

GRADE 3 LIFE SCIENCE: PLANTS AND ANIMALS TOGETHER

A year of true stories about living things and how they depend on one another, from George Washington Carver's peanuts and Maria Sibylla Merian's painted caterpillars to the yucca moth, the barn owl's pellet, the porcupine's quills and Mary Anning's sea dragon on the beach at Lyme Regis, each one watched closely, measured carefully and drawn in a nature notebook of the student's own.

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 follows plants and animals through one school year and asks one question again and again: how do living things depend on each other? The student meets the parts of a plant and the seeds that fly, float and hitch a ride; the bees, butterflies, hummingbirds and bats that carry pollen from flower to flower; the food chains that run from a blade of grass to a hawk; the prairie, the rainforest, the coral reef and the backyard; the quills, spray and armor animals use to stay alive; and the great sea reptiles and flying reptiles found in the rocks. The year ends with the student's own nature journal, and an optional **Nature Lab** takes the notebook outdoors for walks, surveys and a visit to a zoo, farm or museum.

Every lesson follows the same path. First comes **the story**: a real person, place or creature, such as George Washington Carver at Tuskegee, Mary Anning on the cliffs of Lyme Regis or the yucca moth in the desert at night. Then **look closely**: what can we see with our own eyes and a hand lens? Then **measure it**: how tall, how many, how long, how warm, counted in inches and cups with centimeters and milliliters alongside. Then **the big idea**, explained for a third grader. Last, the student does a simple experiment and draws and labels what he or she found in the nature notebook.

The thread of the year is **plants and animals together**. A flower feeds a bee and the bee carries the flower's pollen; an owl eats a mouse and a beetle returns what is left to the soil; a yucca cannot make seeds without its moth, and the moth cannot raise its young without the yucca. Each unit adds one more strand to the web, so that by spring the student can stand in the backyard and tell who lives there, what each one eats and who helps whom.

Underneath it all is the wonder of creation. The living world is not an accident but the work of a wise Maker, who made each creature to reproduce after its kind and set them to need one another: "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). The course teaches the student to look carefully, measure honestly and give thanks for what he or she sees.

WHO IT IS FOR

Written for third graders who are reading on their own and learning to add, subtract and measure with a ruler. A parent or teacher reads the stories aloud, helps with the experiments and supervises anything involving sharp tools, the stove, wild animals or work outdoors. Nothing needs to be bought beyond ordinary household things: jars, paper towels, dried beans, celery, food coloring, a ruler, a measuring cup and a notebook.

HOW TO USE THIS COURSE

The weekly rhythm. The year has 32 lessons, one a week, in 8 units of 4, plus the optional Nature Lab. Session 1 (about 45 minutes) is the warm-up, the story and teaching, and the picture study. Session 2 (about 45 minutes) is the experiment and the nature notebook. Families who want a one-quarter version can follow the ★ **quarter path**: the 10 lessons

marked with a star, spread across all eight units, keep the core ideas of the year. The Nature Lab can be used after Unit 8, over the summer, or any week the weather is fine.

The nature notebook. Use one sketchbook or blank composition book for the whole year. Every experiment ends with a page: a labeled drawing, a measurement table, a tally of seeds that sprouted or birds that visited, or a simple bar graph. Date every page, write the weather at the top, and add one sentence that begins “I noticed...”. A careful drawing of one leaf is worth more than a hurried page of ten.

Experiments and safety. Each experiment starts with a guess (“I think...”), then a fair test, then counting or measuring, then a sentence about what happened. Wash hands after handling soil, seeds, pellets or anything found outdoors. Use only owl pellets sold already heat-treated for classrooms, or use the printed bone chart in place of real pellets. Look at bees, wasps and wild animals without touching them, never eat a wild plant, berry or mushroom, and learn to know poison ivy before the backyard survey. A grown-up handles knives, hot water and the stove.

Worked examples and practice. Each lesson has two worked examples that show, step by step, how to read a measurement, count a tally or follow a food chain, and six practice problems with numbers a third grader can handle. Most problems use inches, feet, cups and degrees Fahrenheit, with centimeters, milliliters and degrees Celsius introduced alongside. Answers are given so the student can check his or her own work.

Unit quizzes and unit projects. Each unit ends with a short quiz (40 points, 10 items) of naming, identifying and short answers, and a unit project that pulls the unit together, such as a plant poster with labeled parts, a seed-travel display, a food-chain mobile, a habitat diorama or a reptile model with a museum card. The quiz may be given aloud. Keep the unit projects in one folder or box for the year.

A word about time. This course is written from a Christian view of creation: “In the beginning God created the heaven and the earth” (Genesis 1:1), and the Flood of Noah’s day (Genesis 6–9) reshaped the earth and buried many creatures in mud and sand. Deep-time names such as “Jurassic” or “Ice Age” are taught as museum words, so students can read any sign or textbook. Wherever they come up, a  **Thinking About Time** box sets out what the sign says, what we observe, and how Christians read it.

SCOPE AND SEQUENCE

Unit 1: Plant Parts (1–4)

The root, stem, leaf and flower and what each one does; how a stem carries water up the plant; sorting leaves by shape and edge; and George Washington Carver, who found hundreds of uses for the peanut and helped farmers renew their soil.

Unit 2: Seeds and Growth (5–8)

Watching a bean sprout in a jar; seeds carried by wind, water and fur; a fair test of what seedlings need; and the law of sowing and reaping, each seed growing after its kind.

Unit 3: Pollinators (9-12)

Honeybees and the flowers they visit; the butterfly and moth from egg to wing, as Maria Sibylla Merian painted them; hummingbirds by day and bats by night; and the yucca moth, which cannot live without its plant.

Unit 4: Food Chains (13-16)

Who eats whom in a meadow and a pond; producers and consumers; taking apart a barn owl pellet to find out what the owl ate; and the worms, fungi and beetles that return everything to the soil.

Unit 5: Habitats (17-20)

The tallgrass prairie and its bison and prairie dogs; the layers of the rainforest; the coral reef and its crowded neighbors; and a survey of the living things in the student's own backyard.

Unit 6: Animal Defenses (21-24)

How animals stay alive: the porcupine's barbed quills, the skunk's warning stripes and spray, the armadillo's armor and the bombardier beetle's hot chemical spray.

Unit 7: Sea Monsters and Flying Reptiles (25-28)

Mary Anning and the first complete plesiosaur, found at Lyme Regis in 1823; the great mosasaurs; the pterosaurs that flew on wings of skin; and Leviathan in the Book of Job. 🕒 Thinking About Time boxes explain the museum words.

Unit 8: Nature Journal (29-32)

Learning to draw what is really there, label the parts, date each page and record the weather, and share a finished journal with family, the way naturalists have done for centuries.

Unit 9: Nature Lab (optional) (Any time)

Four outdoor sessions that use the nature notebook in the field: a journal walk, a second backyard survey to compare with the first, a visit to a zoo, farm or museum, and a small collection of leaves, seeds, feathers or shells.

MATERIALS

- **Nature notebook (a sketchbook or blank composition book):** One for the whole year: labeled drawings, measurement tables, tallies, weather notes and bar graphs.
- **A hand lens (magnifying glass):** Used in nearly every unit for leaves, seeds, insects, bones and soil.
- **A ruler marked in inches and centimeters, a measuring cup and a measuring tape:** For measuring seedlings, leaves, stems and the backyard survey plot.

