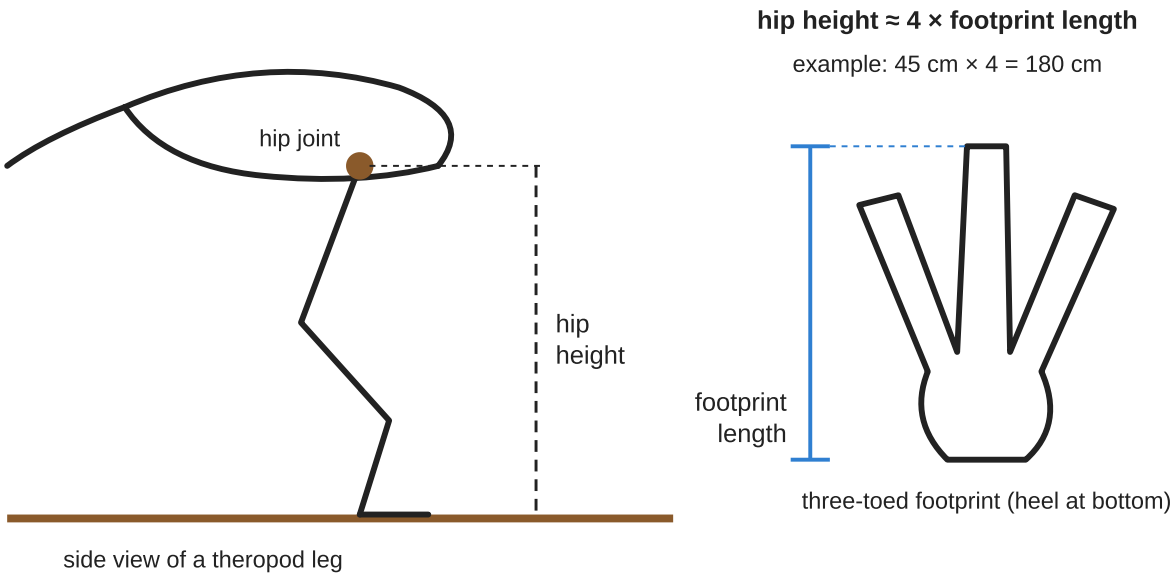
How they figured it out. Buckland had only a few bones, so he could not see the whole animal. From the teeth he reasoned that it ate meat, because sharp, saw-edged blades are made for slicing flesh, not for grinding plants. That is the same rule you learned for mammal teeth in Unit 5: *teeth tell diet*. As more skeletons were found, scientists saw that *Megalosaurus* belonged to a large family of similar dinosaurs. In 1881 the American paleontologist Othniel Marsh named them the **theropods**, "beast feet."

The big idea. A **theropod** is a lizard-hipped dinosaur with a body plan you can learn to spot in any museum. It was **bipedal**, walking only on its hind legs. Each foot had **three main toes** pointing forward, so its tracks look like giant three-pronged bird tracks. Its bones were **hollow**, with air spaces that made them light but strong. Most had **serrated teeth** that curved backward, **hands with sharp claws** and a **long, stiff tail** that balanced the heavy head and chest over the hips like a seesaw. Many theropods, even *Tyrannosaurus*, had a wishbone, as birds do. Theropods came in every size, from *Compsognathus*, about 1 meter (3 feet) long, to *Tyrannosaurus rex*, about 12 meters (40 feet) long.

In the world today. The most famous theropod was first dug up in 1902 by **Barnum Brown**, a fossil hunter for the American Museum of Natural History, in the badlands of eastern Montana. In 1905 the museum's head of fossil studies, **Henry Fairfield Osborn** (later its president), named it *Tyrannosaurus rex*, "tyrant lizard king." Its biggest teeth, root and all, were about 30 cm (12 inches) long. In 1990 a fossil hunter named Sue Hendrickson found one of the most complete *T. rex* skeletons ever discovered, in South Dakota. Named "SUE" in her honor, it now stands in the Field Museum in Chicago, where visitors can look straight into its jaws.

Reading the tracks. Bones are not the only clues. Theropods left thousands of three-toed footprints in rock, in places such as Connecticut, Texas and Colorado. Scientists use a rule of thumb: an animal's **hip height is about 4 times the length of its footprint**. A footprint 50 cm (about 20 inches) long means the hips were about 2 meters (about 6½ feet) off the ground. The space between prints tells whether the animal was walking slowly or hurrying.

Try it and see. Does the footprint rule work for people? In the project you will measure the feet and hip heights of your family, find how many times taller each hip is than the foot, and see how close you come to 4. Then you can be a track detective like the scientists who read the stone footprints of the theropods.



Measure a three-toed footprint from heel to the tip of the middle toe. Multiply by 4 to estimate how high the hips were.

⏳ Thinking About Time

What the sign says. Museum signs say *Tyrannosaurus rex* lived near the end of the Cretaceous period, many millions of years ago, and was among the last dinosaurs before they died out.

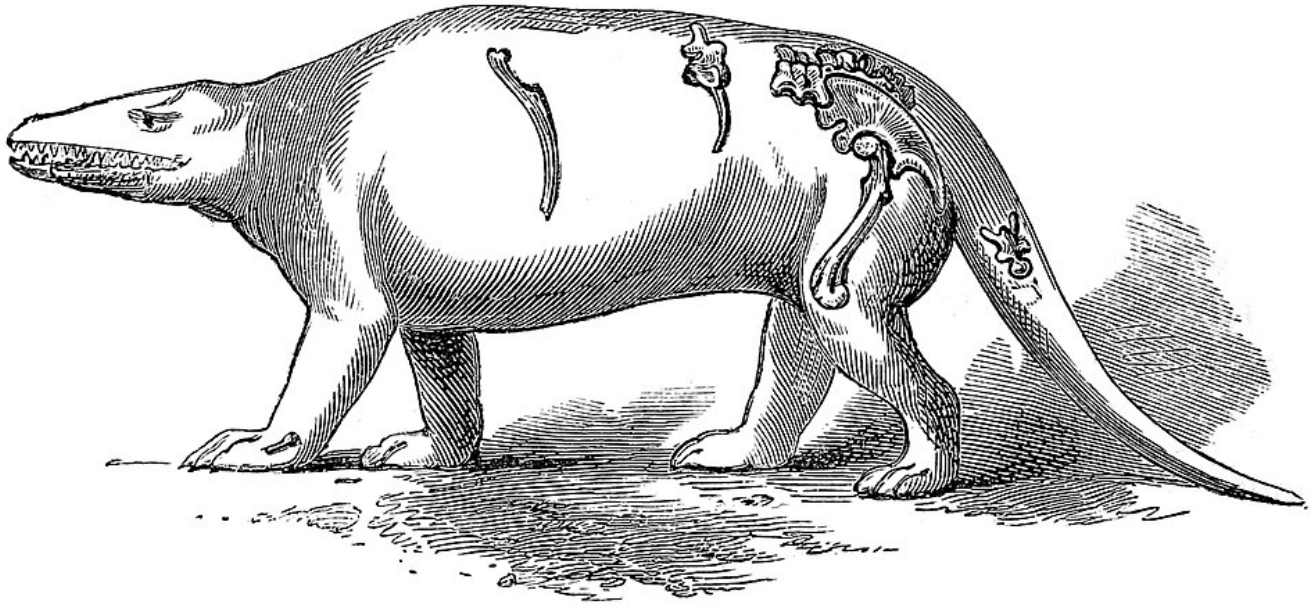
What we observe. In 2005 the scientist Mary Schweitzer and her team reported that when they dissolved the mineral from inside a broken *T. rex* thigh bone from Montana, they found soft, stretchy material that looked like tiny blood vessels. Scientists have found similar soft material in other dinosaur bones since then, and they still debate how it could last so long.

How Christians read it. Many Christians think soft material inside dinosaur bones fits well with a young earth, in which these animals were buried in the Flood only thousands of years ago, not millions. They read the bones as the remains of land animals God made on the sixth day.

Try it. Look at a cooked chicken bone that an adult has cleaned and broken open. Draw the spongy inside and the hollow spaces, and compare them with the theropod bones in this lesson.

Genesis 7:21

PICTURE STUDY



Megalosaurus, from Geology and Inhabitants of the Ancient World, Benjamin Waterhouse Hawkins, for Richard Owen's guidebook, 1854 · Printed illustration in a book · Printed in Richard Owen's guidebook to the Crystal Palace models, *Geology and Inhabitants of the Ancient World* (London, 1854); copies are kept in libraries. Hawkins's life-size sculpture still stands in Crystal Palace Park, London.

Benjamin Waterhouse Hawkins was an English artist who drew and sculpted animals. For the new park around the Crystal Palace he built the first life-size dinosaur models in the world, and they still stand there today, on islands in a lake. Richard Owen told him how each animal should look, using the few bones known at the time. Owen also wrote a small guidebook for visitors, and this picture of the *Megalosaurus* was printed in it.

Owen thought *Megalosaurus* must have walked on four legs like a giant, heavy lizard or bear. Later finds of complete theropod skeletons showed that it walked on two legs, with a long tail held out behind for balance. The picture is a wonderful record of what the best scientists thought in 1854.

Look closely

- Count the legs in the drawing. How many legs did a real theropod walk on?
- Look at the head and the teeth. What do they tell you about what *Megalosaurus* ate?
- Look at the hump on the back. Why might Owen have given it one?
- Look at the tail. Is it held up or dragging on the ground? How is that different from a theropod skeleton in a museum today?

Talk about it

1. Owen had only part of a skeleton. What could he know for sure, and what did he have to guess?
2. If you redrew this *Megalosaurus* today, what three things would you change?

3. Is it a good thing or a bad thing that scientists changed their minds about *Megalosaurus*? Explain.

EXPERIMENT: TRACK DETECTIVE: TESTING THE FOOTPRINT RULE

Question: Is a person's hip height about 4 times the length of his or her foot, as the rule of thumb for dinosaur tracks says? You will measure several people, calculate a ratio for each one and compare your results with 4.

You will need

- Meter stick or tape measure marked in centimeters
- Ruler marked in centimeters
- Large sheets of paper and a pencil, or a shallow tray of damp sand or flour for making footprints
- At least four people of different ages (family members or friends)
- Calculator (optional), notebook and pencil

Steps

1. Write your prediction: Will each person's hip height be more than, less than or about 4 times his or her foot length?
2. Have each person stand barefoot on paper while you trace one foot, or step into damp sand and step out carefully.
3. Measure each footprint from the back of the heel to the tip of the longest toe, in centimeters. Record it.
4. Find each person's hip joint by having him or her lift a knee; the hip bends at the top of the leg. Measure from the floor to that point while the person stands straight, barefoot. Record it.
5. Make a table with columns: Name, Foot length (cm), Hip height (cm), Hip ÷ Foot.
6. Divide hip height by foot length for each person. Round to one decimal place.
7. Find the average ratio by adding all the ratios and dividing by the number of people.
8. Write your conclusion: How close was your family to 4? Does the rule work better for children or for grown-ups? Why might the rule for people be a little different from the rule for theropods?

Tips

- What we change: the person being measured. What we keep the same: barefoot, standing straight, the same measuring tools and the same way of finding the heel, toe and hip. What we measure: foot length and hip height, then the ratio.
- Measure each foot twice. If the two numbers differ, use the average.
- A dinosaur trackway in rock is measured the same way: heel to the tip of the middle toe.

Check your work

- I measured at least four people the same way each time.
- I recorded my measurements in a table and calculated a ratio for each person.
- I can use the footprint rule to estimate a dinosaur’s hip height.
- I can name four features of a theropod.

NATURE NOTEBOOK

1. Draw a theropod skeleton from a book or museum photo. Label the skull, serrated teeth, clawed hand, three-toed foot, hip and long tail.
2. Trace your own foot and draw a theropod footprint beside it to scale: if your foot is 20 cm long, draw the dinosaur print 2 or 3 times longer. Label both with their lengths.
3. Make a size line across two pages. Mark 1 m for *Compsognathus*, 2 m for *Velociraptor*, 6 m for *Megalosaurus*, 9 m for *Allosaurus* and 12 m for *Tyrannosaurus*, using 1 cm for each meter.

> **From history.** William Buckland was as famous for his odd habits as for his science. He kept a house full of animals, from a bear to guinea pigs, and liked to give lively lectures on horseback during field trips. He was also one of the first scientists to study coprolites, which are fossil droppings, and he showed that they could tell what ancient animals had eaten. His wife, Mary Buckland, was a skilled artist who drew many of the fossils for his books and helped him in his work.

WORKED EXAMPLES

Example 1. A three-toed footprint in rock measures 45 cm (about 18 inches) from heel to the tip of the middle toe. Use the footprint rule to estimate the hip height of the theropod that made it. Is it taller or shorter than a grown man who is about 180 cm (6 feet) tall?

(Use the map or drawing “Hip height is about 4 times footprint length.” shown earlier in this lesson.)

1. The rule: hip height is about 4 times footprint length.
2. 4 × 45 cm = 180 cm.
3. In inches: 4 × 18 inches = 72 inches = 6 feet.
4. Compare: the dinosaur’s hips were about as high as the top of a tall man’s head.

Answer: About 180 cm (about 6 feet). Its hips alone were about as high as a tall man, so the whole animal stood much taller than he.

Example 2. Read the table of approximate theropod lengths: *Compsognathus*, 1 m (3 ft); *Velociraptor*, 2 m (6½ ft); *Megalosaurus*, 6 m (20 ft); *Allosaurus*, 9 m (30 ft); *Tyrannosaurus*, 12 m (40 ft). (a) How many *Velociraptors*, nose to tail, would equal one *Tyrannosaurus*? (b) How much longer was *Tyrannosaurus* than *Allosaurus*? (c) Put the five in order from shortest to longest.

1. (a) 12 m ÷ 2 m = 6.
2. (b) 12 m − 9 m = 3 m. In feet: 40 ft − 30 ft = 10 ft.
3. (c) The lengths in order are 1, 2, 6, 9, 12 meters.

Answer: (a) 6 Velociraptors. (b) About 3 m (10 ft) longer. (c) Compsognathus, Velociraptor, Megalosaurus, Allosaurus, Tyrannosaurus.

PRACTICE

1. EASY What does the word “theropod” mean?
2. EASY Which dinosaur was the first ever to be given a scientific name, and who named it?
3. EASY Name four features that help you recognize a theropod.
4. MEDIUM A theropod footprint is 30 cm (12 inches) long. About how high were the animal’s hips?
5. MEDIUM Read this table of footprint lengths from one rock surface: Track A, 20 cm; Track B, 50 cm; Track C, 35 cm; Track D, 50 cm. (a) Which track-maker had the highest hips? (b) Which two tracks might have been made by the same kind of animal? (c) What was the hip height for Track C?
6. MEDIUM Why did Buckland decide that *Megalosaurus* ate meat, even though he never saw it eat?
7. HARD Jonah wants to test whether walking or running changes the distance between his footprints. (a) What should he change? (b) Name two things he should keep the same. (c) What should he measure?
8. CHALLENGE In two or three sentences, explain why a theropod needed a long, stiff tail.

COMMON MISTAKES

- Thinking every dinosaur with sharp teeth was huge. Many theropods were small; *Compsognathus* was about the size of a turkey.
- Thinking *T. rex* stood straight up like a person with its tail dragging. That is how many old pictures showed it, but the bones show it held its back level and its tail straight out behind.
- Thinking a footprint tells you only how big the foot was. From a trackway, scientists can also estimate hip height, the number of legs used and whether the animal was walking or hurrying.

Make it a game · Track Detective. A parent cuts out paper footprints of three sizes, small, medium and large, and lays a trail of each kind around the house or yard. Follow each trail and measure one print with a ruler. Multiply by 4 to estimate the hip height of the "theropod" that made it, then stand next to a wall and mark that height with tape. The player whose estimate is closest to the parent's secret answer wins the round.

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

Even the hunters of the animal world depend on God for their food. The psalmist looked at fierce lions and saw a Creator who provides for every creature He made.

Practice answers

1. "Beast foot."
2. *Megalosaurus*, named by William Buckland in 1824.
3. Any four: walked on two legs; three main toes on each foot; hollow bones; sharp, curved, serrated teeth; clawed hands; a long tail for balance; lizard-hipped (pubis pointing forward).
4. 4 × 30 cm = 120 cm, about 1.2 m (4 × 12 inches = 48 inches, or 4 feet).
5. (a) B and D tie for the longest prints (50 cm), so they had the highest hips, about 200 cm (2 m). (b) B and D, because their prints are the same length. (c) 4 × 35 cm = 140 cm.
6. Its teeth were sharp, curved, blade-like and serrated like a steak knife. Teeth like that are made for slicing meat, not for grinding plants. Teeth tell diet.
7. (a) Whether he walks or runs. (b) Any two: the same person, the same shoes or bare feet, the same ground (such as damp sand), the same number of steps measured. (c) The distance from one footprint to the next print of the same foot (the stride length).
8. A theropod walked on two legs, with its heavy head and chest in front of its hips. The long tail stuck out behind and balanced that weight over the hips, like the other side of a seesaw, so the animal did not tip forward when it walked or ran.

7.3 Sauropods

OBJECTIVES

- Tell how Earl Douglass found a great bed of sauropod bones near Jensen, Utah, in 1909, and how that quarry became Dinosaur National Monument.
- List the features of a sauropod (long neck, long tail, small head, peg- or spoon-shaped teeth, four pillar-like legs, light air-filled vertebrae) and explain how each one fits a giant plant eater.
- Compare sauropod sizes on a bar graph and run a fair test of which column shape holds the most weight.

Warm-up. Hold a ruler straight out in front of you by one end and hang a small bag of coins on the far end. Now hold the ruler straight up with the bag on top. Which way is harder to hold? Then think: how could an animal with a neck as long as a school bus hold up its head? Write one guess.

Video. Coming soon. Sauropod dinosaurs for kids (Diplodocus, Brontosaurus, Apatosaurus, Brachiosaurus), the Carnegie Quarry wall of bones at Dinosaur National Monument, and Dippy the Diplodocus cast: search National Park Service (Dinosaur National Monument), Carnegie Museum of Natural History, Natural History Museum London, Smithsonian National Museum of Natural History, Homeschool Pop (Alternate) and SciShow Kids.

KEY TERMS

sauropod
A lizard-hipped dinosaur with a very long neck, a long tail, a small head and four thick legs. All were plant eaters. The name means “lizard foot.”

herbivore
An animal that eats only plants.

quadrupedal
Walking on four legs.

column
A tall, upright support, like a pillar holding up a porch roof. Sauropod legs worked like columns.

quarry
A place where rock is dug out of the ground. A dinosaur quarry is a dig site where many fossil bones are found together.

CORE IDEAS

The story. In the summer of 1909 a fossil hunter named **Earl Douglass** was searching the dry, rocky hills near Jensen, Utah, for the Carnegie Museum of Pittsburgh. On August 17 he climbed a ridge of tilted sandstone and saw, sticking out of the rock, eight tail bones of a giant sauropod lying in a row, just as they had been in the living animal. He wrote in his diary that it was a beautiful sight. Douglass and his crew dug there for more than ten years and sent car after car of bones to Pittsburgh. In 1915 the site was set aside as **Dinosaur National Monument**. Today visitors can walk into a building and see a wall of rock with about 1,500 dinosaur bones still in place.

How they figured it out. Bones in a quarry are often jumbled, so a paleontologist must work like a puzzle solver. Douglass and his helpers carefully mapped where each bone lay before lifting it, wrapped it in burlap and plaster to protect it, and later matched necks, backs, hips and tails into skeletons. By comparing many skeletons, scientists saw that the long-necked giants shared a plan. In 1878 Othniel Marsh named them the **sauropods**, "lizard feet." Like the theropods, they are lizard-hipped dinosaurs, with the pubis bone pointing forward.

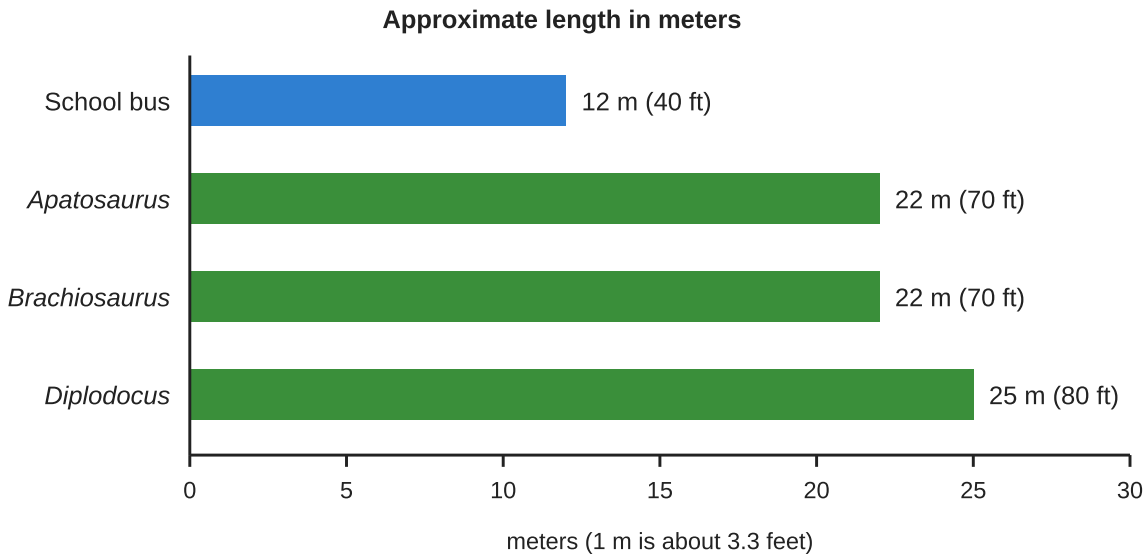
The big idea. A **sauropod** is easy to recognize. It had a **very long neck**, a **very long tail** and a **small head**. It was **quadrupedal**, standing on four thick legs straight under its body like the columns of a building. Its teeth were shaped like **pegs or spoons**, good for stripping leaves from branches, not for slicing meat, so it was a **herbivore**. Many sauropods swallowed their leaves without much chewing. Their neck and back vertebrae were full of **air spaces**, which made the long neck light enough to lift, the same way a hollow steel beam is strong but light.

Some famous sauropods. *Diplodocus* was long and slender, about 25 meters (80 feet) from nose to tail, with 15 vertebrae in its neck. Copies of a *Diplodocus* skeleton paid for by the steel maker Andrew Carnegie were given to museums around the world. *Brontosaurus* and *Apatosaurus* were heavier cousins, about 22 meters (70 feet) long. *Brachiosaurus* had front legs longer than its back legs, so its back sloped down like a giraffe's, and it could raise its head about 12 meters (40 feet) above the ground, as high as a four-story building. Some sauropods found in South America may have been longer than 30 meters (100 feet). They were the largest animals that ever walked on land.

God's handiwork. How could anything so big stand up? God gave the sauropods legs like pillars, with thick bones stacked straight above the feet, and broad feet with a thick pad behind the toes, like an elephant's. A straight column carries weight straight down, so the bones push against the load instead of bending under it. In Job 40, the Lord points Job to a great beast called behemoth, which "eateth grass as an ox" and "moveth his tail like a cedar." Many Christians think a creature like a sauropod fits that description well.