- **Clear jars or zip-top bags, paper towels and dried beans:** For the germination jar and the seed experiments in Unit 2.
- **Celery, food coloring and a few cups:** For the colored-water experiment in Unit 1 and other kitchen-table tests.
- **Potting soil, small pots or paper cups, and a sunny window:** For growing seedlings and the light experiment.
- **An outdoor thermometer:** For recording the weather on each notebook page and in the Nature Lab.
- **Colored pencils, a pencil sharpener, string, tape and modeling clay:** For drawings, food-chain mobiles, habitat dioramas and reptile models.
- **Disposable gloves, toothpicks and tweezers:** For the owl pellet lesson and for handling soil and specimens.
- **Optional: a heat-treated owl pellet and a regional field guide to birds, trees or insects:** Never required. A printed bone chart works in place of the pellet, and a library field guide is fine.

GRADING

Grades come mostly from the experiments and the nature notebook, because life science is learned by looking, measuring and recording. An experiment that did not turn out as expected but is honestly recorded and explained earns full credit.

- Experiments (a guess, a fair test, careful measuring and a sentence about what happened): 35%
- Nature notebook (dated pages, weather, labeled drawings, honest records): 25%
- Unit quizzes (40 points each): 20%
- Unit projects: 20%

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

- Grade the process, not just the result. Did the student guess first, test fairly, measure carefully, record honestly and say what he or she noticed?
- A notebook page earns full marks when it has a date, the weather, a title, a drawing with at least three labels and one “I noticed...” sentence.
- Unit quizzes may be given orally for a student who writes slowly; the parent writes down the answers.
- Keep each unit project in one folder or box. Together with the nature notebook, they make a fine record of the year to share in Lesson 8.4.

A NOTE TO PARENTS

You do not need to be a biologist to teach this course. Read the story aloud together, look at the picture, and then do the experiment side by side. Ask “What do you notice?”, “How could we measure it?” and “Who does this creature need, and who needs it?” Those three questions are most of what a good science teacher does.

Some of the best lessons happen outdoors. Take the hand lens and the notebook into the yard, a park or a field whenever you can, and let the student sit still long enough for the birds and insects to come back. Keep wild animals at a respectful distance, and wash hands when you come in.

Above all, the course hopes to raise a child who looks closely at the world God made, tells the truth about what he or she sees, and gives thanks for it. "O LORD, how manifold are thy works! in wisdom hast thou made them all: the earth is full of thy riches." (Psalm 104:24)

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Unit 7: Sea Monsters and Flying Reptiles

- 7.1 Plesiosaurs: Mary Anning’s Great Find (1823) ★
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Unit 8: Nature Journal

- 8.1 Drawing What I See ★
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Unit 9: Bonus: Nature Lab (optional)

9.1 Nature Journal Walk

9.2 Backyard Survey by Day and by Night

9.3 Zoo, Farm or Museum Visit

9.4 Specimen Collection

★ quarter path ·  Thinking About Time box

PLANT PARTS

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” (Genesis 1:11). Every plant He made, from a dandelion in the lawn to a towering redwood, is built from the same few parts: **roots** that hold tight and drink, **stems** that stand up and carry water, **leaves** that make food from sunlight, and **flowers** that make seeds. In this unit you will dig up, measure, slice, sort and test those parts the way real botanists do.

You will meet John Bartram, the Pennsylvania farmer who stopped his plow to look at a daisy and became Royal Botanist for North America. You will weigh water with Stephen Hales and watch colored water climb a celery stalk. You will walk the fields of Sweden with Carl Linnaeus and learn the names he gave to leaf shapes. Last, you will go to Tuskegee, Alabama, with George Washington Carver, who used the humble peanut to rebuild worn-out soil and help struggling farmers. In every lesson you will ask: **what job does this part do, and how can I find out?**

BEFORE YOU BEGIN

- Can add and subtract numbers to 100
- Can measure with a ruler to the nearest inch
- Knows that plants are living things that need water and light
- Can write a short sentence about something observed

MASTERY CHECKLIST

- I can name the root, stem, leaf and flower of a plant and tell the job of each.
- I can explain how water travels from the roots, up through the xylem, and out of the leaves.
- I can describe a leaf by its shape, edge, veins, and simple or compound, and use a key to name it.
- I can set up a fair test, naming what I change, what I keep the same and what I measure.
- I can tell how George Washington Carver used peanuts and crop rotation to help the soil and the farmers.

OPTIONAL BOOKS AND RESOURCES

- **George Washington Carver National Monument (National Park Service)** (<https://www.nps.gov/gwca/>): Free. The park’s website has Carver’s life story, photographs and learning pages for families. If you live near southwest Missouri, the park itself is a wonderful field trip for Lesson 1.4.
- **Bartram’s Garden, Philadelphia** (<https://www.bartramsgarden.org/>): Free to visit the grounds. John Bartram’s garden by the Schuylkill River is still growing. The website

tells the Bartram family story for Lesson 1.1.

- **Biodiversity Heritage Library** (<https://www.biodiversitylibrary.org/>): Free. A huge online library of old natural history books with their pictures. A parent can search for Fuchs's 1542 herbal or Linnaeus to page through the original plant drawings with a child.

1.1 ROOT, STEM, LEAF, FLOWER ★

OBJECTIVES

- Name the four main parts of a plant (root, stem, leaf, flower) and tell the job of each.
- Sort common vegetables by the plant part we eat and measure plant parts in inches and centimeters.
- Tell how John Bartram became one of America's first great plant collectors.

Warm-up. Set out a carrot (with its leafy top if you can find one), a head of broccoli, a leaf of lettuce and a potato. Look at each one closely. Which one do you think grew under the ground? Which one soaked up sunlight? Which one was getting ready to bloom? Write down your guesses now and check them at the end of the lesson.

Video. Coming soon. Parts of a plant and what each part does (roots, stems, leaves, flowers) for kids; search SciShow Kids, Homeschool Pop (Alternate), Smithsonian Gardens, Moody Science classics, and time-lapse nature footage of roots and seedlings growing.

KEY TERMS

root

The part of a plant that grows down into the soil, holds the plant in place and soaks up water and minerals.

stem

The part of a plant that holds it up and carries water and food between the roots and the leaves.

leaf

The flat green part of a plant that uses sunlight to make food for the plant.

flower

The part of a plant that makes seeds so new plants of the same kind can grow.

photosynthesis

The way a green leaf makes sugar for food from sunlight, water and a gas in the air called carbon dioxide. The word means "putting together with light."

CORE IDEAS

The story. In 1728 a Pennsylvania farmer named John Bartram bought a farm beside the Schuylkill River, near Philadelphia, and began to plant a garden of wild plants. A French writer who visited American farms later told a story about how it all began. One day, as Bartram was plowing, he stopped to look closely at a small daisy. He felt sorry that he had plowed under so many flowers without knowing anything about them. So he bought books, learned enough Latin to read them, and began to study every plant he could find. Before long

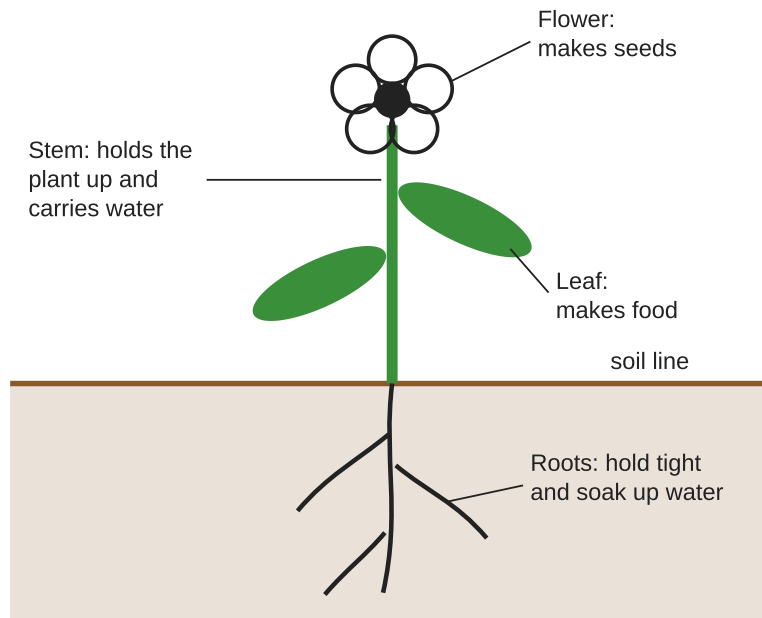
he was traveling through woods and mountains from Lake Ontario to Florida, digging up plants, gathering seeds and shipping them in boxes across the ocean to gardeners in England. In 1765 King George III named him Royal Botanist for North America.

How they figured it out. Bartram did not just snip off pretty flowers. To keep a plant alive on a long trip by sailing ship, he had to dig it up whole, roots and all, and pack it with care. A plant collector learns every part of a plant, because each part does a job the plant cannot live without. Botanists (scientists who study plants) found that almost all the plants we see, from a dandelion in the lawn to a tall oak tree, are built from the same four main parts: **roots, stems, leaves and flowers.**

The big idea. Roots grow down into the soil. They hold the plant tight so wind and rain cannot pull it out, and they soak up water and minerals (nourishment that comes from broken-down rock in the soil). Some roots, like carrots, also store food. The stem holds the plant up toward the light. Inside it are tiny tubes that carry water up from the roots and carry food to every part of the plant. Leaves are the plant's kitchens. Using sunlight, water and a gas from the air called carbon dioxide, a green leaf makes sugar for food. This is called **photosynthesis**. Flowers make seeds. When pollen from one flower reaches another, part of the flower grows into a fruit with seeds inside, and each seed can grow into a new plant of the same kind.

Try it and see. You eat all four parts! A carrot or a radish is a root. Asparagus is a stem, and a potato is a stem too, one that grows underground; its "eyes" are buds that can sprout new shoots. Lettuce and spinach are leaves. Broccoli and cauliflower are bunches of tiny flower buds, picked before they open. Next time you help in the kitchen, ask, "Which part of the plant am I eating?"

God's handiwork. On the third day of creation God told the earth to bring forth grass, herbs and fruit trees, each with its seed in itself (Genesis 1:11). Every part of a plant works with the others, like players on a team. The roots send water up to the leaves, the leaves send sugar down to the roots, and the flowers make seeds so there will be plants of the same kind next year. Bartram looked closely at one little daisy and found a lifetime of things to learn. You can do the same.



The four main parts of a plant and their jobs.

PICTURE STUDY



Turkish Corn (Maize), from De historia stirpium, Leonhart Fuchs, with artists Albrecht Meyer, Heinrich Füllmaurer and Veit Rudolph Speckle, 1542 · Woodcut in a printed book (some copies were colored by hand) · Printed in Basel, Switzerland; copies are kept in many libraries

Photo: Wellcome Collection · CC BY 4.0 (<https://creativecommons.org/licenses/by/4.0>) · via Wikimedia Commons

Leonhart Fuchs was a German doctor who wanted people to know exactly which plants were which, because doctors used plants as medicines. In 1542 he published a large book of plants filled with more than five hundred pictures. He asked his artists to draw each plant

whole, from roots to flowers, so a reader could match the picture to a real plant. He was so proud of their work that he printed their portraits in the book.

This picture is one of the first printed pictures of corn in Europe. Corn had come across the ocean from the Americas, but Fuchs thought it came from the East, so he called it “Turkish corn.” Even when a scientist gets a name wrong, a careful drawing of what he sees can still be right.

Look closely

- Start at the bottom. Find the roots. Is there one thick root, or many thin ones?
- Follow the stem up. Can you see the joints where the leaves grow out?
- Look at the long leaves. Do the lines (veins) on them run side by side, or branch like a net?
- Find the tassel at the top and the ears with their silk. Both are flower parts of the corn plant.

Talk about it

1. Why do you think Fuchs wanted his artists to show the roots as well as the flowers?
2. Which part of the corn plant do people eat? Which plant part does it come from?
3. If you drew a plant for a book, what would you be careful to show?

Safety first. Ask permission before digging up any plant, and dig only common weeds. Wear garden gloves, and learn to spot poison ivy (“leaves of three, let it be”) before you start. Never taste a wild plant. Wash your hands when you finish.

EXPERIMENT: WEED DIG: HOW LONG ARE THE ROOTS?

Scientists start with a question. Ours is: **Is the part of a weed below the ground longer or shorter than the part above the ground?** You will dig up three common weeds whole, the way John Bartram dug up plants to ship to England, then measure them and record what you find. Last of all you will press one and label its parts.

You will need

- A garden trowel and garden gloves
- Three common weeds from a lawn or garden bed, such as a dandelion, a clover and a clump of grass
- A bucket of water for gently rinsing soil off the roots
- A ruler marked in inches and centimeters
- Paper towels, a heavy book and a sheet of card stock
- Clear tape, a pencil and your science notebook

Steps

1. **Predict.** In your notebook write: "I think the roots will be (longer / shorter / the same) as the part above the ground."
2. Dig in a circle around each weed, not straight down on top of it, so you lift out as much root as you can. Swish the roots gently in the bucket of water to wash off the soil.
3. Lay each plant on a paper towel. Find the **soil line**, the place where the plant came out of the ground. Roots are below it; stem and leaves are above it.
4. **Measure.** Measure the longest root from the soil line to its tip. Then measure from the soil line to the top of the tallest leaf or flower. Write both numbers in inches, then measure again in centimeters.
5. Make a table with four columns: Plant, Roots (inches), Above ground (inches), Which is longer?
6. **What we change:** the kind of weed. **What we keep the same:** we dig each one the same careful way and always measure from the soil line. **What we measure:** the two lengths.
7. Lay your best plant flat between paper towels inside a heavy book for about a week. When it is dry, tape it to card stock and label the root, stem, leaf and (if it has one) flower.
8. **Conclude.** Write one or two sentences: Was your prediction right? Did any root snap off, so that your measurement is too short?

Tips

- A dandelion has one long, thick root called a taproot. It often snaps, so dig deep and slow.
- Grass has many thin roots spread out like a mop. Both kinds of roots hold a plant tight in different ways.
- There are about 2½ centimeters in one inch, so each centimeter number should be about two and a half times its inch number.

Check your work

- I measured from the soil line and recorded inches and centimeters.
- I compared my results with my prediction.
- I pressed a plant and labeled its root, stem, leaf and flower.

NATURE NOTEBOOK

1. Draw your dandelion or clover from the roots to the top. Label the root, stem, leaf and flower, and write one job beside each label.
2. Draw a carrot, a stalk of asparagus, a lettuce leaf and a head of broccoli. Under each, write which plant part it is.
3. Do what John Bartram did with the daisy: look closely at one flower for five minutes and draw everything you notice. Write the date and where you found it.

From history. John Bartram was a friend of Benjamin Franklin, and in 1743 the two of them helped start the American Philosophical Society in Philadelphia, a club for people who wanted to study nature and science. Bartram's son William grew up helping in the garden and became a famous naturalist and artist himself. The garden by the Schuylkill River is still growing today, and it is often called the oldest surviving botanic garden in North America.