Try it and see. Why are pillars round? In the project you will fold sheets of paper into columns of three shapes, round, square and triangle, and stack books on each one until it

crumples. You will discover why builders, and the Creator who designed the sauropod's legs, use columns to hold up great weight.



Approximate lengths of three sauropods compared with a school bus. Scientists' estimates vary, so these are round numbers.

⏳ Thinking About Time

What the sign says. Park signs and guidebooks say the bones lie in a rock layer called the Morrison Formation, from the Jurassic period, many millions of years ago. They explain that an ancient river carried the bodies of dinosaurs and buried them in a sandbar.

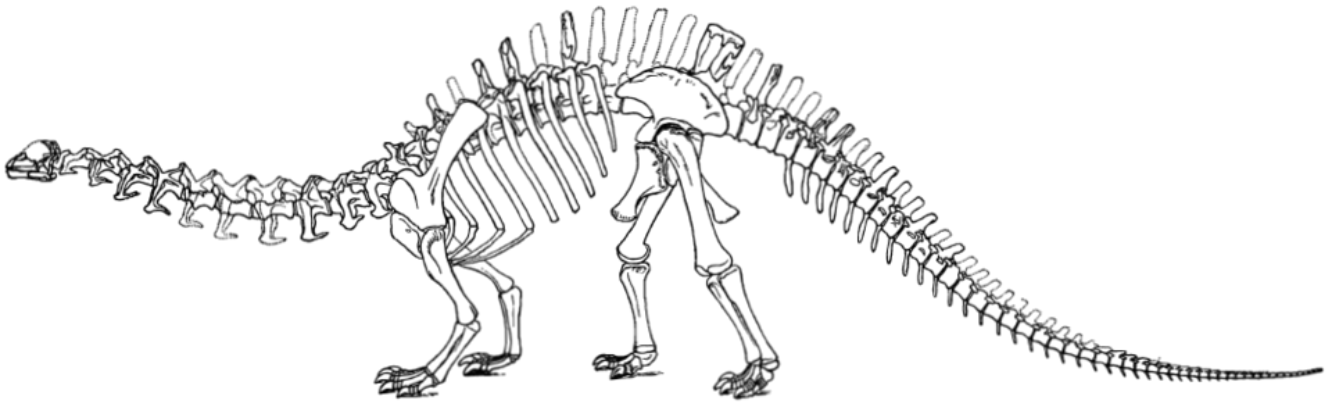
What we observe. We can see about 1,500 bones in one wall of tilted sandstone, from several kinds of dinosaurs mixed together. Many skeletons are broken apart and scattered. The bones were buried in sand that was moved and laid down by water.

How Christians read it. Many Christians read this great jumble of bones as the work of fast-moving water in the Flood of Noah's day, which swept up animals and buried them quickly in sand, before the bones could rot away or be eaten.

Try it. Put some sand, small pebbles and a few small plastic animals in a clear jar of water, shake it and let it settle. Draw how the animals ended up buried in the layers.

Genesis 7:19–20

PICTURE STUDY



Restoration of BRONTOSAURUS EXCELSUS. Marsh. One-eightieth natural size.

Restoration of Brontosaurus, Drawn for Othniel Charles Marsh, 1883 · Printed scientific drawing · Published in the *American Journal of Science*, 1883; Marsh's fossils are kept at the Yale Peabody Museum, New Haven, Connecticut

Othniel Charles Marsh, a professor at Yale College, collected many sauropod bones from the American West. In 1883 he published one of the first drawings of a whole sauropod skeleton, which he called *Brontosaurus*, "thunder lizard." The drawing showed people for the first time how the bones of these giants fit together.

Marsh did not have a skull found with this skeleton, so the head in his drawing was based on bones of a different sauropod. Later finds showed that the real head was longer and lower. Even a great scientist must sometimes fill a gap with his best guess, and good scientists are glad to fix it when better evidence comes.

Look closely

- Trace the backbone with your finger from the head to the tip of the tail. Which part is longest?
- Look at the legs. Are they sprawled out or straight under the body like columns?
- Compare the size of the head with the size of the body. What does that tell you about how this animal must have eaten?
- Look at the feet. How are they like an elephant's feet?

Talk about it

1. Why do you think the tail was so long? (Think about the long neck at the other end.)
2. Marsh guessed at the head. How should a scientist show readers which parts are known and which are guessed?

> **Safety first.** Stack books slowly and keep your hands, face and feet out of the way when a column might collapse. Work on the floor, not on a table, so nothing falls far.

EXPERIMENT: PILLAR LEGS: WHICH COLUMN HOLDS THE MOST?

Question: If you fold the same size sheet of paper into a round, a square and a triangular column, which shape will hold the most books? Sauropod legs were columns. You will run a fair test to find the strongest shape.

You will need

- 6 sheets of printer paper, all the same size (letter size is 21.6 cm × 27.9 cm, or 8½ × 11 inches)
- Clear tape
- Ruler marked in centimeters
- A stack of books of about the same size (such as hardcover picture books or old phone books)
- A bathroom scale (optional)
- Notebook and pencil

Steps

1. Write your prediction: Which column shape will hold the most books?
2. Round column: roll one sheet the short way into a tube about 7 cm (2¾ inches) across, overlapping the edges 2 cm, and tape it top, middle and bottom.
3. Square column: fold a sheet the short way into four equal panels plus a 2 cm flap, crease it sharply, form a square tube and tape the flap.
4. Triangle column: fold a sheet into three equal panels plus a 2 cm flap, form a triangular tube and tape the flap.
5. Stand one column on the floor. Lay a thin book flat on top so the weight is spread evenly. Add books one at a time until the column crumples. Record the number of books that it held before it crumpled (do not count the book that crushed it).
6. Test the other two shapes the same way.
7. Build a second set of three columns with the other three sheets and repeat the test.
8. Record your results in a table: Shape, Trial 1, Trial 2. If you have a scale, weigh the stack of books each column held.
9. Write your conclusion: Which shape was strongest? Why do you think so? How are sauropod legs like your strongest column?

Tips

- What we change: the shape of the column. What we keep the same: the size and kind of paper, the amount of overlap and tape, the height of the column, the books and how gently they are added. What we measure: the number of books each column holds.
- Make the top and bottom edges of each column flat and even so the books press straight down.
- A round column has no corners to bend first, so the weight is shared all around its edge.

Check your work

- I made three columns from the same size paper that differ only in shape.
- I tested each shape twice and recorded my results in a table.
- I can explain why a straight, pillar-like leg helps a very heavy animal.
- I can name four features of a sauropod.

NATURE NOTEBOOK

1. Draw a sauropod skeleton from a book or museum photo. Label the small head, the long neck, the column legs, the hip and the long tail.
2. Draw a sauropod’s peg-shaped tooth beside a theropod’s serrated tooth. Under each, write what the animal ate and how you can tell.
3. Draw a giraffe and a *Brachiosaurus* side by side to the same scale, using 1 cm for each meter of height (giraffe about 5.5 cm tall, *Brachiosaurus* about 12 cm tall).

From history. In 1877 Othniel Marsh named a sauropod *Apatosaurus*, and in 1879 he named another skeleton *Brontosaurus*. In 1903 the paleontologist Elmer Riggs decided the two were so alike that they belonged in one group. By the rules of naming, the older name wins, so for most of the 1900s scientists said *Apatosaurus*, even though museums and storybooks kept saying *Brontosaurus*. In 2015 a team of scientists compared many sauropod skeletons bone by bone and argued that *Brontosaurus* was different enough to have its own name after all. Classification is careful work, and names can change as more bones are compared.

WORKED EXAMPLES

Example 1. Use the bar graph of lengths. A school bus is about 12 m (40 feet) long and *Diplodocus* was about 25 m (80 feet) long. (a) About how many school buses parked end to end would match one *Diplodocus*? (b) How much longer was *Diplodocus* than *Apatosaurus*?

(Use the map or drawing “Read the end of each bar against the scale at the bottom.” shown earlier in this lesson.)

1. (a) Two buses: 2 × 12 m = 24 m. That is just 1 m short of 25 m, so about 2 buses.
2. In feet: 2 × 40 feet = 80 feet, the same as the *Diplodocus*.
3. (b) Read the graph: *Apatosaurus* was about 22 m. 25 m − 22 m = 3 m (about 10 feet).

Answer: (a) About 2 school buses. (b) About 3 m (10 feet) longer.

Example 2. A tall giraffe can raise its head about 5.5 m (18 feet) above the ground. *Brachiosaurus* could raise its head about 12 m (40 feet). (a) How much higher could *Brachiosaurus* reach? (b) About how many times as high is that? (c) A giraffe has 7 neck vertebrae and *Diplodocus* had 15. How many more did *Diplodocus* have?

1. (a) 12 m − 5.5 m = 6.5 m. In feet: 40 − 18 = 22 feet.
2. (b) 5.5 × 2 = 11, which is close to 12, so a little more than 2 times as high.
3. (c) 15 − 7 = 8 more neck vertebrae.

Answer: (a) About 6.5 m (22 feet) higher. (b) A little more than twice as high. (c) 8 more neck vertebrae.

PRACTICE

1. EASY What does the word “sauropod” mean?
2. EASY Name four features of a sauropod.
3. EASY Who found the great bed of dinosaur bones that became Dinosaur National Monument, and in what state?
4. MEDIUM A sauropod tooth is shaped like a peg and has no saw edge. What did the animal eat, and how do you know?
5. MEDIUM Read this table from a column test (books held before crumpling). Round: Trial 1, 14; Trial 2, 16. Square: 7; 9. Triangle: 5; 5. (a) What was the average for each shape? (b) Which shape was strongest? (c) How many more books did the round column hold on average than the square one?
6. MEDIUM *Apatosaurus* was about 22 m long. How long is that in feet? (Use 1 m ≈ 3.3 feet.)
7. HARD Lily wants to find out whether a taller paper column holds less weight than a shorter one. (a) What should she change? (b) What should she keep the same? Name three things. (c) What should she measure?
8. CHALLENGE A sauropod’s neck was very long, yet the animal could hold it up. Give two reasons from this lesson.

COMMON MISTAKES

- Thinking sauropods had to live in lakes to hold up their weight. Older books showed them wading, but their pillar legs and footprints show they walked on dry land.
- Thinking a sauropod’s long neck came only from having many neck bones. Sauropods did have more neck vertebrae than mammals (*Diplodocus* had 15, a giraffe has 7), but each of their neck bones was also very long.
- Thinking *Brontosaurus* was just a made-up name. Marsh named it in 1879; for many years scientists filed it under *Apatosaurus*, but many now treat it as its own kind again.

Make it a game · Pace a Sauropod. Go to a yard, a park or a long hallway. Each player places a marker where he or she thinks 25 m (82 feet), the length of a *Diplodocus*, ends

from a starting line. Then measure with a tape measure or by counting giant steps you have measured beforehand. The closest guess wins a point. Play again with 12 m for *Tyrannosaurus*, 22 m for *Apatosaurus* and 12 m up a tall building or tree for the height of *Brachiosaurus*'s head.

Scripture. "Behold now behemoth, which I made with thee; he eateth grass as an ox. Lo now, his strength is in his loins, and his force is in the navel of his belly." (Job 40:15–16, KJV)

God told Job to look at behemoth, a mighty grass-eating beast with great strength in its hips and belly, which "moveth his tail like a cedar" (Job 40:17). Whatever behemoth was, God made it, and its strength shows His power.

Practice answers

1. "Lizard foot."
2. Any four: very long neck; very long tail; small head; peg- or spoon-shaped teeth; four thick, pillar-like legs; air spaces in the vertebrae; lizard-hipped; plant eater.
3. Earl Douglass, in 1909, near Jensen, Utah.
4. Plants. Peg-shaped teeth are good for stripping leaves from branches, not for slicing meat; slicing teeth are blade-like and serrated.
5. (a) Round: (14 + 16) ÷ 2 = 15. Square: (7 + 9) ÷ 2 = 8. Triangle: (5 + 5) ÷ 2 = 5. (b) Round. (c) 15 − 8 = 7 more books.
6. 22 × 3.3 = 72.6, so about 73 feet (about 70 feet).
7. (a) The height of the column. (b) Any three: the shape (all round), the kind of paper, the width of the tube, the amount of tape and overlap, the books used, how gently the books are added. (c) The number of books (or the weight) each column holds before it crumples.
8. First, the neck vertebrae were full of air spaces, which made the neck much lighter while keeping it strong. Second, the head was small, so there was little weight at the end of the neck. (The long tail on the other side also helped balance the neck over the legs.)

7.4 Ornithischians: The Bird-Hipped Plant Eaters

OBJECTIVES

- Tell how Gideon Mantell named *Iguanodon* from its teeth in 1825, and how later skeletons from a Belgian coal mine showed that its “horn” was really a thumb spike.
- Compare a lizard hip and a bird hip, and list the features shared by ornithischians (backward-pointing pubis, a beak at the front of the jaws, cheek teeth for chewing plants).
- Sort ornithischians into armored, horned, duck-billed, bone-headed and two-legged plant-eater groups with a dichotomous key, and test how a rough grinding surface breaks down leaves.

Warm-up. Tear a lettuce or spinach leaf in half with your fingers, then try to “chew” the other half by rubbing it between two smooth spoons. Is it easier to snip a leaf or to grind it into tiny bits? Plant eaters must do both. Write down which job your front teeth do and which job your back teeth do.

Video. Coming soon. Ornithischian dinosaurs for kids (Stegosaurus, Triceratops, Ankylosaurus, duck-billed hadrosaurs, Iguanodon), bird-hipped and lizard-hipped dinosaurs compared, and Gideon Mantell and the Iguanodon teeth: search Natural History Museum London, Smithsonian National Museum of Natural History, Royal Belgian Institute of Natural Sciences, Homeschool Pop (Alternate), SciShow Kids and museum fossil-hall tours.

KEY TERMS

ornithischian
A “bird-hipped” dinosaur, whose pubis bone pointed backward. All ornithischians were plant eaters with a beak at the front of their jaws.

pubis
One of the three bones on each side of the hip. It points forward in lizard-hipped dinosaurs and backward in bird-hipped dinosaurs.

beak
A hard, horny covering on the front of the jaws used to snip or grab food. Ornithischians had a beak supported by an extra bone at the tip of the lower jaw.

frill
A wide shield of bone that grows back from the skull over the neck, as in *Triceratops*.

armor
Bony plates, spikes or knobs set in the skin that protect an animal, as in *Ankylosaurus* and *Stegosaurus*.

CORE IDEAS

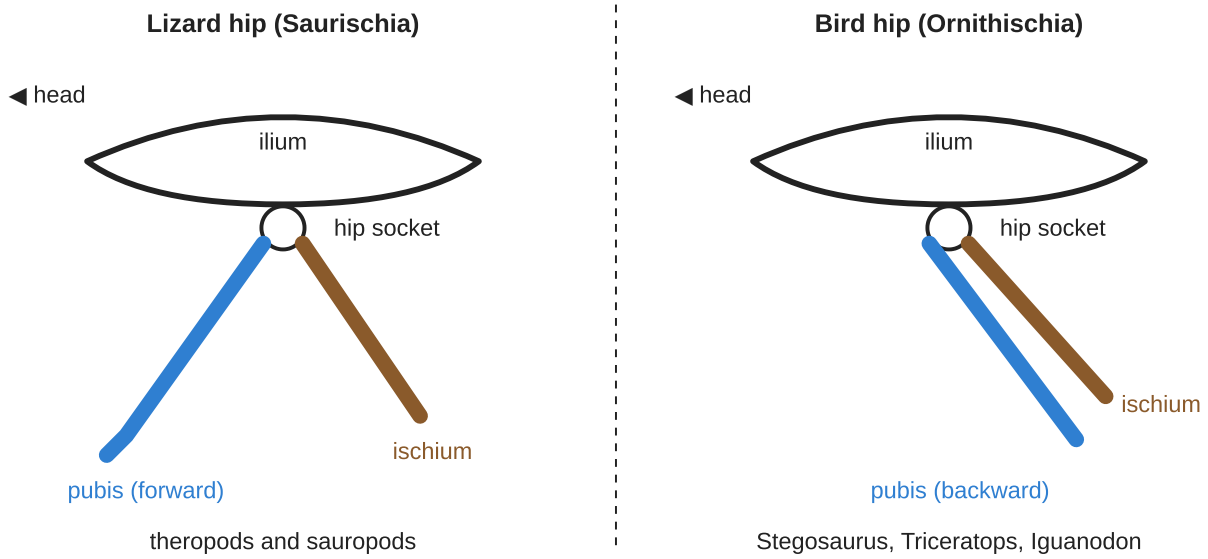
The story. In the early 1820s **Gideon Mantell**, a busy country doctor in Sussex, England, spent every spare hour hunting fossils. Family tradition says his wife, Mary Ann, spotted the first large, worn teeth in a pile of road stone while he was visiting a patient. Whoever saw them first, Gideon studied them for years. The teeth were broad and ridged, and their tops were worn flat, as if they had ground up tough plants. No one knew any reptile with teeth like that. At last, at the Royal College of Surgeons in London, a young assistant named Samuel Stutchbury showed him the skeleton of an iguana, the plant-eating lizard of Central and South America. Its tiny teeth looked like small copies of Mantell's giant ones. In 1825 Mantell named the animal *Iguanodon*, "iguana tooth."

How they figured it out. Mantell later found a cone-shaped spike of bone and guessed it sat on the nose like a rhinoceros horn, and the Crystal Palace model of 1854 was built that way. Then, in 1878, coal miners at Bernissart, Belgium, broke into a pocket of clay deep underground and found more than thirty skeletons of *Iguanodon*, many of them nearly complete. The Belgian scientist Louis Dollo spent years studying them. The whole skeletons showed that the spike was not a horn at all. It was a **thumb spike**, one on each hand. One complete skeleton can correct a guess made from a few loose bones.

The big idea. *Iguanodon* belongs to the **ornithischians**, the "bird-hipped" dinosaurs named by Harry Seeley in 1887. Look at the hip. In a lizard-hipped dinosaur, the **pubis** bone points **forward**. In a bird-hipped dinosaur, it points **backward** and lies along the ischium bone. Every ornithischian was a **plant eater**. Each had a **beak** on the front of its jaws, held up by an extra bone at the tip of the lower jaw, for snipping leaves and twigs, and rows of **cheek teeth** farther back for chewing them. That is a different plan from a sauropod, which stripped leaves with peg teeth and swallowed them whole.

Five kinds to know. Like a dichotomous key, the ornithischians can be sorted by what you see. The **armored** dinosaurs had bony plates or knobs: *Stegosaurus* had tall plates along its back and four spikes on its tail, and *Ankylosaurus* was covered in armor and swung a bony club on the end of its tail. The **horned** dinosaurs had horns and a frill: *Triceratops*, "three-horned face," was about 9 meters (30 feet) long, with two brow horns that could be about 1 meter (3 feet) long. The **duck-billed** dinosaurs, such as *Edmontosaurus* and *Parasaurolophus*, had wide, flat beaks and hundreds of cheek teeth packed into rows, with new teeth growing up to replace worn ones. The **bone-headed** dinosaurs, such as *Pachycephalosaurus*, had a thick dome of bone on top of the skull. The **two-legged plant eaters**, such as *Iguanodon*, could walk on their hind legs or on all fours.

Try it and see. A beak can snip a leaf, but how do cheek teeth turn a tough leaf into tiny pieces that the stomach can use? Duck-billed dinosaurs had worn, rough grinding surfaces like a file. In the project you will grind leaves between rough sandpaper and between smooth surfaces, count the strokes and the pieces, and see why God gave these plant eaters such wonderful chewing tools. As Genesis says, God gave "every green herb for meat" to the beasts of the earth (Genesis 1:30).



The pubis is the key. Forward means lizard-hipped (theropods and sauropods). Backward means bird-hipped (ornithischians).

⏳ Thinking About Time

What the sign says. Museum signs say *Iguanodon* lived in the Early Cretaceous and *Triceratops* and the duck-billed dinosaurs in the Late Cretaceous, many millions of years ago, and that herds of them were sometimes killed by floods or storms near rivers.

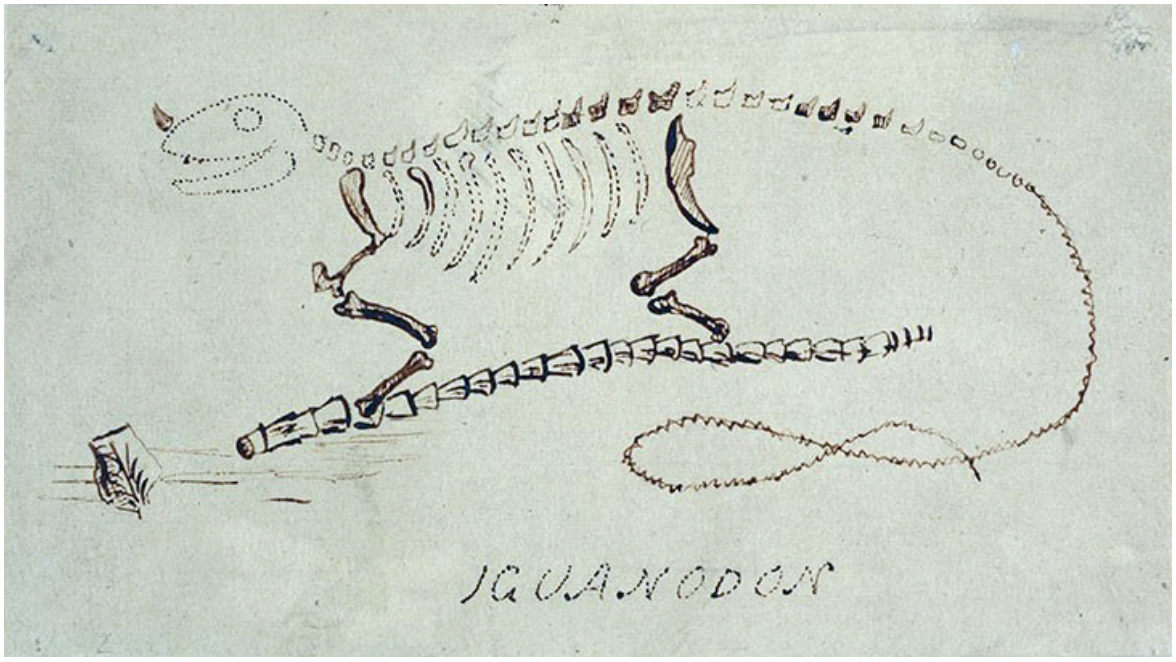
What we observe. In Montana and in Alberta, Canada, scientists have dug up bonebeds holding the bones of hundreds or even thousands of horned or duck-billed dinosaurs, mostly of one kind, buried together. At Bernissart, Belgium, more than thirty *Iguanodon* skeletons were found together in clay deep underground.

How Christians read it. Many Christians see these great graveyards as the work of the Flood of Noah’s day, when rushing water and mud overtook whole herds of animals at once and buried them quickly enough for their bones to be preserved.

Try it. Look at a picture of a bonebed dig. Count how many bones you can see in one square, and write one thing the picture shows and one thing someone would have to interpret.

Genesis 7:22–23

PICTURE STUDY



Mantell's sketch of Iguanodon, Gideon Mantell, about 1834 · Sketch on paper · Natural History Museum, London

After a slab of rock holding many *Iguanodon* bones was found in a quarry near Maidstone, Kent, Gideon Mantell tried to picture the whole animal. He drew it as a huge, long-tailed lizard on four legs and placed the cone-shaped spike on its nose.

The sketch is precious because it shows a scientist thinking on paper. Mantell drew what he knew from the bones and filled in the rest with his best guess. The whole skeletons from Belgium later showed which parts he had right and which he had wrong.

Look closely

- Find the spike. Where did Mantell put it? Where do we now know it belongs?
- Look at the legs and body. Is this animal sprawling like a lizard or standing tall?
- Look at the tail. How does it compare with the tails of the theropods you studied in Lesson 7.2?
- What features of an ornithischian can you find, and which ones are missing?

Talk about it

1. Mantell named the animal after the iguana. What do you think made him picture it as a giant lizard?
2. Why is it wise for a scientist to say "this is my best guess" when part of the evidence is missing?

> **Safety first.** Rub gently so the sandpaper does not scrape your knuckles. Wash your hands after handling the leaves and sandpaper, and do not eat the leaves you used in the

> test.

EXPERIMENT: GRINDING TEETH: ROUGH OR SMOOTH?

Question: Does a rough grinding surface break a leaf into more pieces than a smooth surface with the same number of strokes? Duck-billed dinosaurs had rough, file-like rows of cheek teeth. You will test whether roughness really helps.

You will need

- 2 small wooden blocks or thick books of the same size
- 1 sheet of medium-grit sandpaper, cut in half
- Tape
- 8 fresh spinach or lettuce leaves of about the same size
- Scissors (the “beak”)
- Ruler marked in centimeters, a white plate, notebook and pencil

Steps

1. Write your prediction: Will the rough or the smooth surface break the leaf into more pieces?
2. Make the rough “jaw”: tape a half sheet of sandpaper, rough side out, to the bottom of one block and the other half to the top of the second block.
3. Make the smooth “jaw”: use the smooth bottom of the first block against the smooth top of a book or a second clean block.
4. Use the scissors like a beak: snip each leaf into a square about 5 cm × 5 cm (2 inches × 2 inches).
5. Put one leaf square between the rough surfaces. Press with the same gentle push and rub back and forth exactly 10 times. Shake the pieces onto the plate and count the pieces bigger than a grain of rice. Record the number.
6. Do the same with a fresh leaf square between the smooth surfaces.
7. Repeat each test three more times with new leaf squares, so you have four trials for each surface.
8. Make a table: Trial, Rough (pieces), Smooth (pieces). Find the average for each surface.
9. Write your conclusion: Which surface broke the leaf down more? How does this help explain the rough, worn cheek teeth of the plant-eating dinosaurs?

Tips

- What we change: the grinding surface (rough or smooth). What we keep the same: the kind and size of leaf, the number of strokes, how hard you press and how you count pieces. What we measure: the number of pieces after 10 strokes.
- Let the same person do all the rubbing so the push stays the same.

- Notice the job of the scissors: the beak snips, the cheek teeth grind. Ornithischians had both tools.

Check your work

- I tested two surfaces that differ in only one way, roughness.
- I did four trials for each surface and found the averages.
- I can explain the difference between a lizard hip and a bird hip.
- I can name five groups of ornithischians with one example of each.

NATURE NOTEBOOK

1. Draw the two hip shapes from the figure in this lesson. Color the pubis bone in each one and label it “forward” or “backward.”
2. Draw *Iguanodon* twice: once as Mantell first imagined it, with a horn on its nose, and once as the Belgian skeletons showed it, with thumb spikes. Write one sentence under each.
3. Make a page with five boxes titled Armored, Horned, Duck-billed, Bone-headed and Two-legged plant eater. Draw one dinosaur in each box and label the feature that puts it there.

> **From history.** In 1822 Gideon Mantell published a book called *The Fossils of the South Downs*, with plates engraved by his wife, Mary Ann, who was a skilled artist. Mantell later opened his home in Brighton as a museum so that visitors could see his collection, and in 1838 he sold most of it to the British Museum. Some of his original *Iguanodon* teeth are kept today at the Natural History Museum in London, where people can still see the fossils that started the story of the bird-hipped dinosaurs.

WORKED EXAMPLES

Example 1. Use this dichotomous key to identify a bird-hipped dinosaur that has a bony frill over its neck and three horns on its face. 1a. Has bony plates, spikes or a tail club: armored, go to 2. 1b. No armor: go to 3. 2a. Tall plates on the back and spikes on the tail: *Stegosaurus*. 2b. Armor all over and a tail club: *Ankylosaurus*. 3a. Has a frill and horns: *Triceratops*. 3b. No frill: go to 4. 4a. Wide, flat duck-like beak: *Edmontosaurus*. 4b. Thumb spikes: *Iguanodon*.

(Use the map or drawing “Before using the key, check the hip: a backward pubis puts the dinosaur among th” shown earlier in this lesson.)

1. Step 1: Does it have bony plates, spikes or a tail club? No. Go to 3.
2. Step 3: Does it have a frill and horns? Yes.
3. The key ends at 3a.

Answer: *Triceratops*, a horned ornithischian.

Example 2. Suppose a model of a duck-billed dinosaur's jaws has 4 tooth rows (upper left, upper right, lower left, lower right). Each row has 50 columns of teeth, and each column holds 3 teeth stacked one above another, with new teeth waiting to replace worn ones. How many teeth are in the model?

1. Teeth in one row: 50 columns × 3 teeth = 150 teeth.
2. Teeth in all four rows: 4 × 150 = 600 teeth.
3. Check another way: 4 × 50 = 200 columns, and 200 × 3 = 600.

Answer: 600 teeth. Real duck-billed dinosaurs had hundreds of teeth packed in rows like this.

PRACTICE

1. EASY What does the name *Iguanodon* mean, and why did Mantell choose it?
2. EASY Which way does the pubis bone point in a bird-hipped dinosaur?
3. EASY Name three features all ornithischians shared.
4. MEDIUM Sort these into armored, horned or duck-billed: *Ankylosaurus*, *Triceratops*, *Edmontosaurus*, *Stegosaurus*, *Parasaurolophus*.
5. MEDIUM Read this table from a grinding test (pieces after 10 strokes). Rough: 18, 22, 20, 24. Smooth: 4, 6, 5, 5. (a) Find the average for each surface. (b) How many times as many pieces did the rough surface make?
6. MEDIUM What did the skeletons found at Bernissart, Belgium, in 1878 show about *Iguanodon*'s spike?
7. HARD Eli wants to test whether the number of grinding strokes changes how many pieces a leaf breaks into. (a) What should he change? (b) Name three things he should keep the same. (c) What should he measure? (d) Why should he use a fresh leaf each time?
8. CHALLENGE *Triceratops* and *Diplodocus* were both plant eaters. Explain in two or three sentences how you could tell from the skeletons that they belong in different main groups of dinosaurs.

COMMON MISTAKES

- Thinking all plant-eating dinosaurs belong together. Sauropods ate plants too, but they are lizard-hipped; only the beaked plant eaters are ornithischians.
- Thinking "bird-hipped" dinosaurs were the dinosaurs most like birds. The name describes only the backward pubis. Most scientists say the lizard-hipped theropods share far more features with birds, such as hollow bones, three-toed feet and wishbones.
- Thinking *Stegosaurus*'s plates or *Iguanodon*'s spike were where old pictures put them. Scientists changed their pictures as more complete skeletons were found, so always check a book's date.

Make it a game · Who Am I? Dinosaur Key. One player secretly picks a dinosaur from this unit: Megalosaurus, Tyrannosaurus, Velociraptor, Diplodocus, Brontosaurus, Brachiosaurus, Iguanodon, Stegosaurus, Ankylosaurus, Triceratops, Edmontosaurus or Pachycephalosaurus. The others may ask only yes-or-no questions about features, such as "Does your pubis point backward?" or "Do you have a frill?" Each question is one step of a key. Guess the dinosaur in six questions or fewer to win the round, then switch roles.

Scripture. "And to every beast of the earth, and to every fowl of the air, and to every thing that creepeth upon the earth, wherein there is life, I have given every green herb for meat: and it was so." (Genesis 1:30, KJV)

God gave the animals green plants for food. The beaks and grinding teeth of the plant-eating dinosaurs show how well He fitted each creature for the food He provided.

Practice answers

1. "Iguana tooth." Its teeth looked like giant copies of the teeth of an iguana.
2. Backward, lying along the ischium.
3. Any three: bird hip (pubis pointing backward); plant eater; a beak at the front of the jaws with an extra bone at the tip of the lower jaw; cheek teeth for chewing.
4. Armored: *Ankylosaurus*, *Stegosaurus*. Horned: *Triceratops*. Duck-billed: *Edmontosaurus*, *Parasaurolophus*.
5. (a) Rough: 18 + 22 + 20 + 24 = 84, and 84 ÷ 4 = 21. Smooth: 4 + 6 + 5 + 5 = 20, and 20 ÷ 4 = 5. (b) 21 ÷ 5 is a little more than 4, so a little more than 4 times as many.
6. That it was not a horn on the nose, as Mantell had guessed, but a spike on each thumb.
7. (a) The number of strokes (for example 5, 10 and 20). (b) Any three: the same rough surface, the same kind and size of leaf, the same push, the same person, the same way of counting. (c) The number of pieces after the strokes. (d) A leaf that was already ground would start out in pieces, so the test would not be fair.
8. Look at the hips. *Diplodocus* has a pubis that points forward, so it is lizard-hipped (a saurischian sauropod). *Triceratops* has a pubis that points backward and a beak at the front of its jaws, so it is bird-hipped (an ornithischian). Eating plants alone does not decide the group; the bones do.

Unit 7 review

Answer each question. Show your work for calculations and use complete sentences for explanations. The quiz is worth 50 points.

1. (5 pts) Who named the Dinosauria, in what year, and what does the name mean?
2. (5 pts) Name two features Owen used to show that dinosaurs were different from lizards.
3. (5 pts) Which of these are dinosaurs? *Pteranodon*, *Stegosaurus*, plesiosaur, *Tyrannosaurus*, *Dimetrodon*. Give a reason for one animal that is not.
4. (5 pts) Draw or describe the difference between a lizard hip and a bird hip. Which groups of dinosaurs belong to each?
5. (5 pts) List four features of a theropod.
6. (5 pts) A three-toed footprint is 40 cm long. Use the footprint rule to estimate the hip height of the dinosaur that made it, in centimeters and meters.
7. (5 pts) List four features of a sauropod, and tell how its teeth show what it ate.
8. (5 pts) Read the data: school bus 12 m; *Apatosaurus* 22 m; *Diplodocus* 25 m. (a) How much longer was *Diplodocus* than a school bus? (b) About how many buses long was *Diplodocus*?
9. (5 pts) Name the ornithischian group for each: (a) *Triceratops*, (b) *Ankylosaurus*, (c) *Edmontosaurus*, (d) *Pachycephalosaurus*, (e) *Iguanodon*. Then name two features that all ornithischians shared.
10. (5 pts) A student wants to test whether wider paper columns hold more books than narrow ones. Name what she should change, two things she should keep the same and what she should measure. Then tell how this test connects to sauropod legs.

Unit project: my dinosaur family tree

Make a large poster of the dinosaur classification tree, starting with **Dinosauria** at the top and splitting into the lizard-hipped and bird-hipped branches, then into theropods, sauropods and the five groups of ornithischians. Draw at least twelve dinosaurs in their correct places, with a small sketch of the hip type on each main branch. Beside each dinosaur, write its length in meters (and feet), what it ate and one feature that puts it in its group.

Add a scale bar showing a child, a school bus and your longest dinosaur, and attach your results tables from the four experiments (leg posture, footprint rule, column strength and grinding teeth), each with one sentence telling what you learned.

- **Accuracy**: Every dinosaur is on the correct branch, the hip types are drawn correctly and the facts about size and diet are right.
- **Classification thinking**: Each dinosaur has a feature written beside it that explains why it belongs in its group, as in a dichotomous key.
- **Records**: The four experiment tables are complete, with what was changed, what was kept the same and what was measured, and a clear conclusion.

- **Care**: The poster is neat, labeled, colorful and easy to follow, with a correct scale bar.

Answer key

1. Richard Owen, in 1842. It means “terrible lizard” or “fearfully great lizard.”
2. Their legs stood straight under the body (upright posture) instead of sprawling, and five vertebrae were fused in the sacrum instead of two.
3. Dinosaurs: *Stegosaurus* and *Tyrannosaurus*. Reason (any one): *Pteranodon* is a flying reptile (pterosaur); a plesiosaur is a sea reptile; *Dimetrodon* had sprawling legs. None stood on upright legs on land like a dinosaur.
4. In a lizard hip (Saurischia), the pubis points forward. In a bird hip (Ornithischia), the pubis points backward along the ischium. Lizard-hipped: theropods and sauropods. Bird-hipped: the beaked plant eaters such as *Stegosaurus*, *Triceratops* and *Iguanodon*.
5. Any four: walked on two legs; three main toes on each foot; hollow bones; sharp, curved, serrated teeth; clawed hands; a long tail for balance; lizard-hipped.
6. Hip height ≈ 4 × 40 cm = 160 cm = 1.6 m (about 5 feet 3 inches).
7. Any four: very long neck; very long tail; small head; four pillar-like legs; air spaces in the vertebrae; lizard-hipped. Its peg- or spoon-shaped teeth were made for stripping leaves, not slicing meat, so it was a plant eater.
8. (a) 25 − 12 = 13 m longer. (b) 25 ÷ 12 is a little more than 2, so about 2 buses.
9. (a) Horned. (b) Armored. (c) Duck-billed. (d) Bone-headed. (e) Two-legged plant eater. All ornithischians had a backward-pointing pubis, a beak at the front of the jaws and cheek teeth for chewing plants (any two).
10. Change: the width of the column. Keep the same (any two): the shape (round), the kind and size of paper, the height, the tape, the books and how they are added. Measure: the number of books each column holds before it crumples. Connection: sauropod legs were thick, upright columns, and the test shows how column size and shape help carry great weight.

UNIT 8

Field Guide Project

All year you have classified God's creatures the way Linnaeus taught: vertebrates and invertebrates, birds and mammals, mosses, conifers and flowering plants. Now you will put it all to work in your own neighborhood. In this unit you will make a real **field guide** to twelve local species, the kind of book a naturalist carries outdoors to name living things. You will survey small plots in different habitats, choose a Balanced Dozen of species, keep careful field notes and photos, write a species page for each one, build a dichotomous key, and test your finished guide on a real reader.

Along the way you will meet four naturalists who did the same work before you. Gilbert White spent a lifetime watching one English village. Joseph Grinnell taught his students to write notes so careful that scientists could use them a century later. Florence Merriam wrote one of the first American field guides for people who watched living birds. Mark Catesby learned to etch his own copper plates so his book of American birds and plants could be finished. By the end you will have a guide of your own and the habits of a real field scientist: "The works of the LORD are great, sought out of all them that have pleasure therein" (Psalm 111:2).

BEFORE YOU BEGIN

- Can follow and write a simple dichotomous key and write a two-part scientific name (Unit 1)
- Can sort animals into vertebrates and invertebrates and name the five classes of vertebrates (Units 2 and 3)
- Can sort plants into mosses, ferns, conifers and flowering plants (Unit 6)
- Can measure in centimeters, find an average, and read and make a bar graph

MASTERY CHECKLIST

- I can survey a measured plot fairly and choose twelve common, safe local species using the Balanced Dozen rule.
- I can write complete field notes with date, time, place, weather, measurements, behavior and a sketch, and tell an observation from a guess.
- I can take a nature photo with a scale object and use it to work out a real size.
- I can write a species page with common and scientific names, classification, size, field marks, look-alikes, habitat, behavior and my own observation.
- I can write and test a dichotomous key and run a fair field test of my guide.
- I can tell the stories of Gilbert White, Joseph Grinnell, Florence Merriam and Mark Catesby and present my finished field guide.

OPTIONAL BOOKS AND RESOURCES

- **iNaturalist and the Seek app** (https://www.inaturalist.org/): Free. Helps identify plants, insects and animals from photos and shows which species others have seen near you. Children should use it with a parent; the companion Seek app can be used without an account (Lessons 8.1 and 8.2).
- **All About Birds, from the Cornell Lab of Ornithology** (https://www.allaboutbirds.org/): Free. Photos, songs, sizes, look-alikes and scientific names for North American birds. Use it to check the facts on your bird pages (Lesson 8.3).
- **USDA PLANTS Database** (https://plants.usda.gov/): Free, from the U.S. Department of Agriculture. Search a plant's common name to find its scientific name, its family and the states where it grows. A parent can help with the search (Lesson 8.3).

8.1 Choosing Twelve Local Species

OBJECTIVES

- Tell how Gilbert White studied the living things of one English village for most of his life and wrote *The Natural History of Selborne* (1789).
- Survey small square plots near home, record every kind of living thing found, and compare the plots with a bar graph.
- Choose twelve local species for a field guide using clear rules: common, safe, easy to find again, and spread across the groups studied this year.

Warm-up. Look out one window for two minutes and list every living thing you can see: “grass,” “a bird,” “a tree.” Now look at your list. How many of those words name one exact kind, like “dandelion” or “American Robin”? How many name a whole big group? A field guide needs exact kinds.

Video. Coming soon. How to start a backyard nature survey and find common local species with children: search Cornell Lab of Ornithology, iNaturalist and Seek tutorials, Smithsonian Science Education, National Park Service junior ranger videos, SciShow Kids, Homeschool Pop (Alternate), and nature footage of backyard birds, insects and plants.

KEY TERMS

field guide
A book that helps you name living things outdoors, with a picture and a short description of each species.

species
One exact kind of living thing, such as the dandelion or the Eastern Gray Squirrel, whose members look alike and can have young together.

local
Living or found near your home: your yard, street, park or nearby woods.

habitat
The place where a living thing finds the food, water, shelter and space it needs, such as a lawn, a pond edge or a woodpile.

survey
A careful search of one place, done the same way each time, to record what lives there.

CORE IDEAS

The story. Gilbert White was born in 1720 in Selborne, a small village in Hampshire, England, and he spent most of his life there as a country clergyman. He never sailed to faraway lands to find strange animals. Instead he walked the same lanes, woods and fields

year after year and wrote down what he saw: when the swallows came back in spring, where the field crickets dug their burrows, how his old pet tortoise buried itself for the winter. He kept a nature journal for twenty-five years. His letters about his village became a book, *The Natural History and Antiquities of Selborne*, printed in 1789. It has been read and reprinted ever since, because it showed that one ordinary place is full of wonders if you look carefully.

How they figured it out. White's great tool was patience. In the woods of Selborne lived three little greenish birds that looked almost exactly alike. Most people called them all by one name. White listened, and he noticed that each had its own song and its own habits. He wrote that they were three different species, and he was right; today they are called the chiffchaff, the willow warbler and the wood warbler. White could tell them apart because he knew his own place so well. The lesson for us is simple: a naturalist who studies a small area closely, in every season, will see things a hurried visitor misses.

The big idea. In this unit you will make your own **field guide** to twelve **local** species. That means you must choose wisely. A good species for your guide is *common*, so you can find it again; *safe* to watch, so you are not handling stinging insects or poison ivy; and *exact*, so you can name one species, not just "a bird" or "a bug." Your twelve should also show the groups you have studied this year. Use the **Balanced Dozen** rule: 3 birds, 2 other vertebrates (a mammal, a toad, a lizard or a fish), 3 invertebrates (insects, spiders, pillbugs, snails or worms), 3 plants with at least one tree, and 1 free choice, such as a mushroom, a moss or a fern.

Try it and see. Before you choose, find out what lives near you. Scientists do a **survey**: they search a measured area in the same way each time. Make a square plot 1 meter (about 3 feet) on each side with string and four sticks. Search it for 10 minutes and list every kind of living thing you find. Then make plots in two other **habitats**, such as a mowed lawn, a garden edge and the ground under a tree. Because each plot is the same size and searched for the same time, you can compare them fairly. The bar graph shows one family's results. The garden edge, with many kinds of plants, had the most species.

God's handiwork. "The earth is the LORD'S, and the fulness thereof" (Psalm 24:1). That fulness is not only in rain forests and coral reefs; it is in the crack of your sidewalk and the corner of your yard. Gilbert White found enough to fill a lifetime in one village. When you choose your twelve species, you are learning to see your own home as part of God's good creation, made with care and full of things worth knowing.



One family's survey: each plot was 1 meter (about 3 feet) square and searched for 10 minutes.

PICTURE STUDY



North-East View of Selborne from the Short Lythe, Samuel Hieronymus Grimm, for Gilbert White, 1789 · Engraving, the fold-out frontispiece of *The Natural History and Antiquities of Selborne* · Printed in London in the first edition of Gilbert White's book; copies are kept in many libraries, and Gilbert White's House in Selborne is now a museum.

Gilbert White asked the Swiss-born artist Samuel Hieronymus Grimm to draw Selborne for his book. This view, which folds out at the front of the first edition, shows the place White

studied for most of his life: the lanes, fields, woods and houses where he watched swallows, crickets and his tortoise year after year.

The picture is a map of habitats. Every field, hedge, wood and garden in it was home to different living things, and White came to know them well.

Look closely

- Find the houses and the church. Where is the village, and where are the fields and woods?
- Count how many different habitats you can see: fields, hedges, woods, gardens, lanes. What might live in each one?
- Look for any people or animals in the picture. What are they doing?
- Imagine Gilbert White walking through this scene. Where would you go first to look for birds? For insects?

Talk about it

1. If someone drew a picture of your neighborhood for your field guide, which habitats would it show?
2. Why might a scientist want readers to see the whole place where the observations were made, not only the plants and animals?

> **Safety first.** Do all outdoor searching with an adult. Look but do not touch wild animals, nests, bees, wasps or spiders. Learn to spot poison ivy (“leaves of three, let it be”) and never touch it. Never taste any plant, berry or mushroom. Wear long pants and closed shoes in tall grass, check for ticks afterward, and wash your hands with soap when you come in.

EXPERIMENT: THREE-PLOT SPECIES SURVEY

You will survey three small plots in different habitats and use what you find to build a master list for your field guide. **Question:** Which habitat near my home has the most kinds of living things? Write your **prediction** before you start.