WORKED EXAMPLES

Example 1. A bean seedling has a root 4 inches long and a stem with leaves that is 6 inches tall. How long is the whole plant? Which part is longer, and by how much? About how many centimeters long is the whole plant? (1 inch is about $2\frac{1}{2}$ centimeters.)

1. Add the two parts to find the whole plant: 4 inches + 6 inches = 10 inches.
2. Compare: 6 is more than 4, so the part above the ground is longer.
3. Subtract to find how much longer: 6 inches – 4 inches = 2 inches.
4. Change to centimeters: every 2 inches is about 5 centimeters. 10 inches is five groups of 2 inches, so $5 + 5 + 5 + 5 + 5 = 25$ centimeters.

Answer: The whole plant is 10 inches long (about 25 centimeters). The part above the ground is 2 inches longer than the root.

Example 2. A grocery bag holds a carrot, a radish, a potato, a bundle of asparagus, a head of lettuce, a bunch of spinach, a cabbage, a head of broccoli and a head of cauliflower. Sort them by plant part and count how many are in each group.

1. Roots grow down and store food: carrot, radish. That is 2.
2. Stems hold up the plant or, underground, carry buds ("eyes"): asparagus, potato. That is 2.
3. Leaves are the flat food-makers: lettuce, spinach, cabbage. That is 3.
4. Flowers come as bunches of flower buds: broccoli, cauliflower. That is 2.
5. Check the total: $2 + 2 + 3 + 2 = 9$, the same as the number of foods in the bag.

Answer: Roots 2 (carrot, radish); stems 2 (asparagus, potato); leaves 3 (lettuce, spinach, cabbage); flowers 2 (broccoli, cauliflower).

PRACTICE

1. **EASY** Name the four main parts of a plant. Which part makes food?
2. **EASY** Which part of a plant makes seeds?
3. **MEDIUM** A potato grows under the ground, but it has "eyes" that sprout new shoots. Is a potato a root or a stem? How do you know?

4. **MEDIUM** A dandelion has a root 8 inches long. The part above the ground is 5 inches tall. Which part is longer, and by how much? How long is the whole plant?
5. **HARD** Three bean plants grew on a sunny windowsill for one week. Plant A grew 4 inches, Plant B grew 6 inches and Plant C grew 5 inches. Which plant grew the most? List them from most to least. How many inches did they grow all together? About how many centimeters is 4 inches?
6. **CHALLENGE** Someone picks a daisy and leaves it on the table with no water. By evening it is drooping. In two or three sentences, explain which plant part is missing and why the flower droops.

COMMON MISTAKES

- Thinking plants get their food from the soil. Plants make their own food (sugar) in their leaves using sunlight; from the soil they take water and minerals.
- Thinking everything that grows underground is a root. A potato is an underground stem, and an onion is a bulb made of thick, stored-up leaves.
- Thinking flowers are only for looking pretty. A flower's main job is to make seeds.

Make it a game • Plant Part Freeze. A parent calls out a food (carrot, celery, broccoli, spinach, potato, cauliflower, asparagus, lettuce, radish). You freeze in the pose for that plant part: crouch low for a root, stand straight and tall for a stem, stretch your arms out flat for a leaf, or open your hands above your head like petals for a flower. Get it right to earn a point, and say the part's job for a bonus point. Watch out for tricky ones like the potato (a stem) and celery (a leaf stalk, which you will learn about in the next lesson; score it as either a stem or a leaf today)!

Scripture. "And 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, KJV)

From the very beginning God made plants with seeds "after his kind." A bean seed grows into a bean plant, never into an oak tree. The flower and its seeds carry each plant's kind on to the next year.

Practice answers

1. Root, stem, leaf and flower. The leaf makes food.
2. The flower. Part of the flower grows into a fruit that holds the seeds.
3. A stem (an underground stem). The eyes are buds, and buds grow on stems, not on roots.
4. The root is longer, by 3 inches ($8 - 5 = 3$). The whole plant is 13 inches long ($8 + 5 = 13$).
5. Plant B grew the most. Order: B (6 inches), C (5 inches), A (4 inches). All together: $4 + 6 + 5 = 15$ inches. 4 inches is about 10 centimeters.
6. The roots are missing, so nothing is soaking up water and sending it up the stem. The leaves and petals keep losing water into the air, so they go limp and droop. If the stem is put in a glass of water soon, it can drink again and the flower may perk up.

1.2 CELERY IN COLORED WATER

OBJECTIVES

- Explain how water travels from a plant's roots, up through tiny tubes, and out of its leaves.
- Set up a fair test with celery and colored water, naming what we change, what we keep the same and what we measure.
- Read a data table and a bar graph of how far the color climbed, using inches and centimeters.

Warm-up. Put a drinking straw in a glass of water and sip slowly. Watch the water climb up the straw. Now put your finger over the top of the straw and lift it out. What happens to the water inside? Talk about this: a plant has no mouth to sip with, so how could water get from its roots all the way up to its top leaves?

Video. Coming soon. Celery and white carnations in colored water, how water moves up a plant stem (xylem and transpiration) for kids; search SciShow Kids, Science Max, Homeschool Pop (Alternate), Smithsonian Gardens, and time-lapse footage of flowers changing color.

KEY TERMS

absorb

To soak up, the way a sponge soaks up water. Roots absorb water from the soil.

xylem

(ZY-lum) Tiny tubes inside roots, stems and leaves that carry water up through a plant, like a bundle of very thin drinking straws.

transpiration

The way a plant lets water out of its leaves into the air as an invisible gas called water vapor. As water leaves, more is pulled up from below.

leaf stalk

The narrow part that joins a leaf to the stem. The celery “stalk” we eat is really a big, thick leaf stalk.

CORE IDEAS

The story. In the village of Teddington, near London, there lived a minister named Stephen Hales who loved to ask questions about God's creation and then measure the answers. In 1727 he published a book called *Vegetable Staticks*, full of experiments on how water moves through plants. In one, he planted a sunflower in a pot and covered the soil with a lid so no water could dry out of the dirt. Then he weighed the pot and plant, morning and evening,

day after day. The pot kept getting lighter. Since the soil was covered, the water had to be leaving through the plant itself, out of its leaves.

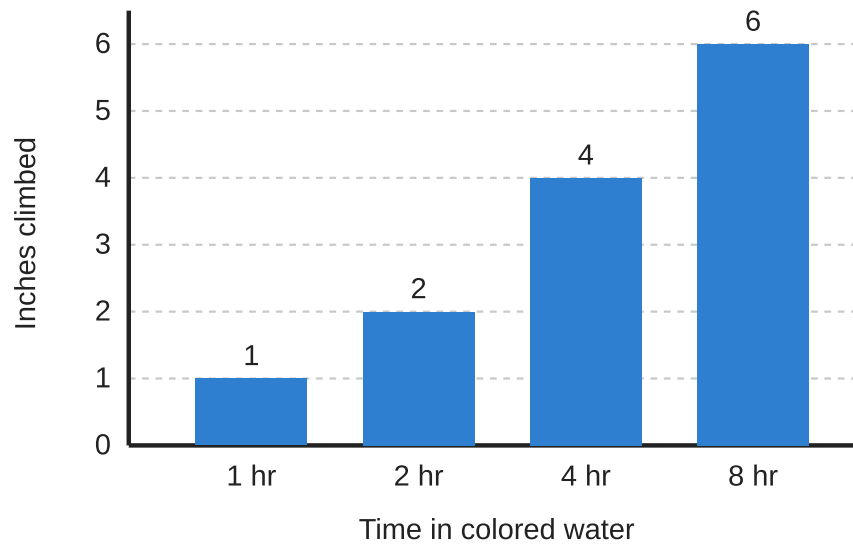
How they figured it out. Hales could not see water moving inside a stem, so he found ways to measure it. Weighing told him how much water left the plant. He also fastened glass tubes to the cut stems of grapevines in the spring and watched the sap push up inside the tubes. Today we can do an easier test that lets us *see* the path of the water. Stand a stalk of celery in water with food coloring, and the color travels up with the water, showing exactly where it goes.