You will need

- About 4.5 meters (15 feet) of string, cut into one long loop or four pieces
- Four sticks or tent stakes for corners
- Meter stick or tape measure
- Timer
- Hand lens (magnifying glass)
- Science notebook and pencil
- A local bird, plant or insect guide from the library, or the free Seek or iNaturalist app with a parent’s help

Steps

1. **What we change:** the habitat (for example, mowed lawn, garden edge, ground under a tree). **What we keep the same:** the size of the plot (1 meter by 1 meter), the search time (10 minutes), the searcher and the time of day. **What we measure:** the number of different species found.
2. Measure and mark your first plot with the sticks and string. Write the date, time, place, habitat and weather at the top of a notebook page.
3. Search for 10 minutes. Look at the ground, under leaves and on every plant stem. Use the hand lens for tiny things.
4. List each different kind you find. If you do not know the name, describe it (“small black beetle with orange spots”) and sketch it.
5. Repeat in the other two habitats, on the same day if you can.
6. Count the species in each plot and make a bar graph with one bar for each habitat.
7. Make a **master list** of every species you found in all three plots plus any birds, mammals and trees you see nearby. Write each species only once.
8. Sort your master list into groups and choose your Balanced Dozen: 3 birds, 2 other vertebrates, 3 invertebrates, 3 plants (one a tree) and 1 free choice. Ask a parent to check your list.

Tips

- Turn over a flat stone or log gently and put it back exactly as it was, so the creatures underneath keep their home.
- Birds and squirrels rarely land in a tiny plot, so add them to your master list from what you see around the yard.
- Pick species that will still be around in the coming weeks, so you can watch them again for your field notes.

Check your work

- I kept the plot size and search time the same in all three habitats.
- My bar graph has a title, labels and a bar for each habitat.
- My twelve species follow the Balanced Dozen rule and each one is an exact species.

NATURE NOTEBOOK

1. Draw a map of your yard or nearby park from above. Mark your three plots and label each habitat.
2. Draw one tiny creature or plant from your plots, three times larger than life, using the hand lens. Write its size in centimeters.
3. Make a page titled “My Balanced Dozen” with twelve boxes. Write a species name in each box and leave room for a sketch.

> **From history.** Gilbert White’s home in Selborne, a house called The Wakes, is now a museum with gardens open to visitors. White’s tortoise, Timothy, came to live with him in

1780, and for years he wrote down when it dug itself into the ground for winter and when it came out again in spring. Those patient notes on one ordinary animal are one reason scientists still admire him as a model observer.

WORKED EXAMPLES

Example 1. Mia's master list has 15 species: 5 birds (American Robin, Northern Cardinal, Mourning Dove, House Sparrow, Blue Jay), 3 other vertebrates (Eastern Gray Squirrel, Eastern Cottontail, American Toad), 4 invertebrates (pillbug, earthworm, seven-spotted lady beetle, common eastern bumble bee) and 3 plants (dandelion, white clover, red maple). Using the Balanced Dozen rule, how many species must she drop from each group, and how many does she drop in all?

1. The rule asks for 3 birds, 2 other vertebrates, 3 invertebrates, 3 plants and 1 free choice: $3 + 2 + 3 + 3 + 1 = 12$.
2. Birds: she has 5 and needs 3, so $5 - 3 = 2$ left over. Other vertebrates: $3 - 2 = 1$ left over. Invertebrates: $4 - 3 = 1$ left over. Plants: $3 - 3 = 0$ left over, and the red maple is her tree.
3. The left-over species are $2 + 1 + 1 = 4$. One of them can be her free choice, so she drops $4 - 1 = 3$.
4. Check: 15 species − 3 dropped = 12 species.

Answer: She keeps all 3 plants, chooses 3 of 5 birds, 2 of 3 other vertebrates and 3 of 4 invertebrates, then keeps one left-over species as her free choice. She drops 3 species in all, leaving 12.

Example 2. Use the bar graph of the three-plot survey. (a) How many more species were in the garden edge than in the mowed lawn? (b) The family added $4 + 9 + 6$ and said, "Our yard has 19 species." Why might that be wrong?

(Use the map or drawing "Read each bar against the scale on the left." shown earlier in this lesson.)

1. Read the bars: mowed lawn 4, garden edge 9, under the oak 6.
2. (a) $9 - 4 = 5$ more species in the garden edge.
3. (b) Some species, such as grass, dandelions or ants, may have been found in two or three plots. Adding the bars counts those species more than once.
4. To find the true number, they should make one master list and write each species only once.

Answer: (a) 5 more species. (b) A species found in more than one plot would be counted two or three times, so 19 may be too many. The real total comes from a master list with each species written once.

PRACTICE

1. EASY What village did Gilbert White study, and what was the name of his famous book?
2. EASY Which of these is an exact species, ready for a field guide: “a tree,” “a red maple” or “a leaf”?
3. EASY Name the five parts of the Balanced Dozen rule and show that they add up to twelve.
4. MEDIUM How did Gilbert White show that three look-alike birds were really three different species?
5. MEDIUM Read the survey table.
   Mowed lawn: 3 plants, 1 invertebrate
   Flower bed: 5 plants, 4 invertebrates
   Woodpile: 2 plants, 5 invertebrates
   (a) How many species were found in each plot? (b) Which plot had the most invertebrates? (c) Give one reason the woodpile might have so many invertebrates.
6. MEDIUM A plot is 1 meter on each side. How many centimeters of string do you need to go all the way around it? About how many feet is that?
7. HARD Sam searched his lawn plot for 5 minutes and his garden plot for 20 minutes, and found more species in the garden. He says gardens have more species. What is wrong with his test, and how should he fix it?
8. CHALLENGE Lily wants a mountain lion and a bald eagle in her local field guide, but she has never seen either near her home. In two or three sentences, explain why common species make a better choice.

COMMON MISTAKES

- Writing a group name such as “bug” or “bird” as if it were a species. A field guide page needs one exact kind.
- Thinking only rare or exciting animals are worth studying. Gilbert White made great discoveries with ordinary village birds and insects.
- Adding up the species counts from several plots to get a total. A species found in more than one plot would be counted twice; use a master list.

> **Make it a game · Name It Exactly.** A parent calls out a group word, such as “bird,” “tree,” “bug” or “flower.” You have ten seconds to name one exact species from that group that lives near your home, such as “Mourning Dove” or “red maple.” Score a point for each correct species and a bonus point if you can say where you have seen it. Trade places and let the parent try. First to ten points wins.

> **Scripture.** “The earth is the LORD’S, and the fulness thereof; the world, and they that dwell therein.” (Psalm 24:1, KJV)

Your yard and your town belong to the Lord too. Choosing twelve local species is a way to notice the fulness He has put right outside your door.

Practice answers

1. Selborne, in Hampshire, England. His book was *The Natural History and Antiquities of Selborne* (1789), usually called *The Natural History of Selborne*.
2. “A red maple.” The other two name a whole group or only a part of a living thing.
3. 3 birds, 2 other vertebrates, 3 invertebrates, 3 plants (one a tree) and 1 free choice: 3 + 2 + 3 + 3 + 1 = 12.
4. He listened and watched carefully in his own woods and found that each one had its own song and habits. Today they are called the chiffchaff, the willow warbler and the wood warbler.
5. (a) Mowed lawn 3 + 1 = 4; flower bed 5 + 4 = 9; woodpile 2 + 5 = 7. (b) The woodpile, with 5. (c) The woodpile is dark, damp and sheltered, so pillbugs, worms, beetles and spiders can hide and find rotting wood to eat.
6. 1 meter = 100 cm, and a square has 4 sides: 4 × 100 = 400 cm (4 meters), about 13 feet.
7. He changed two things at once: the habitat and the search time. More time could explain why he found more. He should keep the search time the same (for example, 10 minutes in each plot), along with the plot size and time of day, and change only the habitat.
8. Sample answer: A field guide page needs her own observations, notes, measurements and sketches, so she must be able to find and watch the species again. Common local species can be observed many times in different seasons, and they are the ones readers near her home are most likely to meet.

8.2 Field Notes and Photos

OBJECTIVES

- Tell how Joseph Grinnell taught naturalists to keep careful field notes so that scientists could use them a hundred years later.
- Write complete field notes for each of your twelve species, with date, time, place, weather, measurements, behavior and a sketch.
- Take useful nature photos with a scale object, and use the scale to work out a real size.

Warm-up. Ask someone to tell you what they ate for lunch three days ago, and what the weather was. Can they remember exactly? Now look at a calendar or a note you wrote that day. Memory fades fast, which is why scientists write things down on the spot.

Video. Coming soon. How to keep a nature journal and field notebook, and how to take good nature photos with a scale, for kids: search Smithsonian, National Park Service, Cornell Lab of Ornithology, the California Academy of Sciences, SciShow Kids, Homeschool Pop (Alternate), and nature-journaling teachers who sketch outdoors.

KEY TERMS

field notes
Careful written records made outdoors, at the time you observe something, with the date, time, place and what you saw.

observation
Something you notice with your senses, such as a color, a sound, a size or a behavior, and write down exactly.

locality
The exact place where an observation was made, written clearly enough that someone else could find it.

scale object
Something of known size, such as a ruler or a coin, placed beside a living thing in a photo so others can tell how big it is.

behavior
What a living thing does: how it moves, feeds, calls, hides or cares for its young.

CORE IDEAS

The story. In 1908 Joseph Grinnell became the first director of the new Museum of Vertebrate Zoology at the University of California in Berkeley. Grinnell loved the birds, mammals, reptiles and amphibians of California, and from 1914 to 1920 he and his helpers traveled across the Yosemite region, from the low valleys to the high mountain passes, recording what lived at each level. But Grinnell cared about more than the animals they

found. He cared about the *notes*. He believed that careful field notes might be most useful to scientists who had not yet been born, perhaps a hundred years later, who would want to know exactly what lived in each place long before.

How they figured it out. Grinnell taught his students a strict system. Every evening in camp, each person wrote a daily journal in ink that would last, on good paper. Every entry began with the date, the exact **locality**, the habitat and the weather. Then came the **observations**: which species were seen, how many, what they were doing and where. Later the notes about each species were gathered on separate pages, so all the facts about one kind of animal were together. Grinnell's team also took photographs of their study sites. About a century later, scientists from the same museum used the old notes and photos to stand in the very same spots and survey them again, to see what had stayed the same and what had changed. Grinnell had been right.

The big idea. Your field guide will only be as good as your field notes. A good entry answers the questions *when, where, what, how many* and *what was it doing?* Write the date and time, the place, and the weather and temperature in °C (°F). Name the species if you know it; if not, describe it. Add measurements in centimeters, a quick sketch with labels, and the **behavior** you saw. Write only what you actually observed. "The robin pulled three earthworms from the lawn" is an observation. "The robin was hungry" is a guess, and if you write it, label it as one.

Try it and see. Photos help too, if they are taken well. A photo without a **scale object** can fool the eye: a small leaf up close can look as big as a dinner plate. Lay a ruler or a coin beside a leaf, flower, mushroom or shell, and anyone can tell its size. A United States quarter is about 2.4 centimeters (just under 1 inch) across. Take several photos of each species: the whole plant or animal, then close-ups of the parts that help name it, such as a leaf edge, a flower or a pattern of spots. Write the photo number in your notes so the picture and the words stay together. For birds and squirrels, stay back and let them be; a fuzzy photo of a calm animal is better than a scared one.

God's handiwork. Jesus told His listeners, "Consider the lilies of the field, how they grow" (Matthew 6:28). To consider means to look closely and think. Field notes are a way of considering. When you sit still long enough to measure a leaf and watch a bee move from flower to flower, you notice the care God has put into small things, and you learn that He cares for you even more.

Field Notes, page 7

Date: Saturday, May 9 **Time:** 7:30 to 7:50 a.m.

Place: back yard, lawn by the maple

Weather: sunny, light wind, 14 °C (57 °F)

Species: American Robin

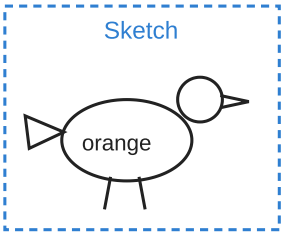
Count: 2 (most at one time)

Size: about 25 cm (10 in) long

Behavior: ran, stopped, tipped head, then pulled 3 earthworms from lawn

Call: “cheerily, cheer-up” from roof

Photos: numbers 041 to 043

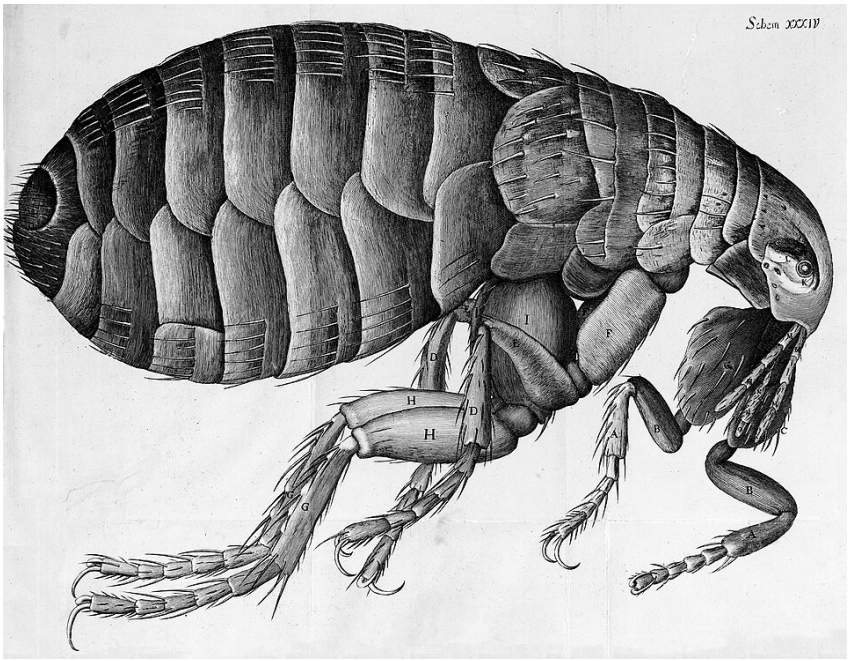


Question: Does it hear the worms or see them?

(guess: sees them; check in a book)

A complete field note entry answers when, where, what, how many and what it was doing.

PICTURE STUDY



The Flea, from Micrographia, Robert Hooke, 1665 · Engraving, printed as a large fold-out plate in Hooke’s book *Micrographia* · Published in London for the Royal Society; copies are kept in many libraries, including the Royal Society and the Library of Congress.

Photo: Wellcome Collection · CC BY 4.0 (https://creativecommons.org/licenses/by/4.0) · via Wikimedia Commons

Robert Hooke was an English scientist who built his own microscopes. He looked at a flea, an insect smaller than a grain of rice, and drew it so large that the picture had to fold out of his book. People were amazed to see that a tiny pest had a body built like a knight in armor.

Hooke did not guess or decorate. He looked again and again until he had drawn what was really there. That is the same habit a good field note-taker needs.

Look closely

- Count the legs. Is this flea an insect? How do you know?
- Look at the body. How many overlapping plates can you find?
- Find the hairs and bristles. Where are they longest?
- Look at the back legs. What do you think they are good for?

Talk about it

1. Hooke drew the flea far bigger than life. What should he tell the reader so they know its real size?
2. Which is more useful to a scientist: a beautiful drawing with guessed details, or a plain drawing of exactly what was seen? Why?

> **Safety first.** Work outdoors with an adult nearby. Look at wild animals from a distance and never chase, corner or feed them for a photo. Stay back from nests and dens. Do not touch poison ivy, stinging insects, spiders or mushrooms; photograph them where they are. Never point a camera, phone or your eyes toward the sun. Ask a parent before using a phone or camera, and wash your hands after handling leaves or shells.

EXPERIMENT: DOES A SCALE OBJECT HELP?

You will start your field notes for all twelve species and run a small photo experiment. **Question:** Can people judge the real size of a leaf, rock or pinecone better when the photo has a ruler in it? Write your **prediction** first.

You will need

- Science notebook (your field notebook) and pencil
- Ruler marked in centimeters and inches
- A United States quarter or other coin
- A phone or camera, used with a parent’s permission
- Thermometer, if you have one
- Three objects from nature of different sizes, such as a leaf, a rock and a pinecone
- Two or more family members to be testers

Steps

1. **What we change:** whether the photo has a ruler beside the object. **What we keep the same:** the same three objects, the same distance from the camera, the same light and the same background. **What we measure:** how many centimeters each tester’s guess is from the true length.
2. Measure each object’s true length with the ruler and write it down.

3. Photograph each object twice from the same height: once alone, once with the ruler beside it.
4. Show the no-ruler photos to one tester and the ruler photos to a different tester. Ask each to guess the length of each object in centimeters.
5. For every guess, find how far off it was: subtract the smaller number from the larger.
6. Add up how far off each tester was. Which set of photos gave closer guesses? Was your prediction right?
7. Now go outdoors and write a full field note entry for at least three of your twelve species, using the sample page as a guide. Take photos with a scale object where you safely can, and write each photo number in your notes.
8. Over the next week, add entries until you have notes on all twelve species. Visit some species twice, at different times of day.

Tips

- Write while you watch, not after you come in. Short notes on the spot beat long notes from memory.
- If you cannot name a species yet, describe it fully and take a photo; you can find the name later.
- Use the same notebook for the whole project and number the pages.

Check your work

- Every entry has a date, time, place and weather.
- I wrote observations, and I labeled any guesses as guesses.
- My photos have a scale object, and the photo numbers are written in my notes.

NATURE NOTEBOOK

1. Copy the parts of the sample field note page into the front of your notebook as a checklist: date, time, place, weather, species, count, size, behavior, sketch, photos, questions.
2. Draw one leaf from your twelve species at its real size by tracing around it, then measure its length and width and write them beside it in centimeters and inches.
3. Sit still for five minutes near one animal on your list and write down three things it did, in order, with the time of each.

> **From history.** Long before Grinnell, President Thomas Jefferson gave Meriwether Lewis written instructions in 1803 for the journey west with William Clark. Among many tasks, Jefferson asked them to record the plants and animals of the country, especially those not yet known in the United States. Lewis and Clark kept journals all the way to the Pacific and back, describing many species new to science, and in 1805 they even sent a live prairie dog to Jefferson, who received it in Washington.

WORKED EXAMPLES

Example 1. In a printed photo, a quarter beside a maple leaf measures 2 cm across, and the leaf measures 10 cm long. A real quarter is about 2.4 cm across. How long is the real leaf, in centimeters and in inches?

1. Find how many quarter-widths long the leaf is in the photo: 10 ÷ 2 = 5 quarter-widths.
2. The real leaf is also 5 quarter-widths long, because the leaf and the coin were photographed side by side at the same distance.
3. Real length: 5 × 2.4 cm = 12 cm.
4. Change to inches: 1 inch is 2.54 cm, so 12 ÷ 2.54 is about 4.7 inches, a little less than 5 inches.

Answer: The real leaf is about 12 cm (about 4¾ inches) long.

Example 2. Noah measured the widths of five leaves on the same red maple: 9 cm, 11 cm, 10 cm, 12 cm and 8 cm. What is the average width, and what is the range from smallest to largest? Why is it better to measure five leaves than one?

1. Add the widths: 9 + 11 + 10 + 12 + 8 = 50 cm.
2. Divide by the number of leaves: 50 ÷ 5 = 10 cm average. That is about 4 inches.
3. Range: the smallest is 8 cm and the largest is 12 cm, so the leaves were 8 to 12 cm wide, a range of 12 − 8 = 4 cm.
4. Leaves on one tree vary in size. One leaf might be unusually big or small, but an average of five gives a truer picture.

Answer: Average width 10 cm (about 4 inches); the leaves ranged from 8 to 12 cm, a range of 4 cm. Measuring several leaves shows the normal size and the variation.

PRACTICE

1. EASY Name four things that should be at the top of every field note entry.
2. EASY Which is an observation and which is a guess? (a) “The squirrel buried an acorn under the oak.” (b) “The squirrel was getting ready for winter.”
3. EASY Why did Joseph Grinnell want his students’ notes to be so careful and complete?
4. MEDIUM A photo shows a mushroom with a quarter (about 2.4 cm across) beside it. The mushroom cap is 3 quarters wide. About how wide is the real cap?
5. MEDIUM Read Emma’s field notes for the bird feeder.
   Monday, 7:00 a.m., 5 °C (41 °F): 6 House Sparrows
   Tuesday, 7:00 a.m., 12 °C (54 °F): 4 House Sparrows
   Wednesday, 7:00 a.m., 2 °C (36 °F): 9 House Sparrows

(a) On which day was it coldest? (b) On which day did she see the most sparrows? (c) What pattern do you notice, and what should she do before she is sure of it?

6. MEDIUM Give two tips for taking a nature photo that will help someone identify the species later.
7. HARD Jack wants to know whether more bees visit his clover in the morning or the afternoon. Design a fair test: name the variable he changes, three things he keeps the same, and what he measures and records.
8. CHALLENGE Robert Hooke drew his flea many times bigger than life. In two or three sentences, explain why a scientist's drawing or photo of a small creature should always include its real size.

COMMON MISTAKES

- Waiting until you get home to write your notes. Details are forgotten quickly; write on the spot.
- Mixing guesses with observations. Write what you saw, and label any idea about why as a guess.
- Taking photos with nothing to show size. Without a scale object, a small leaf and a big leaf can look the same.

> **Make it a game · Notebook Detective.** A parent sets out a houseplant, a leaf, a rock and a toy animal for one minute, then covers them. Without peeking, write field notes: size, color, shape and anything special. Uncover them and score a point for every detail that is correct, and lose a point for any made-up detail. Then play again, but this time take notes while you look. Which round scored higher?

> **Scripture.** "And why take ye thought for raiment? Consider the lilies of the field, how they grow; they toil not, neither do they spin:" (Matthew 6:28, KJV)

To consider is to look closely and think, which is exactly what field notes train you to do. Jesus used the lilies to teach that the Father who clothes the flowers will care for His children.

Practice answers

1. The date, the time, the place (locality) and the weather (with temperature if you can).
2. (a) is an observation, because it was seen. (b) is a guess about the reason; if you write it, label it as a guess.
3. He believed scientists far in the future, perhaps a hundred years later, would use the notes to learn exactly what lived in each place. About a century later, scientists did use his notes and photos to survey the same places again.
4. 3 × 2.4 cm = 7.2 cm, about 7 cm (just under 3 inches).
5. (a) Wednesday, 2 °C (36 °F). (b) Wednesday, 9 sparrows. (c) She saw more sparrows on colder mornings. Three days is not enough to be sure, so she should keep counting at the same time on many more days.

6. Any two: put a ruler or coin beside it for scale; take a photo of the whole plant or animal plus close-ups of key parts (leaf edge, flower, spots); keep the light behind you and the subject in focus; write the photo number in your field notes.
7. Change: the time of day (morning or afternoon). Keep the same: the same patch of clover, the same length of watch (for example, 10 minutes), the same spot to sit, and days with similar weather (any three). Measure: the number of bees landing on the clover during each watch, recorded in his field notes with date, time and temperature, on several days.
8. Sample answer: A picture can be blown up or shrunk to any size, so the picture alone does not tell how big the creature really is. Size helps tell one species from another, so the scientist should write the real length or show a scale object, so readers are not fooled.

8.3 Writing the Species Pages

OBJECTIVES

- Tell how Florence Merriam wrote *Birds Through an Opera-Glass* (1889) so that beginners could name living birds by watching them.
- Write a complete species page with common and scientific names, classification, size, field marks, look-alikes, habitat, behavior and your own dated observation.
- Write and test a simple dichotomous key that leads a reader to each species in your guide.

Warm-up. Without saying its name, describe a family member's shoes in three sentences so well that someone else could pick them out of a pile at the door. Which words helped most: color, size, shape or a special mark? Those are the same kinds of words a species page needs.

Video. Coming soon. How field guides are made and how to write a species description and a dichotomous key, for kids: search Cornell Lab of Ornithology, Smithsonian, the Natural History Museum (London), National Park Service, Homeschool Pop (Alternate), SciShow Kids, and close-up nature footage of pillbugs, robins and common backyard plants.

KEY TERMS

species page
One page of a field guide that tells everything a reader needs to name and understand one species.

field mark
A spot, stripe, shape or color pattern that helps tell one species from another.

look-alike
A different species that is easy to mix up with the one on your page.

scientific name
The two-part Latin name of a species, genus first and then species, such as *Turdus migratorius* for the American Robin.

dichotomous key
A set of paired choices that leads a reader, step by step, to the name of a living thing.

CORE IDEAS

The story. In the 1880s many bird books were written for collectors who shot birds and studied them in the hand. Florence Merriam, a young woman from New York State who had studied at Smith College, wanted something different. She wanted ordinary people to learn birds by watching them alive, with a pair of opera glasses, the small binoculars people

carried to the theater. She wrote short, friendly descriptions of common birds for a magazine, and in 1889 they were gathered into a book, *Birds Through an Opera-Glass*. It described about seventy common birds a beginner might see, and it is often called one of the first American field guides. Each description told what the bird looked like, where to find it and what it did.

How they figured it out. Merriam knew that a beginner looking at a live bird does not have long. The bird may fly away in seconds. So a good description must point quickly to what can be seen from a distance: size compared with a familiar bird, the main colors, a special mark, the way it moves, the sound of its song. Later field-guide writers kept her idea and made it sharper, and every good field guide today still answers a beginner's questions: *What does it look like? How big is it? What could I confuse it with? Where and when will I find it?*

The big idea. Each of your twelve species gets one **species page**, built from your field notes. Use the same parts, in the same order, on every page so readers know where to look. (1) The common name and the **scientific name**, in two parts as Linnaeus taught. (2) A classification line, such as *Animals, invertebrates, crustaceans*. (3) Size in centimeters with inches in parentheses. (4) A labeled drawing or photo with arrows to the **field marks**. (5) **Look-alikes** and how to tell them apart. (6) Habitat and when to look. (7) Behavior and food. (8) My observation: one dated sentence from your own notes. The sample pillbug page shows all eight parts.

Try it and see. Common names can fool you. The "robin" of England is a small bird, *Erithacus rubecula*, while the American Robin, *Turdus migratorius*, is a much bigger bird in the thrush family; early settlers named it after the bird from home because both have reddish-orange breasts. That is why every page needs the scientific name. After your pages are written, add a **dichotomous key** at the front of your guide, as you learned in Unit 1. Each step gives two choices, such as "has legs" or "has no legs," until only one species is left. Then test your key on someone who has not seen your notes.

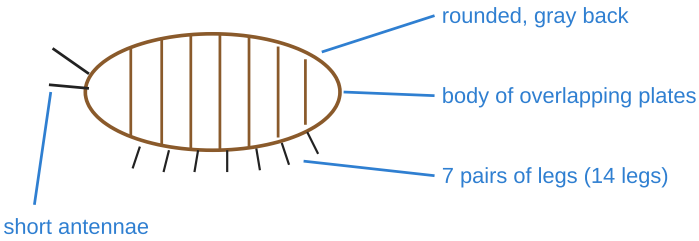
God's handiwork. King Solomon was known for this very kind of work: "he spake of trees, from the cedar tree that is in Lebanon even unto the hyssop that springeth out of the wall: he spake also of beasts, and of fowl, and of creeping things, and of fishes" (1 Kings 4:33). Describing God's creatures carefully, from the tallest tree to the smallest creeping thing, is part of the wisdom God gives, and your species pages put you in good company.

(1) Pillbug *Armadillidium vulgare*

(2) Animals, invertebrates, crustaceans

(3) Size: about 1 cm (less than ½ in) long

(4) Field marks



(5) Look-alike: sowbug. It cannot roll into a ball and has 2 tail points.

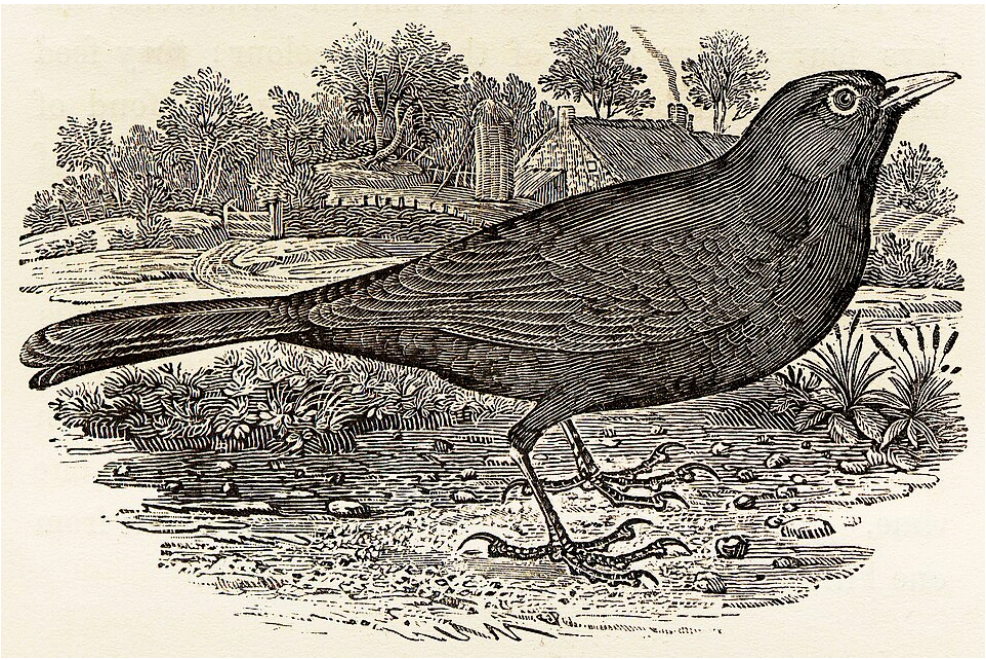
(6) Habitat: under logs, stones and damp leaves; spring to fall.

(7) Behavior and food: rolls into a ball when touched; eats dead leaves.

(8) My observation, May 9: 11 pillbugs under the woodpile,
all curled up when I lifted the log.

A species page has the same eight parts, in the same order, for every species in the guide.

PICTURE STUDY



The Blackbird, from A History of British Birds, Volume 1, Thomas Bewick, 1797 · Wood engraving printed in black ink · Printed in Newcastle upon Tyne, England; copies are kept in many libraries, and Bewick's birthplace at Cherryburn, Northumberland, is now a museum.

Thomas Bewick was an English engraver who carved pictures into the end grain of hard boxwood blocks, which let him cut very fine lines. For his *History of British Birds* he tried to draw from real birds rather than copying other people's pictures, and he set each bird beside a short written account of its looks and habits. In other words, he made species pages.

This bird is the Eurasian blackbird, *Turdus merula*. Its scientific name shows that it belongs to the same genus, *Turdus*, as the American Robin, *Turdus migratorius*. Both are thrushes, even though one is black and the other has an orange breast.

Look closely

- Look at the feathers. How did Bewick show a dark bird with only black lines and white paper?
- Find the beak. Is it thick like a seed-eater's, or thin and pointed like the beak of a bird that eats worms and insects?
- Look at the background. What does it tell you about where this bird lives?
- Compare this bird with an American Robin you have seen. What is the same about their shape, and what is different?

Talk about it

1. If you only had a black-and-white picture, what words would you add to the page so readers knew the bird's colors? (The male blackbird is black with an orange-yellow bill.)
2. The blackbird and the American Robin share the genus name *Turdus*. What does that tell you about them?

EXPERIMENT: WRITE TWELVE PAGES AND TEST MY KEY

You will turn your field notes into twelve species pages and write a dichotomous key to go with them. Then you will test the key. **Question:** Can a reader who has never seen my notes use my key to name my species correctly? **Prediction:** how many of the twelve do you think your tester will get right?

You will need

- Your field notebook and photos from Lesson 8.2
- Twelve sheets of plain paper or cardstock, plus extra sheets for the key
- Pencil, fine black pen, colored pencils and a ruler
- A library field guide, the free All About Birds website, or the USDA PLANTS database for checking scientific names and look-alikes
- Two testers (family members or friends) who have not read your notes

Steps

1. Lightly rule each sheet into the same eight sections, in the same order, using the sample pillbug page as your pattern.
2. Fill in each page from your field notes. Check every scientific name in a trusted book or website and write it in two parts, with the genus capitalized and the species lowercase.
3. Draw your species in pencil, then go over it in pen and color it. Add at least three arrows to field marks.

4. Write a dichotomous key on a separate sheet. Start with a big split (for example, plant or animal), and keep splitting in pairs until each species has its own ending.
5. **What we change:** the version of the key (first draft, then a fixed draft). **What we keep the same:** the same twelve photos or drawings, shown in the same mixed-up order, and no hints. **What we measure:** how many of the twelve the tester names correctly.
6. Give tester 1 your first-draft key and the photos. Record how many they got right and at which step any mistake happened.
7. Fix the steps that caused mistakes. Use choices anyone can see, such as “six legs” rather than “pretty.”
8. Give the fixed key and the same photos to tester 2. Record the score. Did fixing the key help? Was your prediction right?

Tips

- Each choice in a key should be a true pair: “has six legs” and “has more than six legs,” not “has six legs” and “is brown.”
- Write your dated observation in your own words. It is the part of the page no other book has.
- Keep sentences short. Field guides are read outdoors, often in a hurry.

Check your work

- All twelve pages have the same eight parts in the same order.
- Every scientific name is checked and written correctly.
- I tested my key, fixed it and tested it again, and I recorded both scores.

NATURE NOTEBOOK

1. Draw the outline of a blank species page with the eight sections labeled, and glue it inside the cover of your notebook as a pattern.
2. Pick your two most look-alike species, draw them side by side, and put arrows on the marks that tell them apart.
3. Draw your dichotomous key as a branching tree, with each species name at the end of a branch.

> **From history.** Two birds are named after Thomas Bewick. Audubon named a small American bird Bewick’s Wren in his honor, and in 1830, two years after Bewick died, the English naturalist William Yarrell named a swan Bewick’s Swan. Florence Merriam, who later married the naturalist Vernon Bailey and wrote as Florence Merriam Bailey, went on to write a large handbook of the birds of the western United States, and in 1929 she became the first woman elected a fellow of the American Ornithologists’ Union.

WORKED EXAMPLES

Example 1. Use this key to name a small gray creature found under a log. It has many legs, and when touched it rolls into a tight ball.
1a. Has legs: go to 2. 1b. Has no legs: earthworm.
2a. Has 6 legs: seven-spotted lady beetle. 2b. Has more than 6 legs: go to 3.
3a. Has 8 legs and two body parts: black-and-yellow garden spider. 3b. Has 14 legs and a body of many plates; rolls into a ball: pillbug.

1. Step 1: The creature has legs, so choose 1a and go to 2.
2. Step 2: It has many legs, more than 6, so choose 2b and go to 3.
3. Step 3: It does not have 8 legs and two body parts. It has a body of many plates and rolls into a ball, so choose 3b.
4. Check with the species page: the pillbug has 7 pairs of legs (14 legs) and rolls into a ball, which matches.

Answer: Pillbug (*Armadillidium vulgare*), reached by 1a, 2b, 3b.

Example 2. Ava’s field guide will have a cover, a table of contents, a “How to Use This Guide” page, a key that takes 2 pages, 12 species pages, a glossary page and a “My Sightings” chart page. (a) How many pages in all? (b) If she prints on both sides of each sheet, how many sheets of paper does she need?

1. Add the pages: 1 cover + 1 contents + 1 how-to + 2 key + 12 species + 1 glossary + 1 sightings.
2. 1 + 1 + 1 + 2 + 12 + 1 + 1 = 19 pages.
3. Each sheet holds 2 pages when printed on both sides. 19 ÷ 2 = 9 with 1 left over.
4. The leftover page needs one more sheet, so 9 + 1 = 10 sheets, with one side blank (a good spot for notes).

Answer: (a) 19 pages. (b) 10 sheets, with one blank side left over.

PRACTICE

1. EASY What was Florence Merriam’s 1889 book called, and how did she want beginners to learn birds?
2. EASY Write the scientific name of the American Robin correctly, and tell which part is the genus.
3. EASY List the eight parts of a species page in order.
4. MEDIUM Read the sizes in Mia’s guide:
   Pillbug: 1 cm
   Seven-spotted lady beetle: 0.7 cm
   Northern Cardinal: 22 cm

American Robin: 25 cm
Mourning Dove: 30 cm
(a) List them from smallest to largest. (b) How many times longer is the robin than the pillbug? (c) Change the dove's length to inches (1 inch = 2.54 cm), to the nearest inch.

5. MEDIUM The pillbug and the sowbug are look-alikes. Using the sample page, tell how to tell them apart.
6. MEDIUM What is wrong with this key step? "2a. Has six legs. 2b. Is brown." Rewrite it correctly.
7. HARD Leo wants to know whether adding a "Look-alikes" section helps readers avoid mixing up species. Design a fair test: what does he change, what does he keep the same, and what does he measure?
8. CHALLENGE In two or three sentences, explain why a field guide uses the same order of parts on every species page.

COMMON MISTAKES

- Trusting common names alone. The European robin and the American Robin are different species; the scientific name tells them apart.
- Writing both parts of the scientific name with capital letters. The genus is capitalized and the species part is lowercase, and the whole name is printed in italics (or underlined when written by hand).
- Copying facts from a book without your own observations. A species page in your guide should include what you saw, with the date.

> **Make it a game · Twenty Questions, Key Style.** A parent secretly picks one of your twelve species. You may ask only yes-or-no questions that a key could use, such as "Does it have legs?" or "Does it have feathers?" Score a point for each species you name in ten questions or fewer. Then switch: you pick a species, and the parent asks. Notice which questions split the species most evenly; those make the best first steps in a key.

> **Scripture.** "And he spake of trees, from the cedar tree that is in Lebanon even unto the hyssop that springeth out of the wall: he spake also of beasts, and of fowl, and of creeping things, and of fishes." (1 Kings 4:33, KJV)

Solomon's wisdom included careful knowledge of plants and animals, from great trees to tiny wall plants. Describing creatures well is a way of using the wisdom God gives.

Practice answers

1. *Birds Through an Opera-Glass*. She wanted people to learn birds by watching them alive through opera glasses (small binoculars) instead of shooting them.
2. *Turdus migratorius*. *Turdus* is the genus (capitalized); *migratorius* is the species (lowercase).
3. (1) Common and scientific names, (2) classification line, (3) size, (4) labeled drawing or photo with field marks, (5) look-alikes, (6) habitat and when to look, (7) behavior and food, (8) my dated observation.

4. (a) Lady beetle 0.7 cm, pillbug 1 cm, cardinal 22 cm, robin 25 cm, dove 30 cm. (b) 25 ÷ 1 = 25 times longer. (c) 30 ÷ 2.54 is about 11.8, so about 12 inches.
5. A pillbug can roll into a tight ball. A sowbug cannot roll up, and it has two small tail points sticking out at the back.
6. The two choices are not a true pair: an animal could have six legs *and* be brown, so the reader cannot choose. Correct: “2a. Has six legs. 2b. Has more than six legs.”
7. Change: whether the species pages have a Look-alikes section. Keep the same: the same species, the same photos to identify, the same number of photos, the same time allowed, and testers who have not seen the guide (a different tester for each version). Measure: how many photos each tester names correctly, and how many look-alike mix-ups they make.
8. Sample answer: Readers often use a field guide outdoors in a hurry, while an animal is about to move away. If every page is in the same order, the reader learns where to look for the size or the field marks and can compare two species quickly without reading every word.

8.4 Finishing and Presenting My Field Guide ★

OBJECTIVES

- Tell how Mark Catesby finished and published *The Natural History of Carolina, Florida and the Bahama Islands*, etching many of the plates himself, and how Linnaeus later used his work.
- Put a field guide in good order, grouped by classification, with a cover, contents, a how-to page, a key, a glossary and a sightings chart.
- Field-test the guide with a reader, record the results, and present the guide clearly to an audience.

Warm-up. Pull two books off a shelf: a storybook and a reference book, such as a cookbook, a dictionary or a bird book. Flip through the first and last few pages of each. What does the reference book have that helps you find things fast? Make a list.

Video. Coming soon. How a field guide or nature book is put together, simple bookbinding for kids, and Mark Catesby's natural history plates: search Smithsonian Libraries, the Royal Collection Trust, the Natural History Museum (London), Colonial Williamsburg, Homeschool Pop (Alternate), and simple hand-bookbinding tutorials for children.

KEY TERMS

table of contents
A list at the front of a book that tells what is in it and on which page each part begins.

glossary
A short dictionary at the back of a book that explains the special words used in it.

field test
Trying out a tool or guide in real use, outdoors, to see whether it works and what needs fixing.

audience
The people who will read your guide or listen to your presentation.

revise
To change and improve your work after you test it or after someone gives you advice.

CORE IDEAS

The story. Mark Catesby was an English naturalist who crossed the Atlantic to the American colonies, first to Virginia and later to Carolina. There he painted birds, plants, fish and snakes and sent seeds and specimens back to England. Then came the hard part: turning his paintings into a book. Printing large pictures was very expensive. Catesby could not pay engravers to copy all of them, so he took lessons and learned to etch the copper printing

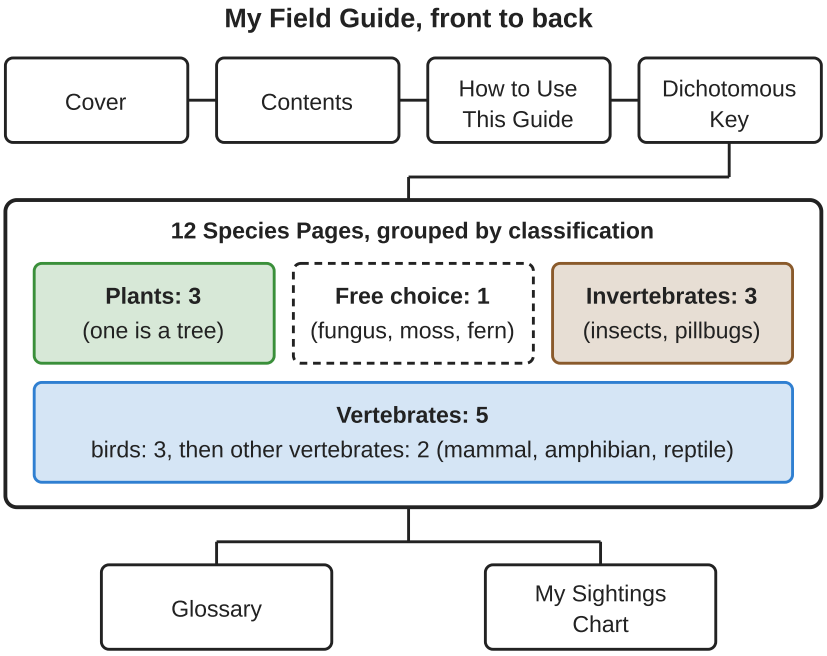
plates himself. He published his book in parts, beginning in 1729, for subscribers who paid as each part came out, and he did not finish until the 1740s. *The Natural History of Carolina, Florida and the Bahama Islands* had about two hundred and twenty plates, each one colored by hand.

How they figured it out. Catesby made two choices that made his book useful. First, he often showed a bird together with a plant from the same place, so readers learned about both, and he wrote a description beside every picture. Second, he finished. A beautiful painting in a drawer helps no one, but a published book can be read by people far away. One of those readers was Carl Linnaeus, who studied Catesby's pictures and descriptions and used them when he gave scientific names to many North American birds and plants. Catesby's patient finishing work helped science name the living things of a whole continent.

The big idea. Your field guide is finished when a stranger can use it. Put the parts in this order: a cover with the title, your name and your area; a **table of contents**; a "How to Use This Guide" page; your dichotomous key; the twelve species pages; a **glossary** of special words, such as *field mark* and *habitat*; and a "My Sightings" chart for new dates and places. Group the species pages by classification, as real field guides do: plants together, then any fungus, then invertebrates, then vertebrates class by class. Number every page and make the table of contents match.

Try it and see. Before you call it done, run a **field test**. Take a family member who has not read your guide outdoors and ask them to name as many of your twelve species as they can find, using only your guide. Write down which ones they named correctly and where they got stuck, then **revise** those pages. Last, present your guide to an **audience**: your family, grandparents, a co-op class or friends. Tell why you chose your area, show three favorite species pages and one surprise from your field notes, and invite listeners to try your key. Speak slowly, hold the pages so people can see, and finish by asking for questions.

God's handiwork. "The works of the LORD are great, sought out of all them that have pleasure therein" (Psalm 111:2). Over this unit you have sought out God's works in your own neighborhood: you chose, watched, measured, wrote and checked. Presenting your guide is a way of sharing that pleasure, so that others will notice and give thanks for the creatures God has placed around them.



The order of a finished field guide, with the species pages grouped by classification.

PICTURE STUDY



The Blew Jay, from The Natural History of Carolina, Florida and the Bahama Islands, Mark Catesby, Plate 15 of Volume 1, first published 1729 to 1732; this copy is from the 1754 edition · Hand-colored etching, from Catesby's own watercolor · Catesby's original watercolors are in the Royal Collection at Windsor Castle, England; printed copies are kept in many libraries.

In his first edition Catesby spelled "blue" the old way, "blew," as many English writers of his time did; this later printing says "Blue Jay." He painted the jay from birds he saw in Carolina

and set it on a plant from the same woods, so a reader in London could imagine the American forest.

Catesby etched many of his copper plates himself, and every printed copy was colored by hand with a brush. A field guide you finish by hand is part of a long tradition.

Look closely

- Find the crest, the black band across the throat, and the black bars on the wings and tail. Which of these would make good field marks?
- Look at the plant. Why do you think Catesby put a plant in a bird picture?
- Compare this picture with Audubon’s birds from Unit 4. Which looks more lifelike? Which looks more like a pattern?
- Look for any writing on the plate. What would a reader need to be told in words?

Talk about it

1. If you saw a blue jay at your feeder, could you name it from this picture? What would help most?
2. Catesby could have kept his paintings to himself. Why was finishing and publishing his book so important for science?

> **Safety first.** Do your field test and any presentation walk with an adult. Stay on paths, look at animals from a distance, and do not touch poison ivy, stinging insects, spiders or mushrooms. Never look toward the sun. If you use scissors, a hole punch or a needle for binding, ask a parent for help and keep fingers clear of sharp points and edges.

EXPERIMENT: FIELD TEST AND FINAL GUIDE

You will put your guide in order, bind it, test it outdoors, revise it, and present it. **Question:** Does my field guide help a reader name local species better than they can without it? Write your **prediction** first.