The big idea. Roots **absorb** water from the soil. The water travels up through tiny tubes called **xylem**, which run like bundles of thin straws through the roots, the stem and the veins of every leaf. Leaves have tiny openings, far too small to see without a microscope, and water slips out of them into the air as water vapor. This is called **transpiration**. As water leaves the top of the plant, it pulls more water up behind it, the way your sipping pulls water up a straw. Here is a surprise: the celery stalk we eat is really a thick **leaf stalk**, and the true stem of celery is the short, pale base where all the stalks join. A leaf stalk has the same water tubes, so it works perfectly for our test.

Try it and see. When you cut across a celery stalk that has stood in colored water, you will see a row of colored dots near the outside curve. Each dot is a bundle of water tubes. The stringy threads you sometimes pull out of celery when you bite it are those same bundles. White carnations work too: in blue water, the edges of the petals slowly turn blue, which proves the water has climbed all the way to the flower.

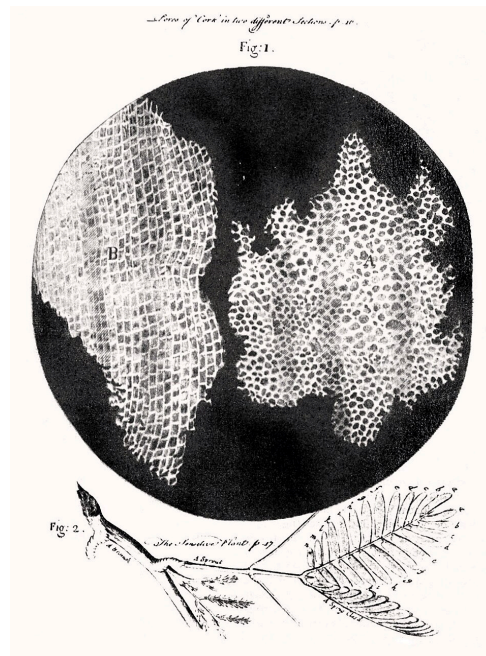
God's handiwork. No plant has a heart or a pump, yet the tallest redwood trees in California lift water more than 350 feet into the air, higher than a thirty-story building. Leaves, tubes and roots working together do it quietly, every sunny day. The Bible describes a righteous man as "a tree planted by the rivers of water" whose "leaf also shall not wither" (Psalm 1:3). A tree with its roots near water stays green because of the very path you will watch today.

How Far the Color Climbed



One family's celery results: inches the blue color climbed after each time.

PICTURE STUDY



Cork Cells, from Micrographia (Observation 18), Robert Hooke, 1665 · Engraving in a printed book · Published in London for the Royal Society; copies are kept in many libraries

Robert Hooke was an English scientist who built one of the best microscopes of his day. He cut a slice of cork, the bark of a kind of oak tree, so thin that light could shine through it, and looked at it under his lenses. He saw that it was made of tiny boxes, row after row, like the cells of a honeycomb. He called them *cells*, and that is the word scientists still use today.

Hooke wondered how a living plant's juices could move through such tiny spaces. You will ask the same kind of question when you cut a thin slice of celery and look at it with a magnifying glass.

Look closely

- Find the tiny boxes. Are they all the same size, or do some look bigger than others?
- Look for the two different slices. One was cut one way through the cork, and the other was cut a different way. How do the boxes look different?
- Cork is the bark of a kind of oak tree. Press a real cork stopper with your thumb. How might millions of tiny air-filled boxes make cork springy and light enough to float?

Talk about it

1. Why did Hooke need to cut his slice so very thin?
2. What do you think you will see when you look at a thin slice of celery with a magnifying glass?

Safety first. An adult should do all cutting with the knife. Food coloring stains clothes, skin and counters, so wear an old shirt and work on a tray or newspaper. Do not drink the colored water after it has stood out overnight. Wipe up spills so no one slips.

EXPERIMENT: DO LEAVES HELP CELERY DRINK?

Our question: **Does a celery stalk with its leaves pull colored water up higher than a stalk with its leaves cut off?** If Stephen Hales was right that water leaves through the leaves, the leafy stalk should drink faster. Let's test it fairly.

You will need

- Two fresh celery stalks from the same bunch, both with leafy tops
- Two clear glasses or jars of the same size
- Water, a measuring cup and blue or red food coloring
- A ruler marked in inches and centimeters
- A knife (for an adult only) and a cutting board
- A magnifying glass, your science notebook and a pencil

Steps

1. **Predict.** Write: "I think the stalk (with leaves / without leaves) will pull the color up higher, because ..."
2. An adult trims the bottom of both stalks so each is 8 inches long from the cut end to where the leaves begin. Then the adult cuts all the leaves off one stalk.
3. Pour $\frac{1}{2}$ cup of water (about 120 milliliters) into each glass. Add 10 drops of food coloring to each glass and stir.

4. **What we change:** leaves on or leaves off. **What we keep the same:** the same bunch of celery, the same length, the same glasses, the same amount of water and coloring, the same spot in the room. **What we measure:** how many inches the color climbs.
5. Stand one stalk in each glass, cut end down. Set both glasses together in a bright spot (not in hot sun). Write the time.
6. After 1 hour, 2 hours and 4 hours, look at the stalks from the inside curve, where you can often see colored lines, and look at the leaves. Write what you see each time.
7. The next morning, an adult cuts each stalk into 1-inch pieces, starting at the bottom. Count how many pieces show colored dots. That is how many inches the color climbed. Write it in your table, then change it to centimeters (every 2 inches is about 5 centimeters).
8. Look at a thin slice with the magnifying glass and draw the dots. **Conclude:** Which stalk drank higher? Was your prediction right?

Tips

- Dark blue and red show up best. Yellow is hard to see.
- If the celery is limp, stand it in plain water in the refrigerator for an hour first so it starts the test fresh.
- A white carnation or a white daisy from the store makes a beautiful extra test: the petals take on the color.

Check your work

- I named what I changed, what I kept the same and what I measured.
- I recorded my observations at each time and measured the color in inches and centimeters.
- I can explain what the colored dots inside the celery are.

NATURE NOTEBOOK

1. Draw a slice of celery as you see it through the magnifying glass. Color in the dots and label them “water tubes (xylem).”
2. Draw two celery stalks side by side, one with leaves and one without, and color each one as high as the color climbed. Write the inches beside each.
3. Draw Stephen Hales’s sunflower in its covered pot, with arrows showing where the water went: up from the roots, through the stem and out of the leaves.

From history. Stephen Hales did not stop with plants. In 1733 he wrote about measuring the pressure of blood inside the body of a horse, the first time anyone had measured blood pressure. He also designed large bellows called ventilators to blow fresh air into ships and prisons, which helped keep sailors and prisoners healthier. All his life he kept preaching in his little church at Teddington.

WORKED EXAMPLES

Example 1. A family stood a leafy celery stalk in blue water and checked how far the color had climbed. Their table: 1 hour, 1 inch; 2 hours, 2 inches; 4 hours, 4 inches; 8 hours, 6 inches. How far had the color climbed after 4 hours? How much farther did it climb between 4 hours and 8 hours? About how many centimeters is 6 inches?