You will need

- Your twelve species pages and key from Lesson 8.3
- Paper for the cover, contents, how-to, glossary and sightings pages
- Cardstock or a cereal box panel for a stiff cover
- Hole punch and yarn or string, or a folder with brads
- Colored pencils, fine black pen and ruler
- Two testers of about the same age who have not read your guide
- Clipboard, pencil and timer

Steps

1. Lay out all pages in order: cover, contents, how-to page, key, species pages grouped by classification, glossary and My Sightings chart. Number every page.

2. Write the table of contents last, so the page numbers match. Write a glossary with at least eight words from your pages.
3. Make a stiff cover with the title (for example, “Twelve Living Things of Maple Street”), your name, the date and a drawing.
4. **What we change:** whether the tester has your guide. **What we keep the same:** the same area, the same 20-minute walk, the same species to look for, and testers of about the same age. **What we measure:** how many species each tester names correctly.
5. Walk with tester 1, who has no guide. Point to each of your species you find and record whether they name it correctly.
6. Walk the same route with tester 2, who uses your guide. Record their correct answers and any page where they got stuck.
7. Compare the scores in a table. Revise any page or key step that caused trouble.
8. Bind your guide with yarn through punched holes, or brads in a folder.
9. Plan and give a presentation of about 10 minutes. Practice once with a timer, then present to your audience and answer questions.

Tips

- Ask your tester to think aloud. You will learn exactly which words confused them.
- Leave space on the My Sightings chart so you can keep adding to your guide in every season.
- Bring one real thing to your presentation, such as a pressed leaf or a photo with a scale object.

Check your work

- My guide has every part in order, and the contents page numbers match.
- I ran a fair field test, recorded both scores, and revised at least one page.
- I presented my guide clearly, showed my favorite pages and answered questions.

NATURE NOTEBOOK

1. Sketch two or three cover designs for your field guide and choose the best one.
2. Draw a simple map of the area your guide covers, with a compass arrow, and mark where you found each species.
3. After your presentation, write three sentences: what went well, one question someone asked, and one thing you would add next season.

> **From history.** In 1911 Anna Botsford Comstock of Cornell University in Ithaca, New York, published the *Handbook of Nature Study*, a thick book written to help teachers and parents lead children outdoors to observe birds, insects, plants, rocks and the sky. Each lesson gave a short account of a living thing and then a list of questions to answer by watching it. The book has been reprinted many times and is still used by homeschooling families today.

WORKED EXAMPLES

Example 1. In a field test on the same 20-minute walk, Grace (without the guide) named 5 of the 12 species correctly, and her brother Ben (with the guide) named 10 of the 12. (a) How many more did Ben name? (b) What fraction of the species did each tester name? (c) Does the test show the guide helped?

1. (a) $10 - 5 = 5$ more species.
2. (b) Grace: 5 out of 12, or 5/12. Ben: 10 out of 12, or 10/12, which simplifies to 5/6.
3. Compare: 10/12 is twice 5/12, so Ben named twice as many.
4. (c) The walk, the species and the time were the same, and only the guide was different, so the guide likely helped. To be more sure, test more pairs of people, because two testers may simply know different amounts about nature.

Answer: (a) 5 more. (b) Grace 5/12; Ben 10/12 (5/6). (c) Yes, it suggests the guide helped, but testing more people would make the result more trustworthy.

Example 2. Caleb has 10 minutes for his presentation. He plans a 1-minute welcome, 2 minutes on why he chose his area, 45 seconds each for 4 favorite species pages, and the rest for a key demonstration and questions. How much time is left for the demonstration and questions?

1. Species pages: 4×45 seconds = 180 seconds = 3 minutes.
2. Planned so far: $1 + 2 + 3 = 6$ minutes.
3. Time left: $10 - 6 = 4$ minutes.

Answer: 4 minutes for the key demonstration and questions.

PRACTICE

1. EASY Why did Mark Catesby learn to etch his own copper plates?
2. EASY Name the parts of a finished field guide in order, from the cover to the back.
3. EASY How did Catesby’s book help Carl Linnaeus?
4. MEDIUM Put these species pages in classification order, with plants first and vertebrates last: Mourning Dove, pillbug, red maple, Eastern Gray Squirrel, dandelion, earthworm.
5. MEDIUM Read the field test results.
   Plants (3 species): without guide 2, with guide 3
   Invertebrates (3 species): without guide 0, with guide 2
   Birds (3 species): without guide 2, with guide 3
   Other vertebrates and free choice (3 species): without guide 1, with guide 2
   (a) Total correct without the guide and with the guide? (b) In which group did the guide help most? (c) Which group’s pages should be checked first for revising?

6. MEDIUM Your guide has 19 numbered pages. The key starts on page 4 and takes 2 pages, and the 12 species pages come right after it. On what page does the last species page fall?
7. HARD Hannah gave her guide to her father, who knows a lot about birds, and gave nothing to her 6-year-old sister. Her father named more species. Hannah says her guide works. What is wrong with this test, and how should she fix it?
8. CHALLENGE In two or three sentences, explain why a scientist should test and revise a field guide before calling it finished, and why sharing it matters.

COMMON MISTAKES

- Thinking a guide is done when the writer can use it. It is done when someone else can use it, so test it on a reader.
- Putting species pages in random order. Group them by classification so look-alikes and relatives are close together.
- Reading the pages aloud word for word in a presentation. Tell the audience what you saw and discovered, and show the pictures.

> **Make it a game · Guide Relay.** A parent hides twelve slips around the room or yard, each with a clue about one of your species (“14 legs, rolls into a ball” or “red bird with a black face”). Players race to find a slip, look up the species in the field guide, and bring back the slip with the page number. Score a point for each correct page. The player who finds the most correct pages wins, and any clue that stumps everyone shows a page to improve.

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

Everyone who enjoys God’s works will want to search them out. Your field guide is a record of what you sought out, and sharing it invites others to delight in His works too.

Practice answers

1. Paying engravers to copy all his paintings was too expensive, so he learned to etch the plates himself to make the book possible.
2. Cover, table of contents, “How to Use This Guide” page, dichotomous key, species pages (grouped by classification), glossary, My Sightings chart.
3. Linnaeus studied Catesby’s pictures and descriptions and used them when he gave scientific names to many North American birds and plants.
4. Plants: red maple, dandelion. Invertebrates: pillbug, earthworm. Vertebrates: Mourning Dove (bird), Eastern Gray Squirrel (mammal). (Within each group, other orders are fine if they are kept together.)
5. (a) Without: 2 + 0 + 2 + 1 = 5. With: 3 + 2 + 3 + 2 = 10. (b) Invertebrates, which went up by 2 (from 0 to 2). (c) Invertebrates and the last group each still had one species missed even with the guide. Check the invertebrate pages first, because without the guide the tester knew none of them, so those pages must do the most teaching.

6. The key is on pages 4 and 5, so species pages run from page 6 to page 17 (6 + 12 − 1 = 17). The last species page is page 17.
7. She changed two things: who had the guide and how much each tester already knew (and their ages). Her father might have named the birds without any guide. She should use testers of about the same age and knowledge, keep the same walk and species, and change only whether they have the guide. Testing more than one pair would be even better.
8. Sample answer: The writer already knows the species, so a page that seems clear to them may confuse a beginner; a field test shows where real readers get stuck. Sharing the finished guide lets others learn from the work, just as Linnaeus used Catesby’s published book to name American species.

Unit 8 review

Answer each question. Show your work for calculations and use complete sentences for explanations. The review is worth 50 points.

1. (5 pts) Who was Gilbert White, and what did he show by studying one village for most of his life? Give one discovery he made there.
2. (5 pts) A master list has 6 birds, 2 other vertebrates, 5 invertebrates and 4 plants (one a tree). Using the Balanced Dozen rule (3 birds, 2 other vertebrates, 3 invertebrates, 3 plants with a tree, 1 free choice), how many species are left over before the free choice, and how many are dropped in the end?
3. (5 pts) Survey results: lawn plot 3 species, garden plot 8 species, woodpile plot 6 species. All plots were 1 m (about 3 ft) square and searched for 10 minutes. (a) How many more species were in the garden than the lawn? (b) Why can you not add 3 + 8 + 6 to find how many species live in the yard?
4. (5 pts) Why did Joseph Grinnell want such careful field notes, and what happened about a hundred years later that proved him right?
5. (5 pts) In a photo, a quarter (about 2.4 cm across) sits beside a pinecone. The pinecone is 4 quarters long. How long is the real pinecone in centimeters? About how many inches?
6. (5 pts) Sort these notes into observations and guesses: (a) “The bee visited 6 clover flowers in 1 minute.” (b) “The bee likes clover best.” (c) “The temperature was 18 °C (64 °F).”
7. (5 pts) List the eight parts of a species page, and tell why every page in the guide uses the same order.
8. (5 pts) Why does a field guide need scientific names? Use the European robin (*Erithacus rubecula*) and the American Robin (*Turdus migratorius*) in your answer.
9. (5 pts) How did Mark Catesby finish his *Natural History of Carolina, Florida and the Bahama Islands*, and how did it help Linnaeus?
10. (5 pts) Design a fair field test of whether your guide helps people name local species. Name the variable you change, two things you keep the same, and what you measure. If one tester names 4 of 12 species without the guide and another names 9 of 12 with it, how many more did the guide user name?

Unit project: my field guide to twelve local species

Make a finished, bound field guide to twelve species that live near your home, chosen with the Balanced Dozen rule. It should have a cover with the title, your name and your area; a table of contents; a “How to Use This Guide” page; a dichotomous key; twelve species pages in the same eight-part pattern, grouped by classification; a glossary of at least eight words; and a My Sightings chart.

Include your survey bar graph, your field notebook with dated entries and photo numbers, your key test scores (first draft and revised), and your field test table. Finish by presenting

the guide to an audience for about 10 minutes and writing a short paragraph about one thing you discovered and how it shows the wisdom of the Creator.

- **Accuracy**: Every species is an exact species with a correct common and scientific name, classification, size in centimeters and inches, and field marks that match the real living thing.
- **Field records**: Field notes are dated and complete, with place, weather, measurements, behavior and sketches; observations are kept separate from guesses; photos include a scale object.
- **Testing**: The key and the guide were tested fairly, changing one thing at a time; scores are recorded in tables, and pages were revised where readers got stuck.
- **Care and presentation**: The guide is neat, in good order, with matching page numbers, and the presentation is clear, well timed and answers questions.

Answer key

1. Gilbert White was an English country clergyman in Selborne, Hampshire, who wrote *The Natural History of Selborne* (1789). He showed that one ordinary place is full of things worth studying. Discovery: he found that three look-alike little birds were three different species (now the chiffchaff, willow warbler and wood warbler) by their songs and habits.
2. The list has $6 + 2 + 5 + 4 = 17$ species. Left over: birds $6 - 3 = 3$, other vertebrates 0, invertebrates $5 - 3 = 2$, plants $4 - 3 = 1$, so $3 + 0 + 2 + 1 = 6$ left over. One becomes the free choice, so 5 are dropped, leaving $17 - 5 = 12$.
3. (a) $8 - 3 = 5$ more. (b) Some species may have been found in more than one plot, so adding would count them twice. Make a master list with each species written once.
4. He believed scientists in the future would need to know exactly what lived in each place, so every entry needed the date, locality, habitat, weather and observations. About a century later, scientists from his museum used his notes and photographs to survey the same places again and see what had stayed the same and what had changed.
5. 4×2.4 cm = 9.6 cm, about 10 cm, which is a little less than 4 inches ($9.6 \div 2.54$ is about 3.8).
6. (a) observation; (b) guess (it should be labeled as a guess or tested); (c) observation (a measurement).
7. Common and scientific names; classification line; size; labeled drawing or photo with field marks; look-alikes; habitat and when to look; behavior and food; my dated observation. The same order lets readers find information quickly and compare species, often outdoors in a hurry.
8. Common names can be shared by different species. Both birds are called “robin” because both have reddish breasts, but they are different species; the American Robin is a larger bird in the thrush family. Their scientific names are different, so the scientific name shows exactly which species is meant.
9. Engraving was too expensive, so Catesby learned to etch the copper plates himself and published the book in parts, beginning in 1729 and finishing in the 1740s, with each plate colored by hand. Linnaeus used Catesby’s pictures and descriptions when he gave scientific names to many North American birds and plants.
10. Change: whether the tester has the guide. Keep the same (any two): the same walk or area, the same time allowed, the same species, testers of about the same age and knowledge.

Measure: the number of species each tester names correctly. $9 - 4 = 5$ more species.

Bonus: Nature Lab

All year you have classified living things the way Linnaeus taught: kingdom to species, backbone or no backbone, beak and foot, tooth and hoof. This bonus unit takes you outdoors to do it for real. Linnaeus led his students out of Uppsala on summer walks because he knew a meadow could teach what a classroom could not. In four short, playful labs you will keep a nature journal, survey your own backyard, visit a zoo, farm or museum, and build a labeled specimen collection.

Each lab is a small experiment as well as an adventure. You will make a prediction, change only one thing, keep everything else the same, count and measure, and record your results in metric units with U.S. units beside them. Along the way you will meet the first BioBlitz, the first zoo in America, and Charles Willson Peale, who opened one of America's first natural history museums and dug up a mastodon. The goal is simple and lasting: to look at God's creatures closely, write down what you see, and care well for the small piece of creation outside your own door (Genesis 2:15).

BEFORE YOU BEGIN

- Can name the five classes of vertebrates and tell an insect from a spider by counting legs
- Can measure length with a ruler in centimeters and inches and read a thermometer
- Can make a tally chart and a simple bar graph
- Knows how to use a simple dichotomous key and write a two-part scientific name

MASTERY CHECKLIST

- I can keep a nature journal page with the date, time, place, weather, a labeled sketch, measurements and a question.
- I can measure distance by pacing and record temperature in °C and °F.
- I can survey plots of the same size for the same time, tally what I find, and show the results in a bar graph.
- I can classify animals at a zoo, farm or museum and tell an observation from an interpretation on a sign.
- I can collect specimens safely, lawfully and with permission, and write a complete label for each one.
- I can plan a fair test by changing one thing and keeping the rest the same.

OPTIONAL BOOKS AND RESOURCES

- **All About Birds, from the Cornell Lab of Ornithology** (https://www.allaboutbirds.org/): Free. Bird identification pages with photos, field marks and recorded songs. Use it to name the birds in your nature journal and backyard survey (Lessons 9.1 and 9.2).

- **iNaturalist** (https://www.inaturalist.org/): Free. A parent can use the website or app to photograph plants, insects and animals and get help identifying them; the related Seek app works without an account. Accounts are for adults or with a parent’s permission.
- **Smithsonian National Museum of Natural History** (https://naturalhistory.si.edu/): Free. If you cannot visit a museum, take the museum’s online virtual tour of its halls for the field trip in Lesson 9.3, and read about how its scientists label and store specimens (Lesson 9.4).

9.1 Nature Journal Walk

OBJECTIVES

- Keep a nature journal page that records the date, time, place, weather, a labeled sketch, measurements and at least one question.
- Measure distance by pacing and air temperature with a thermometer, and write each measurement in metric units with U.S. customary units in parentheses.
- Tell how Carl Linnaeus taught his students on walks around Uppsala and explain why a naturalist writes observations down right away.

Warm-up. Look out a window for two minutes without talking. Then close your eyes and say out loud everything you remember seeing: plants, animals, colors, the sky. Now look again for one more minute. What did you miss the first time? That is why naturalists carry a journal.

Video. Coming soon. How to keep a nature journal for kids; nature sketching outdoors, sit-spot observation, and Linnaeus's botany walks (search John Muir Laws nature journaling, Smithsonian, SciShow Kids, Homeschool Pop (Alternate), nature footage of meadows and woodland edges).

KEY TERMS

naturalist
A person who studies living things by watching them carefully where they live.

nature journal
A notebook where a naturalist records the date, place, weather, sketches, measurements and questions about living things.

observation
Something you notice with your senses (sight, hearing, touch, smell) or measure with a tool, written down just as it is.

pace
Two steps (left foot and right foot). Naturalists count paces to measure distance when they have no tape measure.

field mark
A feature that helps you tell one kind of living thing from another, such as a bird's wing bars or the shape of a leaf.

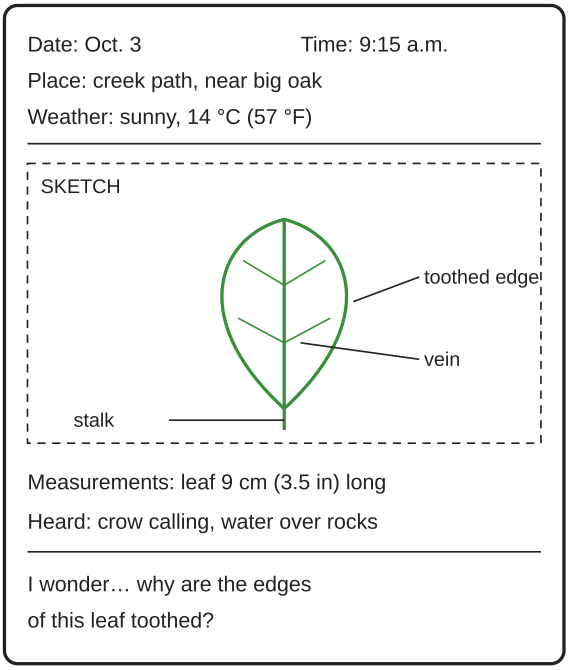
CORE IDEAS

The story. In the 1740s and 1750s, on summer Saturdays, Carl Linnaeus led his students out of the town of Uppsala, Sweden, on long botany walks. Sometimes more than two hundred people came along. They wore light, loose clothes for walking and carried notebooks, plant

presses and boxes for insects. At each stop Linnaeus pointed out plants, insects and birds, told their names and asked his students what they noticed. One student was chosen to write down everything that was found, so nothing would be forgotten. At the end of the day the whole crowd marched back into town with horns and drums, cheering for their teacher. Linnaeus knew that a classroom could not teach what a meadow could.

The big idea. A **naturalist** learns by **observation**, and an observation is only useful if it is written down. Memory is slippery: by tomorrow you may forget whether the beetle had six spots or eight. So a good **nature journal** page always starts the same way: the **date**, the **time**, the **place** and the **weather** (with a thermometer reading, such as 14 °C (57 °F)). Then come a sketch with labels, a few measurements, and what you heard or smelled. Last comes a question that begins “I wonder…”. Draw what you really see, not what you think a leaf ought to look like. Notice **field marks**: the edge of a leaf, the stripes on a caterpillar, the color of a bird’s tail. With no tape measure you can still measure distance by counting **paces**. Measure your own pace once at home, and you carry a ruler on your legs wherever you go.

God’s handiwork. Linnaeus loved to say that the study of nature showed the wisdom of the Creator, and he treated each small plant as worth a careful look. When you sit still for ten minutes, you start to see what hurried people miss: an ant dragging a seed, a spider mending a web, a bud that was not open last week. The same walk taken in a different season becomes a new walk. Keep your journal pages, and next year you can compare them and see the year turn, just as God promised that “seedtime and harvest” would not cease (Genesis 8:22).



A nature journal page: the facts first (date, time, place, weather), then the sketch, the measurements and a question.

PICTURE STUDY



Star-of-Bethlehem and Other Plants, Leonardo da Vinci, about 1506–1512 · Red chalk and pen and ink on paper · Royal Collection, Windsor Castle, England

Photo: Royal Collection Trust · CC BY-SA 4.0 (https://creativecommons.org/licenses/by-sa/4.0) · via Wikimedia Commons

Leonardo da Vinci is famous for paintings, but he also filled thousands of notebook pages with drawings of plants, birds, water and the human body. He drew this study of the star-of-Bethlehem, a small spring flower, and some other plants. He was not making a picture to sell. He was looking hard and recording what he saw, which is exactly what a nature journal is for.

Look closely

- Find the star-shaped flowers. How many petals can you count on one flower?
- Follow the long leaves with your finger. Which way do they curl around the center?
- Look at the lines Leonardo used for shading. Where did he press harder, and why?
- Find the smaller sketches on the page. Why might a naturalist draw more than one plant on the same page?

Talk about it

1. What did Leonardo notice about the leaves that a quick glance would miss?
2. Is this drawing finished like a painting, or is it a study? How can you tell?
3. What one plant near your home would you like to draw as carefully as this?

> **Safety first.** Walk with an adult. Wear closed shoes, and long pants in tall grass; check for ticks when you come home. Learn to recognize poison ivy (“leaves of three, let it be”). Watch for bees and wasps, and never touch wild animals, even ones that seem tame or hurt. Never taste wild berries, plants or mushrooms. Wash your hands after the walk.

EXPERIMENT: SIT SPOT: MORNING AND AFTERNOON

Choose one “sit spot” outdoors, such as a corner of the yard, a park bench or the edge of a garden. You will visit it twice in one day as a real scientist would, to answer a question: **Do I see more animals at my sit spot in the morning or in the afternoon?**

You will need

- Nature journal or notebook, pencil and colored pencils
- Outdoor thermometer
- A clock or timer
- A small cushion or folded towel to sit on
- Optional: hand lens and binoculars

Steps

1. At home, measure your pace: mark a start line, walk 10 paces (20 steps) in a normal way, and measure the distance with a tape measure. Divide by 10 and write “My pace = ___ m (___ ft).”
2. Pace the distance from your door to your sit spot and record it.
3. Write your **prediction**: morning or afternoon, which will have more animals?
4. Morning visit: write the date, time, place and weather. Lay the thermometer in the shade for 3 minutes and record the temperature in °C (°F).
5. Sit still for exactly 10 minutes. Make a tally mark for every animal you see (insects, spiders, birds, squirrels, worms). Write what each one was doing.
6. Sketch one living thing you found and label at least three parts.
7. Afternoon visit: do everything the same way. Same spot, same 10 minutes, same way of counting.
8. Make a small table: Visit, Time, Temperature, Number of animals. Circle the visit with more animals and write whether your prediction was right.

Tips

- **What we change:** the time of day. **What we keep the same:** the place, the 10 minutes, the person counting and the way of counting. **What we measure:** the number of animals and the temperature.
- Animals hide from movement and noise. Settle in for a minute before you start the timer.
- One day is only one test. Repeat it on two more days before you decide the answer.

Check your work

- My journal pages have date, time, place, weather and temperature.
- I kept everything the same except the time of day.
- I wrote my prediction before I counted, and I compared it with my results.

NATURE NOTEBOOK

1. Draw one leaf exactly as you see it, holes and all. Label its edge (smooth, toothed or lobed), its veins and its stalk, and write its length in centimeters and inches.
2. Make a “sound map”: put an X in the middle of the page for yourself and mark every sound you hear in 5 minutes where it came from (bird, wind, dog, car).
3. Write three “I wonder…” questions from your walk and circle the one you could test yourself.

> **From history.** Leonardo da Vinci wrote most of his notebooks in mirror writing, from right to left, so a reader needs a mirror to read them easily. In them he noticed that the leaves on many plants grow in a regular pattern around the stem, so that the leaves above do not completely shade the leaves below. Botanists today still study these leaf patterns.

WORKED EXAMPLES

Example 1. Anna walks 10 paces along a tape measure and covers 6.0 meters. On her walk she counts 250 paces from the gate to the big oak. How far is the oak from the gate, in meters and in feet? (1 meter is about 3.28 feet.)

1. Find the length of one pace: 6.0 m ÷ 10 paces = 0.6 m per pace.
2. Multiply by the number of paces: 250 × 0.6 m = 150 m.
3. Change to feet: 150 × 3.28 = 492 ft, or about 490 feet.

Answer: The oak is about 150 m (about 490 ft) from the gate.

PRACTICE

1. EASY Name the four facts that should go at the top of every nature journal page.
2. MEDIUM Ben’s pace is 0.5 m. He counts 80 paces along a creek path. How long is the path in meters? About how many feet is that?
3. MEDIUM Read this table from a nature walk.
   Stop | Temperature | Insects seen in 5 minutes
   Sunny field | 21 °C (70 °F) | 9
   Creek bank | 18 °C (64 °F) | 5
   Shady woods | 17 °C (63 °F) | 3
   (a) Which stop was warmest? (b) How many more insects were seen in the sunny field than in the shady woods? (c) What pattern do you notice?
4. HARD You want to test whether a sunny patch of flowers or a shady patch has more insects. What will you change? Name three things you must keep the same. What will you measure?
5. CHALLENGE Maria wrote in her journal, “Saw a pretty bird.” Rewrite it as a good scientific observation and explain why your version is better.

COMMON MISTAKES

- Waiting until you get home to write. Details fade within minutes; write and sketch on the spot.
- Drawing what you think a plant should look like instead of what is in front of you. Count the petals and leaves; don't guess.
- Writing opinions ("pretty," "gross," "big") instead of observations and measurements ("blue with black bars," "4 cm long").

Make it a game · Ten Things in Ten Paces. Take ten paces in any direction and stop. You have two minutes to find and name ten different things: five living (a clover, an ant, moss) and five not living (a pebble, a puddle). Your partner checks each one. Score a bonus point for every living thing you can name a field mark for. Then switch places and pace in a new direction.

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 says the creatures themselves can teach us about the God who made them. A nature journal is a way of "asking" them and writing down what they tell us.

Practice answers

1. The date, the time, the place and the weather (with the temperature if you have a thermometer).
2. 80 × 0.5 m = 40 m. 40 × 3.28 = 131.2, so about 131 ft (about 130 feet).
3. (a) The sunny field, 21 °C (70 °F). (b) 9 − 3 = 6 more insects. (c) On this walk, the warmer the stop, the more insects were seen. One walk is not enough to be sure, so the walk should be repeated.
4. Change: sun or shade. Keep the same (controlled): the length of time you watch (for example 10 minutes), the size of the patch, the time of day, the kind of flowers if possible, and the person counting. Measure: the number of insects seen.
5. Example: "Oct. 3, 9:15 a.m., back fence, sunny, 14 °C (57 °F). Bird about the size of a robin, gray back, white patches on wings, long tail; sang many different songs for 2 minutes." It is better because it gives the date, place and weather and lists field marks and behavior that someone could use to identify the bird and compare later. "Pretty" is an opinion, not an observation.

9.2 Backyard Survey

OBJECTIVES

- Carry out a backyard survey: mark off survey plots, search them for a set time, and tally and sort every living thing found into its kingdom and group.
- Make a bar graph of survey counts and compare different places in the yard.
- Explain what a BioBlitz is and why a fair survey keeps the search time and plot size the same.

Warm-up. Guess how many different kinds of living things live in your yard or the nearest park: 5? 20? 100? Write your guess on a slip of paper and seal it in an envelope. You will open it at the end of the lesson.

Video. Coming soon. Backyard BioBlitz and schoolyard nature survey for kids; using a square plot (quadrat) and tally counts, looking under logs, and life in a lawn (search National Park Service, USGS, Smithsonian, Cornell Lab of Ornithology, SciShow Kids, Homeschool Pop (Alternate), Science Max, nature footage of garden insects).

KEY TERMS

survey
A careful count of what lives in a place, done the same way each time so the results can be compared.

BioBlitz
An event where scientists and volunteers try to find and identify as many kinds of living things as they can in one place in a short time.

plot
A marked-off area, often a square such as 1 meter by 1 meter (about 3 feet by 3 feet), that is searched during a survey.

tally
A quick count made with marks in groups of five.

habitat
The place where a living thing finds its food, water, shelter and space.

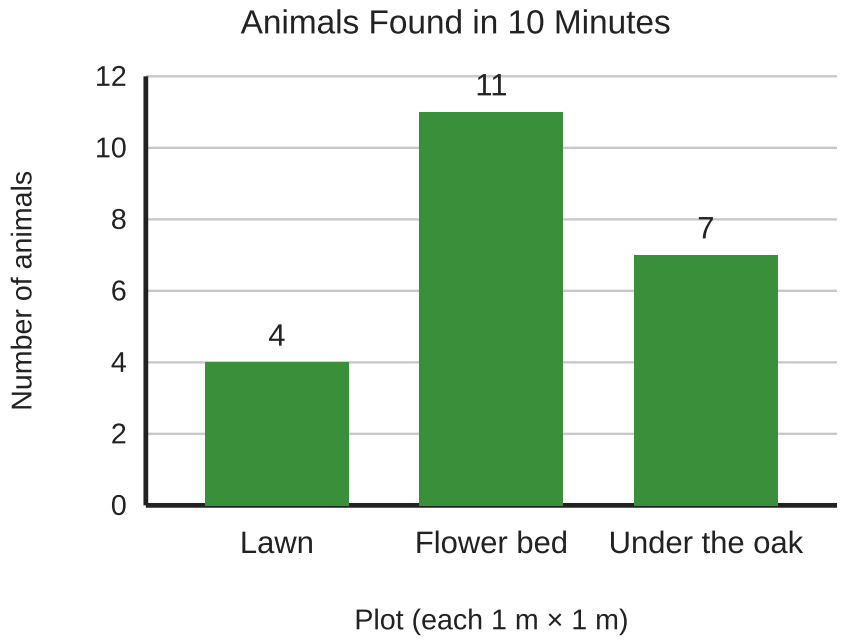
CORE IDEAS

The story. In 1996, scientists from the U.S. Geological Survey and the National Park Service tried something new at Kenilworth Aquatic Gardens, a park of ponds and marshes in Washington, D.C. For 24 hours, teams of experts and volunteers searched the park and tried to list every kind of living thing in it: plants, insects, spiders, birds, fish, frogs, mushrooms and more. They called the event a **BioBlitz**, because it was a “blitz,” a quick all-out push, to count life (*bio*). The idea spread, and today families, schools and parks hold BioBlitzes all

over the country. Many of the creatures found are not rare at all. They are the beetles, mosses and spiders that live right next door and that nobody had ever written down.

How they figured it out. You cannot count every ant in a yard, so scientists **survey** small **plots**. Mark a square 1 meter by 1 meter (about 3 feet by 3 feet) with string and four sticks, search it for a set time, and **tally** what you find. Then do the same in a different **habitat**: the lawn, a flower bed, the shade under a tree, a damp spot by the downspout. To be fair, every plot must be the same size and searched for the same number of minutes. After the count, sort your finds the Linnaeus way: Which kingdom, plant or animal (or a mushroom, which belongs to the fungi)? If an animal, does it have a backbone? If an invertebrate, how many legs: six (insect), eight (spider), or many (millipede, pill bug)? A bar graph then shows at a glance which habitat holds the most life.

Try it and see. Most yards surprise their owners. A plain-looking lawn may hold clover, dandelions, ants, earthworms and leafhoppers, while a flower bed or a rotting log can hold many more. Each habitat gives different creatures what they need: damp shade for pill bugs and slugs, open flowers for bees and butterflies, seeds for sparrows. When you know what lives in your yard, you can care for it well, which is the work God gave people from the start, to dress and keep the garden (Genesis 2:15).



One family's survey: three plots of the same size, each searched for 10 minutes.

PICTURE STUDY



Mocking Bird (Plate 21 of The Birds of America), John James Audubon; engraved and printed by Robert Havell Jr., about 1827–1828 · Hand-colored engraving and aquatint · Copies in many libraries and museums; Audubon's original watercolor is at the New-York Historical Society, New York City

The northern mockingbird is a backyard bird of the American South and much of the rest of the country. It is famous for copying the songs of other birds and for bravely defending its nest. Audubon painted a family of mockingbirds attacking a rattlesnake that has climbed toward their nest in a yellow jessamine vine. Some readers in his day doubted that a rattlesnake would climb into a bush, but snakes of many kinds do climb to reach nests.

Look closely

- Count the mockingbirds. What is each one doing?
- Find the field marks: look at the wings and tail. Where do you see white patches?
- Find the nest. Why are the birds so excited, and which way is the snake heading?
- Look at the vine and its flowers. Is this a plant you might find in a southern backyard?

Talk about it

1. What does this picture tell you about how a mockingbird behaves near its nest?
2. Audubon painted birds doing something, not just sitting still. Why is that useful to a naturalist?
3. If you surveyed your yard in spring, what signs would tell you a bird was nesting nearby?

> **Safety first.** Survey with an adult nearby. Wear gardening gloves when you search through leaves or lift logs and stones, and roll a log toward you so anything under it moves away from you. Put every log and stone back exactly as you found it. Watch for

> stinging insects, poison ivy and snakes, and leave any snake alone. Do not touch mushrooms you cannot name. Wash your hands afterward.

EXPERIMENT: THREE-PLOT BACKYARD SURVEY

You will survey three habitats in your yard (or a park, with permission) to answer a question: **Which habitat in my yard has the most animals?**

You will need

- String (4 m or about 13 ft for each plot) and 12 sticks or pencils for corners
- Meter stick or tape measure
- Timer
- Hand lens, gardening gloves and a white plate or paper for looking at small creatures
- Nature journal, pencil and colored pencils
- Optional: a field guide to insects or a parent's phone with an identification app

Steps

1. Choose three different habitats, such as the lawn, a flower or vegetable bed, and the shade under a tree or shrub.
2. Write your **prediction**: which plot will have the most animals?
3. In each habitat, mark a square plot 1 m by 1 m (about 3 ft by 3 ft) with four sticks and string.
4. Search the first plot for exactly 10 minutes. Part the grass, look under leaves, and watch the flowers. Tally each animal you see, and write what kind it is if you know (ant, worm, beetle, spider).
5. Also list the kinds of plants and any mushrooms in the plot (you don't need to count every blade of grass).
6. Repeat with the other two plots, at about the same time of day.
7. Make a table: Plot, Number of animals, Number of kinds of animals, Kinds of plants.
8. Draw a bar graph of the number of animals in each plot. Write two sentences about what the graph shows and whether your prediction was right.

Tips

- **What we change:** the habitat. **What we keep the same:** the plot size, the 10-minute search, the time of day and the searcher. **What we measure:** the number of animals and the number of kinds.
- Count each creature once. If an ant runs out and back in, don't count it twice.
- Use the leg test to sort invertebrates: 6 legs, insect; 8 legs, spider or mite; 14 legs, pill bug; many legs, millipede or centipede.

Check your work

- All three plots were the same size and searched for the same time.

- My table and bar graph match each other.
- I sorted my finds into plants, fungi, and animals with and without backbones.

NATURE NOTEBOOK

1. Draw a map of your yard from above. Mark your three plots, the house, trees and the garden, and add a compass arrow pointing north.
2. Pick the most interesting creature from your survey and draw it large, with a hand lens if you can. Label its body parts and count its legs.
3. Open your sealed guess from the warm-up. Write how many kinds you actually found and why you think the real number in the whole yard is even larger.

> **From history.** In 1998 the Cornell Lab of Ornithology and the National Audubon Society started the Great Backyard Bird Count. Every February, for four days, families count the birds they see for at least 15 minutes and send in their tallies. Their reports help scientists see where birds are spending the winter, and anyone with a window and a notebook can take part.

WORKED EXAMPLES

Example 1. A family searched three plots, each 1 m by 1 m, for 10 minutes each. They found 4 animals on the lawn, 11 in the flower bed and 7 under the oak. (a) How many animals did they find in all? (b) How many more were in the flower bed than on the lawn? (c) Show the results as a bar graph.

(Use the map or drawing "The flower bed had the most animals in this survey." shown earlier in this lesson.)

1. Add all three plots: 4 + 11 + 7 = 22 animals.
2. Subtract to compare: 11 − 4 = 7 more animals in the flower bed.
3. Draw a bar graph with the plots along the bottom and "Number of animals" up the side, counting by 2s from 0 to 12. Make the bars 4, 11 and 7 units tall.
4. Read the graph: the flower bed bar is tallest, so it had the most animals; the lawn bar is shortest.

Answer: (a) 22 animals. (b) 7 more in the flower bed. (c) The flower bed bar is tallest (11), then under the oak (7), then the lawn (4).

PRACTICE

1. EASY What is a BioBlitz? Where and when was the first one held?
2. EASY Sort these survey finds into insects, spiders, other invertebrates and vertebrates: ant, earthworm, robin, garden spider, pill bug, ladybug, toad.
3. MEDIUM Use the bar graph in the worked example (Lawn 4, Flower bed 11, Under the oak 7). (a) Which plot had the fewest animals? (b) How many animals were found in the

two plots that are not the lawn? (c) Give one reason the flower bed might have the most.

4. HARD Leo searched his lawn plot for 5 minutes and his garden plot for 15 minutes. He found more animals in the garden and said, “The garden has more life.” What is wrong with his survey? How should he fix it?
5. CHALLENGE A 1 m by 1 m plot in the middle of a lawn holds 6 dandelion plants. The whole lawn is 10 m long and 5 m wide. Estimate the number of dandelions in the lawn. Why is this only an estimate?

COMMON MISTAKES

- Thinking a plain lawn or yard has “nothing” living in it. Look closely and slowly, and even a small plot holds many kinds of life.
- Calling every small crawling creature an insect. Spiders have 8 legs, pill bugs have 14 and earthworms have none; only animals with 6 legs and three body parts are insects.
- Comparing plots that were searched for different times or were different sizes. A fair survey changes only one thing: the habitat.

Make it a game · Backyard Bingo. Draw a 4-by-4 grid and fill the squares with things to find: an insect, an animal with 8 legs, a moss, a seed, a bird’s song, a chewed leaf, a mushroom (look but don’t touch), a spider web, a worm, a flower with 5 petals, and so on. Search the yard with a partner. Mark a square only when your partner sees it too. Four in a row wins; a full card is a champion naturalist.

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)

Jesus told His listeners to look at the birds. Every creature in your survey is fed and cared for by God, and He cares even more for you.

Practice answers

1. A BioBlitz is an event where scientists and volunteers try to find and identify as many kinds of living things as possible in one place in a short time. The first one was held in 1996 at Kenilworth Aquatic Gardens in Washington, D.C.
2. Insects (6 legs): ant, ladybug. Spiders (8 legs): garden spider. Other invertebrates: earthworm (no legs), pill bug (14 legs; a crustacean). Vertebrates: robin (bird), toad (amphibian).
3. (a) The lawn, with 4. (b) 11 + 7 = 18. (c) Flowers give nectar and pollen to bees, butterflies and beetles, and the many kinds of plants give food and hiding places that a mowed lawn does not.
4. It was not a fair test: the search time was different, so the garden had three times as long to be searched. He should search both plots for the same time (for example 10 minutes each), keep the plots the same size, and search at about the same time of day. Only the habitat should change.

5. The lawn is 10 × 5 = 50 square meters. 50 × 6 = 300, so about 300 dandelions. It is only an estimate because dandelions are not spread evenly; some parts of the lawn may have more or fewer than the one plot that was counted. Counting several plots and averaging gives a better estimate.

9.3 Zoo, Farm or Museum Visit

OBJECTIVES

- Plan and carry out a field trip to a zoo, farm or natural history museum, classifying at least fifteen animals or specimens into kingdom, vertebrate class or invertebrate group.
- Observe and describe the features farmers and scientists use to sort farm animals, such as hooves, teeth and the cud-chewing stomach of cattle, sheep and goats.
- Read a museum or zoo sign carefully, telling the difference between what is observed and what is an interpretation.

Warm-up. Make a quick chart with six columns: Mammals, Birds, Reptiles, Amphibians, Fish, Invertebrates. In two minutes, write as many animals as you can that you might see at a zoo or farm. Which column was easiest to fill? Which was hardest?

Video. Coming soon. Field trip to a zoo, working farm or natural history museum for kids; how cows chew their cud, hooves of horses and cattle, how zoos care for animals, and behind the scenes of museum collections (search Smithsonian National Museum of Natural History, National Zoo, Philadelphia Zoo, farm and 4-H channels, SciShow Kids, Homeschool Pop (Alternate), nature footage).

KEY TERMS

zoo
Short for “zoological garden”: a park where living wild animals are kept, cared for, studied and shown to visitors.

domestic animal
An animal kind that people have raised and bred for a long time for food, work or company, such as cattle, sheep, chickens, horses and dogs.

ruminant
A hoofed mammal, such as a cow, sheep or goat, that has a stomach with four parts and chews its cud (food brought back up to chew again).

specimen
A real plant, animal, bone or part of one that is kept so people can study it.

interpretation
An explanation of what something means. It is built on observations but goes beyond what can be seen or measured.

CORE IDEAS

The story. On July 1, 1874, the Philadelphia Zoo opened its gates, the first zoo in the United States. A group of Philadelphians had been granted a charter for it in 1859, but the Civil War

put the plans on hold for years. When it finally opened, families could see animals they had only read about. Zoos also helped scientists: they could watch living animals eat, move and raise their young. Long before zoos, farmers were the first animal watchers. Every shepherd and dairy farmer knew his animals well enough to see when one was sick. Natural history museums do a third job. They keep **specimens**, such as skins, skeletons, shells and fossils, so they can be studied again and again, labeled with their two-part Latin names.

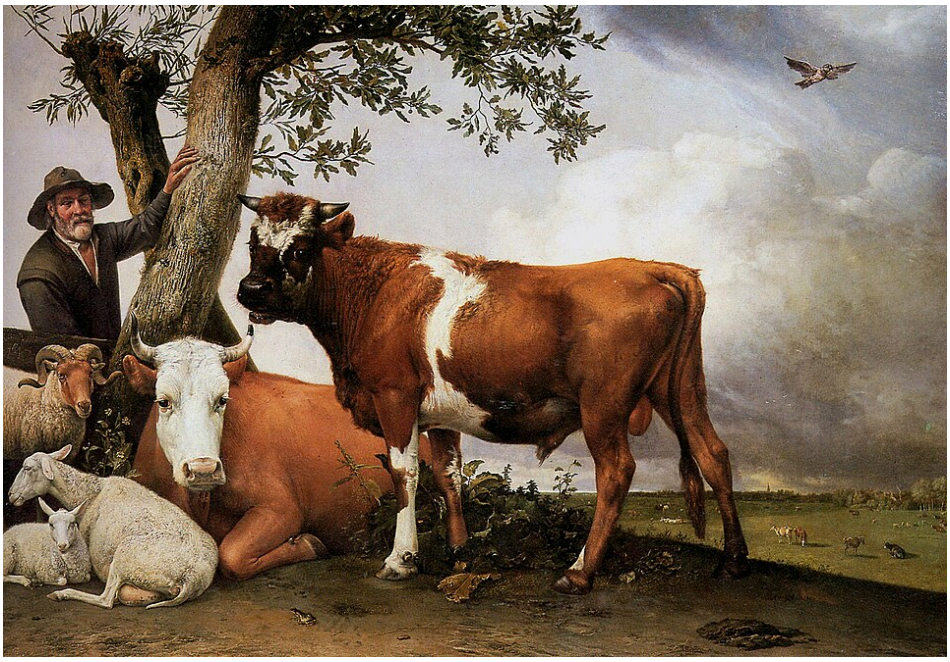
The big idea. A field trip is a chance to use everything you have learned this year. Take your notebook and sort each animal you see: Does it have a backbone? If so, which class: mammal, bird, reptile, amphibian or fish? If not, is it an insect, a spider, a crustacean, a snail? At a farm, look closely at the feet and teeth. Horses walk on one hoof per foot, while cattle, sheep, goats and pigs have split hooves and walk on two toes. A cow has no upper front teeth. It wraps its tongue around grass, presses it against a hard pad on the upper gum, and tears it off. Cattle, sheep and goats are **ruminants**. Their stomachs have four parts, and they bring swallowed food back up to chew again ("chewing the cud"). The Bible uses these very field marks, split hooves and chewing the cud, to describe animals in Leviticus 11. At a museum, read the labels like a detective. Some sentences tell what is **observed** ("This bone is 1.5 meters (about 5 feet) long"). Others are **interpretations** ("This animal may have hunted in packs").

God's handiwork. Watching a goat climb, a hen scratch for seeds or a giraffe's long purple tongue strip leaves from a branch shows how well each creature is made for its life. Remember that animals in zoos and on farms depend on people, and good keepers and farmers work hard to feed them, keep them clean and treat them kindly. "A righteous man regardeth the life of his beast" (Proverbs 12:10).

> ⏳ **Thinking About Time**
>
> **What the sign says.** What the sign says: Many natural history museums label fossil halls with museum words such as "the age of dinosaurs," "Jurassic" or "Ice Age," and their signs say these creatures lived and died millions of years ago, long before any people.
>
> **What we observe.** What we observe: real bones and shells that have turned to stone, buried in layers of rock made from mud and sand. We can measure the bones, count them, compare them with living animals and see which layer they came from. No bone comes with its age written on it; the ages on the signs are figured by methods that rest on assumptions about the past.
>
> **How Christians read it.** How Christians read it: Many Christians read Genesis as a true history in which God created the world recently and a worldwide Flood buried huge numbers of creatures quickly in layers of mud, which helps explain why so many fossils are found together. You can enjoy and learn from every fossil in the museum while reading its sign carefully.
>
> **Try it.** Copy one museum sign into your notebook. Underline the observations in one color and the interpretations in another.

> *Genesis 7:19*

PICTURE STUDY



The Young Bull, Paulus Potter, 1647 · Oil on canvas · Mauritshuis, The Hague, Netherlands

Paulus Potter was a young Dutch painter who loved farm animals. He was only about 22 years old when he painted this huge picture, more than 3 meters (about 11 feet) wide, with the bull nearly life-size. Potter painted every curl of hair and every wrinkle of hide as if he were making a scientific record. The painting became so famous that French soldiers carried it off to Paris in 1795, and it was not returned to the Netherlands until 1815.

Look closely

- Find every animal in the painting. How many different kinds of animals can you count?
- Look at the bull’s feet. Are its hooves one piece, or split into two toes?
- Look at the bull’s hide, horns and face. What details did Potter paint that show he studied a real animal?
- Find the farmer. What is he doing, and how does he seem to feel about his animals?

Talk about it

1. Which of these animals are ruminants? How do you know?
2. Why do you think a painter would make a farm animal as large and important as a king in a portrait?
3. If you visit a farm, what three details will you look for that Potter painted here?

Safety first. Stay with your adult and behind every fence and barrier. Do not feed or touch any animal unless a keeper or farmer says it is safe, and keep fingers away from

> mouths and beaks. Never stand directly behind a horse or cow, which can kick. Wash your hands well with soap and water after touching animals, fences or pens, and before you eat, because farm and zoo animals can carry germs that make people sick.