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

1. Find 4 hours in the table (or the third bar on the graph). The color had climbed 4 inches.
2. At 8 hours it was 6 inches. Subtract: $6 \text{ inches} - 4 \text{ inches} = 2 \text{ inches}$ farther.
3. Change to centimeters: 2 inches is about 5 centimeters. 6 inches is three groups of 2 inches, so $5 + 5 + 5 = 15 \text{ centimeters}$.

Answer: 4 inches after 4 hours; 2 inches farther between 4 and 8 hours; 6 inches is about 15 centimeters.

Example 2. In the leaves-on and leaves-off test, the next morning the leafy stalk had colored dots in 7 of its 1-inch pieces. The stalk with no leaves had colored dots in 3 pieces. Which drank higher, and by how much? Name what was changed, what was kept the same and what was measured. What does the result tell us?

1. Leafy stalk: 7 inches. No-leaf stalk: 3 inches. 7 is more than 3, so the leafy stalk drank higher.
2. Subtract: $7 \text{ inches} - 3 \text{ inches} = 4 \text{ inches}$ higher.
3. Changed: leaves on or off. Kept the same: celery bunch, length, glass, water, coloring, place. Measured: inches the color climbed.
4. Because only the leaves were different, the leaves must be what made the difference. Water leaving through the leaves (transpiration) pulls more water up the tubes.

Answer: The leafy stalk drank 4 inches higher. Leaves help pull water up the plant.

PRACTICE

1. **EASY** What are the tiny tubes that carry water up through a plant called?
2. **EASY** Where does most of the water leave a plant, and what is it called when it does?
3. **MEDIUM** You put 8 fluid ounces of colored water in a glass with a celery stalk. The next morning 6 fluid ounces are left. How much water is gone? (A little of it dried into the air from the top of the glass, and the rest went into the celery.) One fluid ounce is about 30 milliliters. About how many milliliters is gone?

4. **MEDIUM** A white carnation stands in blue water. The next day the edges of its petals are blue. What does this observation tell you?
5. **HARD** Two celery stalks were tested for 4 hours. The one in warm water had color 5 inches up. The one in cold water had color 3 inches up. Which climbed faster, and by how many inches? Name two things that must be kept the same for this to be a fair test.
6. **CHALLENGE** Stephen Hales covered the soil in his sunflower pot, yet the pot got lighter every day. In two or three sentences, explain where the water went and why covering the soil was important.

COMMON MISTAKES

- Thinking a plant drinks mostly through its leaves. Plants take in water mostly through their roots; leaves are where water leaves.
- Thinking the celery stalk is the stem. It is really a thick leaf stalk; celery's true stem is the short base where the stalks join. Both carry water the same way.
- Thinking a plant has a heart or pump like ours. Water is pulled up as it leaves through the leaves, with help from the roots pushing from below.

Make it a game · Xylem Relay. Set a bowl of water on the floor (the roots) and an empty cup on a chair across the room (the leaves). Each player is a water tube. Carry one spoonful of water at a time from the roots to the leaves without spilling. Each time you pour your spoonful into the cup, shout "Transpiration!" and pretend to puff the water out into the air. Use a timer: how many spoonfuls can your family move in two minutes? Play again and try to beat your score.

Scripture. "And he shall be like a tree planted by the rivers of water, that bringeth forth his fruit in his season; his leaf also shall not wither; and whatsoever he doeth shall prosper." (Psalm 1:3, KJV)

A tree by the river stays green because its roots can always reach water, and its xylem carries that water up to every leaf. The psalm says a person who delights in God's word is like that tree.

Practice answers

1. Xylem (water tubes).
2. Through tiny openings in the leaves, as water vapor. This is called transpiration.
3. 2 fluid ounces are gone ($8 - 6 = 2$). That is about 60 milliliters ($30 + 30 = 60$).
4. The water traveled all the way from the bottom of the stem, up through the water tubes, into the flower's petals.
5. The warm-water stalk climbed faster, by 2 inches ($5 - 3 = 2$). Keep the same: for example, celery from the same bunch, the same length of stalk, the same amount of water and coloring, the same leaves, and the same amount of time.
6. The roots took up the water, it traveled up the stem, and it left through the leaves as water vapor (transpiration). Covering the soil kept water from drying out of the dirt, so Hales knew

the weight he lost had gone out through the plant.

1.3 LEAF SHAPES

OBJECTIVES

- Name the parts of a leaf (blade, petiole, veins) and describe leaves by shape, edge, vein pattern, and simple or compound.
- Use a simple sorting key to identify a leaf, and measure leaves in inches and centimeters.
- Tell how Carl Linnaeus gave scientists a shared set of words for describing plants.

Warm-up. Go outside or to a window and find three different leaves (a houseplant, a tree, grass). Lay them side by side. In five minutes, list as many ways as you can that they are different: size, shape, color, edges, lines, feel. Which difference would help you most if you had to tell a friend over the phone which leaf you picked?

Video. Coming soon. How to identify trees by leaf shape (simple and compound leaves, lobed and toothed edges, parallel and net veins) for kids; search Smithsonian Gardens, state forestry or extension service channels, SciShow Kids, Homeschool Pop (Alternate), and nature-walk footage of leaf identification.

KEY TERMS

blade

The wide, flat part of a leaf that catches sunlight.

petiole

(PET-ee-ole) The leaf stalk that joins the blade to the stem or twig.

vein

A line in a leaf made of tiny tubes that bring water in and carry food out. Veins also hold the blade open like the ribs of an umbrella.

lobe

A rounded or pointed part that sticks out from the edge of a leaf, like the fingers of a maple leaf or the bumps of an oak leaf.

compound leaf

A leaf whose blade is split into smaller parts called leaflets, all on one petiole, like a clover. A simple leaf has just one blade.

CORE IDEAS

The story. In the university town of Uppsala, Sweden, a professor named Carl Linnaeus took his students on botany walks through the summer countryside, sometimes with hundreds of students following him, with horns and drums. They collected plants, studied them and wrote down what they found. In 1751 Linnaeus published a book called *Philosophia Botanica*, whose Latin title means the philosophy of botany. In it were pages of small drawings of

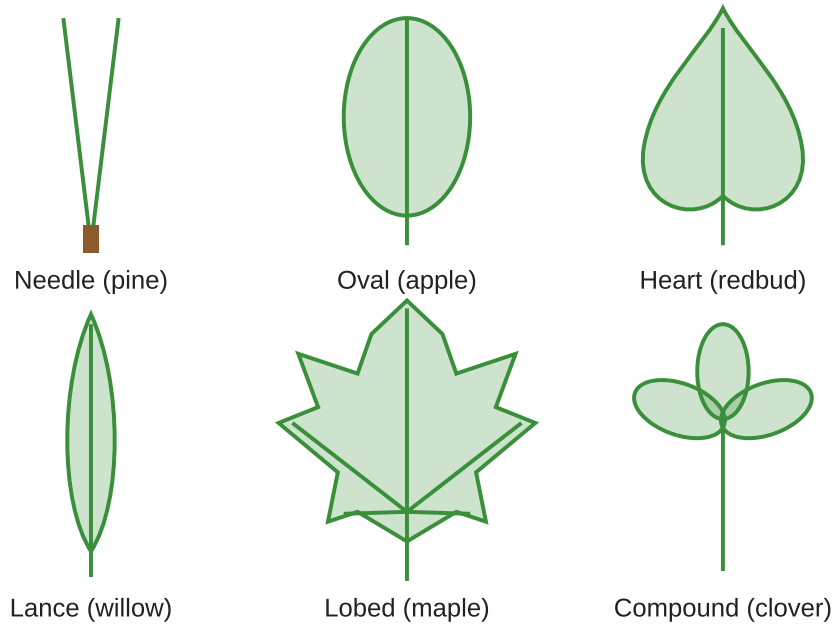
leaves, each with its own name: heart-shaped, spear-shaped, oval, needle-shaped and many more. Two years later, in 1753, he gave every plant he knew a two-part name, the kind scientists still use today.

How they figured it out. Before Linnaeus, botanists in different countries described the same plant in different ways, and it was hard to know if they were talking about the same thing. Linnaeus decided to look at the same features every time and give each one a name. His names were in Latin, the language scholars everywhere could read. *Cordate* means heart-shaped, from the Latin word for heart. *Lanceolate* means shaped like the tip of a lance, a long spear. A botanist in Sweden and a botanist in Pennsylvania could now read the same words and picture the same leaf.

The big idea. A leaf has a flat **blade**, a stalk called the **petiole**, and **veins**, which carry water in and food out (the same tubes you saw in the celery). To describe a leaf, look at four things. *Shape*: needle (pine), oval (apple), heart (redbud), spear or lance (willow). *Edge*: smooth, toothed like a saw (elm, birch) or **lobed** (maple, oak). *Veins*: parallel, running side by side (grass, corn, lilies), or netted, branching like a net (maple, oak, bean). *Simple or compound*: a simple leaf has one blade; a **compound leaf** is split into leaflets, like a clover with three. To tell a leaflet from a whole leaf, look for the bud. A bud sits where the whole leaf joins the twig, never at the base of a single leaflet.

Try it and see. On a leaf walk you may find maple leaves with pointed lobes, white oak leaves with rounded lobes, pine needles in bundles, and grass blades with parallel veins. Pick ten leaves from one tree and lay them in a row. They will not all be the same size, and no two will match perfectly. But every leaf on an oak tree is an oak leaf, and every leaf on a maple is a maple leaf. Each tree's leaves come "after his kind."

God's handiwork. Jesus told His listeners to "consider the lilies of the field, how they grow" (Matthew 6:28). To consider means to look carefully and think. Linnaeus believed that studying the order in creation was a way to honor the Creator who made it. When you learn the names of leaf shapes, you are noticing the variety and the order God put into the plants all around you.



Six leaf shapes to look for on a leaf walk.

PICTURE STUDY



Columbine, Albrecht Dürer, 1526 · Watercolor and gouache on paper · Albertina, Vienna, Austria

Albrecht Dürer was a German artist who lived in the city of Nuremberg. Most painters of his day painted plants only as small decorations, but Dürer painted single plants and patches of meadow as carefully as a scientist, leaf by leaf. His watercolors of plants are still studied by artists and botanists alike.

The columbine is a wildflower whose name comes from the Latin word for dove, because its flower was thought to look like a little group of doves. Look closely at its leaves: they are split into leaflets, and each leaflet has rounded lobes.

Look closely

- Find the leaves. Is each one a simple leaf with one blade, or a compound leaf split into leaflets?
- Look at the edges of the leaflets. Are they smooth, toothed or lobed?
- Find the flowers. Do they point up to the sky or nod down toward the ground?
- Find the thin stems. How did Dürer show that they are thin and tall?

Talk about it

1. Why would a careful painting of a plant help a botanist?
2. If you had to describe a columbine leaf using this lesson's words, what would you say?
3. What is the hardest part of drawing a leaf exactly as it looks?

Safety first. Learn to spot poison ivy before your leaf walk. It has compound leaves with three leaflets ("leaves of three, let it be") and can grow as a small plant, a shrub or a hairy vine on trees. Pick only a few leaves, with permission, and never taste a leaf or berry. Wash your hands after the walk.

EXPERIMENT: SUN LEAVES AND SHADE LEAVES

Our question: **On the same tree, are leaves from the sunny side a different size from leaves in the shade?** You will collect, measure and compare. Then you will make leaf rubbings and build your own leaf key, the way Linnaeus gave every leaf shape a name.

You will need

- One tree or large bush with leaves you can reach, plus a few other trees nearby
- Two paper bags labeled SUN and SHADE
- A ruler marked in inches and centimeters
- Plain paper and crayons with the paper peeled off (for rubbings)
- Your science notebook and a pencil

Steps

1. **Predict.** Write: "I think the (sun / shade) leaves will be bigger, because ..."
2. Pick 5 leaves from the sunny outside of the tree and put them in the SUN bag. Pick 5 leaves from the shady inside or shady side of the same tree and put them in the SHADE bag.
3. **What we change:** sun or shade. **What we keep the same:** the same tree, leaves from about the same height, and the same way of measuring. **What we measure:** the length of each blade.

4. Measure each blade from where it meets the petiole to its tip, in inches. Do not count the petiole. Then measure in centimeters.
5. Make a table with two columns, Sun and Shade, and write all ten lengths. Find the longest and shortest in each column.
6. **Conclude.** Which group was longer in most cases? Was your prediction right?
7. Now collect one leaf from four or five different trees. Lay each under paper, vein side up, and rub with the side of a crayon. Under each rubbing write its shape, edge, vein pattern, and simple or compound.
8. Make a yes-or-no key for your leaves, like the one in the worked example below, and test it on a family member.

Tips

- Many trees grow larger, thinner leaves in the shade, where there is less light to catch, but trees vary, so trust your measurements.
- The underside of a leaf has bumpier veins and makes the best rubbing.
- If a leaf has many leaflets, look for the bud where the whole leaf joins the twig. That tells you it is one compound leaf.

Check your work

- I measured ten blades in inches and centimeters and recorded them in a table.
- I described each leaf by shape, edge, veins, and simple or compound.
- My leaf key works when someone else uses it.

NATURE NOTEBOOK

1. Draw one leaf large and label its blade, petiole, veins and edge.
2. Draw a leaf with parallel veins and a leaf with net veins side by side. Name a plant for each.
3. Draw a compound leaf, such as clover, rose or ash. Count the leaflets, and draw an arrow to where the bud would be.

From history. After Linnaeus died, a young English naturalist named James Edward Smith bought his whole collection of pressed plants, books and letters in 1784 and shipped it to London. In 1788 Smith helped found the Linnean Society of London, a society for the study of nature that still takes care of the collection today. Linnaeus's garden in Uppsala has been replanted and can still be visited.

WORKED EXAMPLES

Example 1. Use this leaf key to name a leaf that is not a needle, has veins that branch like a net, is split into three separate leaflets, and has no lobes.

1. Is the leaf a thin needle? Yes: pine. No: go to 2.
2. Do the veins run side by side (parallel)? Yes: corn. No: go to 3.
3. Is the leaf split into separate leaflets? Yes: clover. No: go to 4.
4. Are the lobes pointed? Yes: maple. No (rounded): white oak.

1. Step 1: It is not a needle, so it is not pine. Go to 2.
2. Step 2: The veins branch like a net, not side by side, so it is not corn. Go to 3.
3. Step 3: It is split into three separate leaflets. The answer is Yes, so the key says clover. We stop here.

Answer: Clover. A key asks one yes-or-no question at a time until only one answer is left.

Example 2. You measure the blades of five maple leaves from one tree: 3 inches, 4 inches, 4 inches, 5 inches and 4 inches. Which is the longest and which is the shortest? How much longer is the longest than the shortest? Which length came up most often? About how many centimeters is that length?