EXPERIMENT: FIELD TRIP CLASSIFICATION LOG

Visit a zoo, farm, petting zoo, aquarium or natural history museum (or, if you cannot go, take a virtual tour of the Smithsonian's National Museum of Natural History). You will log what you see and answer a question: **Which group of animals is shown most at this place, and why?**

You will need

- Clipboard or notebook and pencil
- A log page ruled into columns: Animal, Kingdom or group, Class, One field mark, Sketch
- The map or guide from the zoo, farm or museum
- Optional: a parent's camera or phone for photos, and a watch for timing behavior

Steps

1. Before the trip, look at the map or website and write your **prediction**: which class of animals will you see the most of?
2. At each animal or specimen, write its common name and, if the sign shows it, its two-part scientific name.
3. Fill in its class (mammal, bird, reptile, amphibian, fish) or, if it has no backbone, its group (insect, spider, crustacean, mollusk, starfish).
4. Write one field mark you can see yourself, such as split hooves, feathers, scales, shell or eight legs.
5. Choose one living animal and watch it for 5 minutes. Tally what it does each minute: eating, moving, resting, grooming.
6. At a farm, ask the farmer one question about how the animals are fed or cared for, and write the answer.
7. At a museum, copy one sign and mark the observations and the interpretations.
8. At home, count your log by class and make a tally table. Was your prediction right? Write two sentences about why this place shows more of one group.

Tips

- Aim for at least 15 animals or specimens in your log.
- Read the sign after you have looked at the animal, not before. Notice things for yourself first.
- Zoos and museums often show more mammals and birds than insects, even though insects are the largest group of animals on earth. Think about why.

Check your work

- My log has at least 15 entries, each with a class or group and a field mark.
- I watched one animal for 5 minutes and tallied its behavior.
- I compared my results with my prediction.

NATURE NOTEBOOK

1. Draw the foot of a horse and the foot of a cow, sheep or goat side by side. Label the single hoof and the split hoof.
2. Sketch one museum specimen or zoo animal and copy its full sign underneath, with its scientific name in italics or underlined.
3. Write a thank-you note to a farmer, keeper or museum guide telling one thing you learned.

> **From history.** The word “zoo” is short for “zoological garden.” The Zoological Society of London, founded in 1826 by Sir Stamford Raffles and others, opened its garden in Regent’s Park in 1828. At first it was meant for scientists and members to study animals, and it opened to the paying public in 1847. Londoners soon shortened the long name, and “zoo” has stuck ever since.

WORKED EXAMPLES

Example 1. On a zoo trip, Sam logged 24 kinds of animals: 12 mammals, 6 birds, 3 reptiles, 2 amphibians and 1 fish. (a) Check that the numbers add up to 24. (b) What fraction of the animals were mammals? (c) What fraction were birds?

1. Add: 12 + 6 + 3 + 2 + 1 = 24. The log is complete.
2. Mammals: 12 out of 24 = 12/24. Divide the top and bottom by 12: 12/24 = 1/2.
3. Birds: 6 out of 24 = 6/24. Divide the top and bottom by 6: 6/24 = 1/4.

Answer: (a) The total is 24. (b) One half of Sam’s animals were mammals. (c) One fourth were birds.

PRACTICE

1. EASY Sort these farm and zoo animals into vertebrate classes: goat, chicken, tortoise, bullfrog, trout, camel, ostrich.
2. MEDIUM Name two features that make a cow a ruminant, and explain how a cow bites off grass without upper front teeth.
3. MEDIUM Mia watched a goat for 5 minutes and recorded its activity each minute.
   Minute | Activity
   1 | eating
   2 | eating
   3 | walking
   4 | chewing cud while lying down

5 | chewing cud while lying down
(a) How many minutes was the goat eating hay? (b) How many minutes was it chewing its cud? (c) What fraction of the time was it lying down?

4. HARD You think zoo animals move around more just before feeding time than in the middle of the afternoon. Design a fair test. What will you change, what will you keep the same, and what will you measure?
5. CHALLENGE A museum sign says: “This skull is 1.2 meters (4 feet) long. Its teeth are sharp and curved. This dinosaur was the fiercest hunter of its time.” Which sentences are observations and which is an interpretation? Explain.

COMMON MISTAKES

- Thinking every animal with hooves is the same kind of animal. Horses have one hoof per foot and do not chew the cud; cattle, sheep and goats have split hooves and are ruminants.
- Thinking a cow has four stomachs. It has one stomach with four parts (compartments).
- Treating everything on a museum sign as something that was observed. Signs mix measurements with interpretations, and a careful reader can tell which is which.

Make it a game · Hoof, Feather, Scale or Shell. One player secretly picks an animal from the field trip. The others may ask only yes-or-no questions about field marks: “Does it have hooves? Split hooves? Does it chew the cud? Feathers? A backbone?” Whoever guesses the animal in ten questions or fewer wins the round and picks the next animal.

Scripture. “Be thou diligent to know the state of thy flocks, and look well to thy herds.” (Proverbs 27:23, KJV)

A good farmer watches his animals closely and knows each one. Careful observation is not just for scientists; it is how we take good care of what God has put in our hands.

Practice answers

1. Mammals: goat, camel. Birds: chicken, ostrich. Reptile: tortoise. Amphibian: bullfrog. Fish: trout.
2. A ruminant has a stomach with four parts and chews its cud (brings food back up to chew again); it also has split hooves. A cow wraps its tongue around the grass and pinches it between its lower front teeth and a hard pad on its upper gum, then tears it off.
3. (a) 2 minutes. (b) 2 minutes. (c) 2 out of 5 minutes, or 2/5.
4. Change: the time of watching (just before feeding versus mid-afternoon). Keep the same: the same animal or exhibit, the same length of watch (for example 10 minutes), the same way of tallying, and similar weather. Measure: the number of minutes the animal spends moving (or the number of times it moves). Repeat on more than one day if you can.
5. Observations: “This skull is 1.2 meters (4 feet) long” and “Its teeth are sharp and curved,” because anyone can measure and see them. Interpretation: “This dinosaur was the fiercest

hunter of its time," because no one watched it hunt; it is an explanation built from clues such as the teeth.

9.4 Specimen Collection

OBJECTIVES

- Collect, dry, sort and display at least twelve natural specimens (leaves, seeds, cones, shells, dead insects) gathered safely, lawfully and with permission.
- Write a complete specimen label with a catalog number, name, place, date, collector and measurement, and find the average size of a set of specimens.
- Tell how Charles Willson Peale built one of America's first public natural history museums and explain why a specimen without a label loses most of its value.

Warm-up. Empty a drawer, pocket or box of "treasures" you have saved (rocks, shells, acorns, feathers, buttons). Sort them into two piles: living or once-living things, and things that were never alive. Then try to remember where and when you found each one. Which ones can you not remember?

Video. Coming soon. How to start a nature specimen collection for kids; pressing leaves, labeling specimens, and behind the scenes of natural history museum collections and drawers of specimens (search Smithsonian National Museum of Natural History, Field Museum, natural history museum collections tours, SciShow Kids, Homeschool Pop (Alternate), Science Max).

KEY TERMS

specimen
A real plant, animal or part of one (such as a leaf, seed, shell or bone) that is kept so people can study it.

collection
A group of specimens that are labeled, sorted and stored so they can be found and studied again.

label
A small card kept with a specimen that tells what it is, where and when it was found, and who found it.

catalog number
A number given to each specimen in a collection and written in a list, so that the specimen and its information always stay matched.

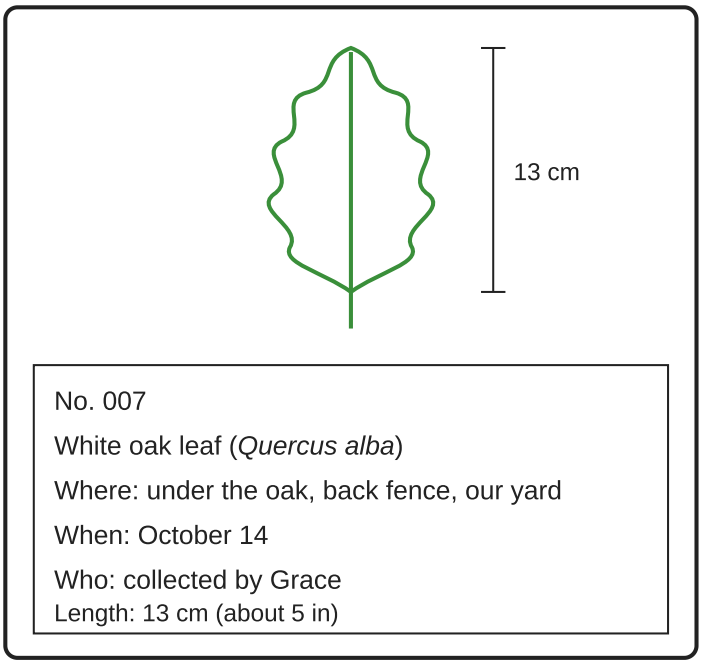
CORE IDEAS

The story. In 1786, in his home in Philadelphia, the painter Charles Willson Peale opened one of the first public museums of natural history in America. He filled it with stuffed birds and mammals, insects, shells and minerals, and he set many birds in glass cases with painted backgrounds that looked like the places where they lived. Peale arranged and labeled his

birds by the Linnaean system, with their scientific names. In 1801 he led a dig on a farm near Newburgh, New York, where giant bones had been found in a pit. His workers built a huge wheel to pump out the water, and they dug up most of a mastodon skeleton, which Peale mounted for visitors to see. Some of the animals Lewis and Clark brought back from the West were later shown in his museum too. Peale wanted ordinary people, not only scholars, to see the variety of God’s creatures with their own eyes.

The big idea. A **specimen** is only as good as its **label**. A pretty leaf in a drawer is a keepsake; the same leaf with a label is **science**. Every label answers *what* (common and scientific name if you know it), *where* (the exact place), *when* (the date), *who* (the collector) and gives a **catalog number** that matches a list in your notebook. With labels, you or anyone else can compare specimens years later: Do the maple leaves on our street turn red on the same week each fall? Are the acorns bigger in a wet year? Then sort the **collection** the way Linnaeus would: plants, fungi and animals; and within plants, mosses, ferns, conifers and flowering plants.

Try it and see. Good collectors take only what is common and what will not be missed: fallen leaves, seeds, cones, empty snail shells, a single flower from a big patch, and insects already found dead on a windowsill. They always ask permission on private land and never collect in national or state parks. Leave birds’ nests, eggs and wild bird feathers where they are; in the United States, a law called the Migratory Bird Treaty Act protects most wild birds, so it is against the law to keep their feathers, nests or eggs. Draw or photograph those instead. Taking care of creation means studying it without using it up.



A complete specimen label answers what, where, when and who, and its catalog number matches the collection list.

PICTURE STUDY



The Artist in His Museum, Charles Willson Peale, 1822 · Oil on canvas · Pennsylvania Academy of the Fine Arts, Philadelphia

Charles Willson Peale painted this life-size self-portrait when he was 81 years old. He shows himself lifting a curtain as if to say, “Come in and see!” Behind him stretches the Long Room of his museum, which by then was on the upper floor of the Pennsylvania State House, the building we now call Independence Hall. The bird cases run along the wall, with portraits of famous Americans hanging above them.

Look closely

- Find the long rows of bird cases. Why do you think Peale put each bird in its own case?
- Look at Peale’s feet and on the table beside him. What specimens and tools do you see?
- Find the woman in the background. What is she reacting to?
- Look at the curtain. What do you think Peale wants you, the viewer, to do?

Talk about it

1. Why would a scientist want to show his collection to the public instead of keeping it to himself?
2. Peale’s mastodon was dug up on a farm. What could you learn from a skeleton that you could not learn from a drawing?
3. If you opened your own small museum, what would you put in the first case?

> **Safety first.** Collect with an adult and only with the landowner’s permission. Do not collect in national or state parks. Do not keep wild bird feathers, nests or eggs (it is against U.S. law). Never pick up a living insect that can sting or bite, and use only insects you find already dead. Wear gloves for dead insects and old shells, never touch dead

> animals larger than an insect, and do not pick wild mushrooms. Let an adult handle any pins. Wash your hands after collecting.

EXPERIMENT: MY LABELED SPECIMEN BOX

You will build a small labeled collection of at least twelve specimens and test one question as you dry your leaves: **Do leaves keep their color better when they are pressed in a heavy book or when they are left to dry flat in the open air?**

You will need

- A shoebox, egg carton or box with small sections, or zip-top bags
- Index cards or small paper slips for labels, and a fine pen
- Newspaper or paper towels and two or three heavy books
- Ruler marked in centimeters and inches
- Gloves, a small bag for collecting, and your nature journal
- Optional: hand lens, and white glue to fix flat specimens to cards

Steps

1. Make a collection list in your notebook with columns: Catalog no., Name, Place, Date, Collector, Size.
2. With your adult, collect at least twelve common specimens: fallen leaves from different trees, seeds and nuts, a pinecone, empty snail shells, a small piece of moss, an insect found dead.
3. Give each specimen a catalog number (001, 002, 003…) and fill in its line in your list right away, while you still remember where it was found.
4. For the leaf test, find four leaves of the same kind and about the same color. Write your **prediction**.
5. Press two of the leaves between paper towels inside a heavy book. Lay the other two flat on paper towels on a shelf. Keep them in the same room for the same time.
6. After 7 days, compare the color of the pressed leaves and the air-dried leaves. Record which ones kept their color and shape better.
7. Measure each leaf and seed with your ruler and write its size in centimeters (and inches) on its label.
8. Arrange your box by groups: plants (mosses, ferns, conifers, flowering plants), fungi and animals. Put each label with its specimen.

Tips

- **What we change:** the drying method (pressed or open air). **What we keep the same:** the kind of leaf, the starting color, the room and the number of days. **What we measure:** the color and flatness after 7 days.
- Seeds and nuts can hold tiny insects. Freeze them in a sealed bag for a few days before you put them in the box.

- A good collection has fewer specimens with complete labels rather than many specimens with none.

Check your work

- I have at least twelve specimens, each with a catalog number and a complete label.
- Every specimen was collected safely, lawfully and with permission.
- I recorded the results of my drying test and compared them with my prediction.

NATURE NOTEBOOK

1. Draw your three favorite specimens life-size, with a ruler line beside each one showing its length in centimeters.
2. Draw a feather you found, but leave the feather where it was. Write where you found it and what bird you think it came from.
3. Design the front of a small museum case for your collection: give it a title and draw where each group will go.

> **From history.** James Smithson, an English scientist who never visited the United States, left his fortune to the United States to found an establishment in Washington for the increase and spread of knowledge. Congress created the Smithsonian Institution in 1846. Today its National Museum of Natural History in Washington, D.C., holds well over a hundred million specimens, from beetles and pressed plants to whale skeletons, most of them stored in drawers and cabinets where scientists study them, each with its own label and catalog number.

WORKED EXAMPLES

Example 1. Grace collected three fallen white oak leaves and measured their lengths: 12 cm, 14 cm and 13 cm. (a) What is the average length? (b) About how many inches is that? (1 inch = 2.54 cm.) (c) Write a label for her leaf number 007, found October 14 under the oak by the back fence.

(Use the map or drawing “Grace’s label for specimen 007.” shown earlier in this lesson.)

1. Add the lengths: 12 + 14 + 13 = 39 cm.
2. Divide by the number of leaves: 39 ÷ 3 = 13 cm. The average length is 13 cm.
3. Change to inches: 13 ÷ 2.54 ≈ 5.1, so about 5 inches.
4. Write the label with every part: catalog number, name, place, date, collector and size.

Answer: (a) 13 cm. (b) About 5 in. (c) “No. 007. White oak leaf (*Quercus alba*). Under the oak by the back fence, our yard. October 14. Collected by Grace. Length 13 cm (about 5 in).”

PRACTICE

1. EASY List the five things every specimen label should include.
2. EASY You find a beautiful blue jay feather on a hiking trail. What should you do, and why?
3. MEDIUM Read this collection list.
   Group | Number of specimens
   Flowering plants (leaves and seeds) | 9
   Conifers (cones and needles) | 4
   Mosses and ferns | 2
   Fungi | 1
   Animals (shells and insects) | 4
   (a) How many specimens are in the collection? (b) Which group has the most? (c) How many more plant specimens (all three plant groups) are there than animal specimens?
4. HARD Jack pressed maple leaves in a phone book for 3 days and oak leaves on a sunny windowsill for 7 days. The maple leaves looked better. Can he say pressing works better? Explain how to make it a fair test.
5. CHALLENGE Two pinecones are found in the same box. One has a label: “No. 012, eastern white pine cone, Grandpa’s farm, Maine, Nov. 2, 2025, 14 cm (5.5 in).” The other has no label. Explain why a scientist would value the first one more, even if the second is bigger and prettier.

COMMON MISTAKES

- Thinking the specimen is what matters and the label is extra. Without a label, a specimen loses most of its scientific value.
- Waiting to write labels until later. By the next day, you may not remember which leaf came from which tree.
- Thinking anything found on the ground is free to take. Wild bird feathers, nests and eggs are protected by law, parks forbid collecting, and private land needs the owner’s permission.

> **Make it a game · Mystery Specimen.** Put one specimen from your collection into a cloth bag without letting your partner see. Your partner reaches in, feels it without looking, and describes it like a naturalist (rough or smooth, light or heavy, about how long in centimeters). Then they guess what it is and which group it belongs to. One point for the right object, one more point for the right group. Take turns until every specimen has been in the bag.

> **Scripture.** “And he spake of trees, from the cedar tree that is in Lebanon even unto the hyssop that springeth out of the wall: he spake also of beasts, and of fowl, and of creeping things, and of fishes.” (1 Kings 4:33, KJV)

King Solomon was a naturalist. He studied everything from the great cedar to the little hyssop plant growing out of a wall, and from beasts to creeping things. Your collection

follows in his footsteps.

Practice answers

1. A catalog number, what it is (its name), where it was found, when it was found (the date) and who collected it. A measurement is a good sixth item.
2. Leave it there and draw or photograph it. Blue jays are wild native birds protected by the Migratory Bird Treaty Act, so in the United States it is against the law to keep their feathers without a permit.
3. (a) 9 + 4 + 2 + 1 + 4 = 20 specimens. (b) Flowering plants, with 9. (c) Plants: 9 + 4 + 2 = 15. 15 − 4 = 11 more plant specimens than animal specimens.
4. No. He changed three things at once: the method, the kind of leaf and the number of days (and the light). For a fair test he should use the same kind of leaf with the same starting color, dry them for the same number of days in the same room, and change only the method (pressed or open air). Then he can compare color and shape.
5. The labeled cone carries information: what kind it is, exactly where and when it grew, and its size, so it can be compared with other cones from other places and years and checked again by someone else. The unlabeled cone could have come from anywhere at any time, so it cannot answer any scientific question; it is only a keepsake.

Unit 9 review

Answer each question. Show your work for calculations and use complete sentences for explanations. The review has 6 problems and is worth 50 points.

1. (10 pts) List five things a good nature journal page should include. Then explain why a naturalist writes observations down on the spot instead of waiting until getting home.
2. (5 pts) Ten of Rosa’s paces cover 7 meters. How far does she walk in 40 paces? Give the answer in meters and about how many feet (1 m is about 3.28 ft).
3. (10 pts) A backyard survey used three plots, each 1 m by 1 m, searched for 10 minutes each.
   Plot | Animals found
   Lawn | 5
   Vegetable garden | 12
   Woodpile | 9
   (a) How many animals were found in all? (b) Which plot had the most? (c) How many more animals were in the woodpile than on the lawn? (d) Describe how you would draw a bar graph of these results.
4. (5 pts) You want to find out whether more insects live in tall grass or in mowed grass. What will you change? Name two things you will keep the same. What will you measure?
5. (10 pts) (a) Sort these animals into classes: sheep, duck, iguana, salamander, goldfish. (b) Which one is a ruminant, and name two features that show it. (c) A museum sign says, “This bone is 2 meters long. The animal probably weighed as much as an elephant.” Which sentence is an observation and which is an interpretation?
6. (10 pts) (a) Write a complete specimen label for a pinecone you found today in your grandmother’s yard, 9 cm long. (b) Name two things a young collector should leave where they are instead of collecting, and tell why. (c) Who was Charles Willson Peale?

Unit project: my nature lab notebook and specimen box

Gather the work from all four labs into one notebook and one box. The notebook holds at least four dated nature journal pages from your walks, your three-plot backyard survey with its table and bar graph, and your field trip classification log. The box holds at least twelve labeled specimens arranged by group, with a collection list whose catalog numbers match the labels. Finish with one page titled “What I Discovered” that tells your favorite find, the result of one of your fair tests, and one new question you would like to answer next season. Present the notebook and box to your family as if you were opening your own small museum.

- **Observation**: Journal pages and logs are dated, give place and weather, and include careful labeled sketches and real observations rather than opinions.
- **Measurement and data**: Measurements are in metric units with U.S. units beside them; the survey table and bar graph are correct and match each other.

- **Classification and labels**: Animals and specimens are sorted into the correct kingdoms, classes and groups, and every specimen has a complete label and a matching catalog number.
- **Fair tests and care**: At least one fair test is recorded with prediction, what changed, what stayed the same and results, and all collecting was done safely, lawfully and with permission.

Answer key

1. Any five of: the date, the time, the place, the weather (with temperature), a labeled sketch, measurements, sounds or smells noticed, and an “I wonder” question. Observations are written on the spot because memory fades quickly and details (such as the number of spots on a beetle) are easily forgotten or mixed up.
2. One pace = 7 ÷ 10 = 0.7 m. 40 × 0.7 = 28 m. 28 × 3.28 = 91.84, so about 92 ft (about 90 feet).
3. (a) 5 + 12 + 9 = 26 animals. (b) The vegetable garden, with 12. (c) 9 − 5 = 4 more. (d) Put the three plots along the bottom and “Number of animals” up the side, counting by 2s from 0 to 12 or 14; draw bars 5, 12 and 9 units tall and give the graph a title.
4. Change: tall grass or mowed grass. Keep the same (any two): the plot size, the search time, the time of day, the weather, the person searching. Measure: the number of insects found.
5. (a) Sheep: mammal. Duck: bird. Iguana: reptile. Salamander: amphibian. Goldfish: fish. (b) The sheep; it chews its cud, has a stomach with four parts, and has split hooves (any two). (c) “This bone is 2 meters long” is an observation (it can be measured). “The animal probably weighed as much as an elephant” is an interpretation (an estimate built from the clues).
6. (a) A complete label has a catalog number, the name (pinecone, and the kind of pine if known), the place (Grandmother’s yard, with town and state), today’s date, the collector’s name, and the size, 9 cm (about 3.5 in). (b) Any two, with reasons: wild bird feathers, nests or eggs (protected by U.S. law); anything in a national or state park (collecting is not allowed); living creatures or rare plants (they should not be taken from their home); mushrooms (they may be poisonous); anything on private land without permission. (c) A Philadelphia painter and naturalist who opened one of America’s first public natural history museums in 1786, labeled his birds by the Linnaean system, and dug up and mounted a mastodon skeleton in 1801.