1. Longest: 5 inches. Shortest: 3 inches.
2. Subtract: 5 inches – 3 inches = 2 inches.
3. Count each length: 3 inches once, 4 inches three times, 5 inches once. 4 inches came up most often.
4. Change to centimeters: 2 inches is about 5 centimeters, so 4 inches is about 5 + 5 = 10 centimeters.

Answer: Longest 5 inches, shortest 3 inches, a difference of 2 inches. The most common length is 4 inches, about 10 centimeters. The leaves vary in size, but they are all maple leaves.

PRACTICE

1. **EASY** What is the flat part of a leaf called? What is the leaf stalk called?
2. **EASY** Are pine needles leaves?
3. **MEDIUM** Each clover leaf has 3 leaflets. How many leaflets are on 4 clover leaves? Is a clover leaf simple or compound?
4. **MEDIUM** Grass has parallel veins. A maple leaf has net veins. Look at a corn leaf or remember the corn picture from Lesson 1.1. Which kind of veins does corn have?
5. **HARD** Three sun leaves from a tree measured 3, 4 and 3 inches. Three shade leaves from the same tree measured 5, 6 and 5 inches. Add each group. Which group was longer, and by how many inches all together? What might explain the difference?

6. **CHALLENGE** Use the key in Worked Example 1 to name this leaf: it is not a needle, it has net veins, it is all one piece, and its lobes are rounded. Then write one sentence explaining why it helps scientists everywhere to use the same leaf words.

COMMON MISTAKES

- Thinking pine needles are not leaves. Needles are leaves with a narrow shape.
- Counting each leaflet of a compound leaf as a separate leaf. Look for the bud: it sits only where the whole leaf joins the twig.
- Thinking every leaf on a tree is exactly the same size. Leaves on one tree vary in size, but they keep the same kind of shape.

Make it a game • Leaf Detective. One player secretly picks a leaf from the collection. The others take turns asking yes-or-no questions using this lesson's words: "Is it compound?" "Are the veins parallel?" "Is the edge toothed?" "Does it have lobes?" Each question that gets a "no" costs one point from 10. Name the leaf before your points run out to win, then switch places.

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 told people to look closely at the flowers of the field. God clothes the plants with more beauty than a king's robes, and He cares for His children even more. Studying leaves is one way to "consider" what God has made.

Practice answers

1. The blade. The petiole.
2. Yes. Pine needles are thin, needle-shaped leaves. They do the same job as other leaves: they make food from sunlight.
3. 12 leaflets ($3 + 3 + 3 + 3 = 12$). A clover leaf is compound.
4. Parallel veins. They run side by side along the long leaf, like grass.
5. Sun: $3 + 4 + 3 = 10$ inches. Shade: $5 + 6 + 5 = 16$ inches. The shade leaves were longer, by 6 inches all together ($16 - 10 = 6$). Leaves in the shade get less light, so many trees grow them bigger to catch more of it.
6. White oak. Explanation (any similar answer): When everyone uses the same words, a scientist in one country can read a description and picture exactly the same leaf as a scientist far away.

1.4 CARVER AND THE PEANUT

OBJECTIVES

- Tell how George Washington Carver helped farmers in the South rest and rebuild worn-out soil with peanuts and other crops.
- Name the parts of a peanut plant and explain how a peanut flower above the ground becomes a pod below it.
- Test foods for oil, record the results in a table and explain why peanuts and cowpeas help the soil.

Warm-up. Hold a peanut in its shell (if no one in your home has a peanut allergy; otherwise use a pea pod or a green bean). Shake it and listen. Guess how many seeds are inside. Now guess: did this peanut grow on a tree, on a bush, or under the ground? Write your guesses and check them during the lesson.

Video. Coming soon. George Washington Carver at Tuskegee, crop rotation and the peanut, and how peanut plants grow pods underground (peanut pegging time-lapse); search National Park Service (George Washington Carver National Monument), Tuskegee University, Smithsonian, Homeschool Pop (Alternate), Moody Science classics, and farm footage of a peanut harvest.

KEY TERMS

legume

(LEG-yoom) A plant in the pea and bean family that grows its seeds in pods. Peanuts, peas, beans and cowpeas are legumes.

crop rotation

Planting different crops in a field from year to year, instead of the same crop every year, so the soil can stay healthy.

root nodule

A little bump on the roots of a legume where tiny living things called bacteria take nitrogen, a plant food, from the air and leave it in the soil.

peg

The stalk that grows down from a peanut flower after it blooms and pushes into the soil, where the peanut pod forms.

seed leaf

One of the two thick halves inside a peanut or bean seed. Seed leaves store food for the baby plant.

CORE IDEAS

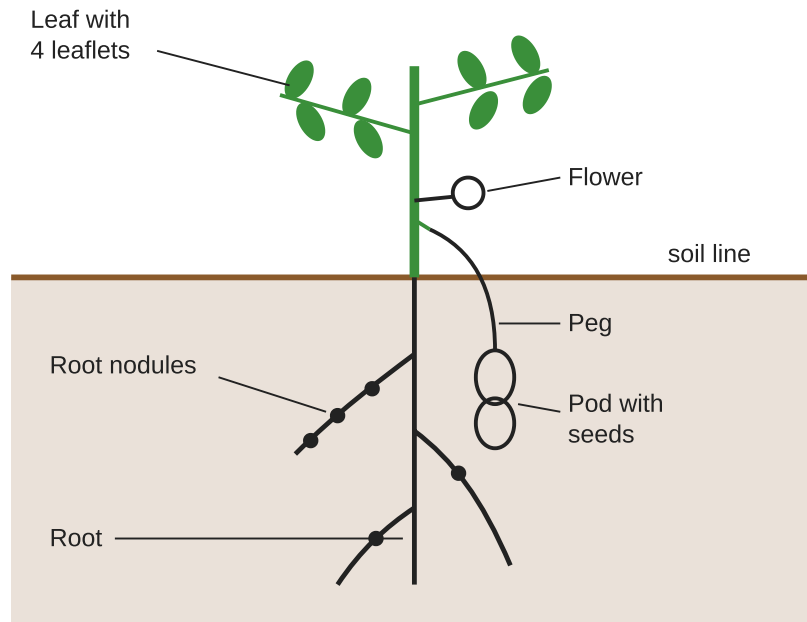
The story. In January 1921 a soft-spoken scientist from Alabama stood before a committee of the United States Congress in Washington, D.C. His name was George Washington Carver, and he had brought a box full of things made from peanuts. Peanut farmers wanted Congress to protect their crop, and Carver had been given ten minutes to explain why peanuts mattered. As he pulled out one product after another, the congressmen grew so interested that the chairman told him to keep going for as long as he liked. He spoke far longer than ten minutes.

How they figured it out. Carver was born into slavery on a farm near Diamond, Missouri, during the Civil War. As a boy he loved plants so much that neighbors called him “the plant doctor.” He studied plants at Iowa State College, and in 1896 Booker T. Washington invited him to teach at Tuskegee Institute in Alabama. There he found worn-out farms. Farmers had grown cotton in the same fields year after year, and the soil had grown poor. Carver taught **crop rotation**: plant cotton one year, then peanuts, cowpeas or sweet potatoes the next. Peanuts and cowpeas are **legumes**, and their roots grow little bumps called **root nodules**, where tiny living things take nitrogen, a plant food, from the air and leave it in the soil. In 1906 Carver even sent out a wagon fitted as a “movable school” to teach farmers right on their own land.

The big idea. The peanut plant shows all the parts you have learned. It has roots with nodules, a stem, and compound leaves with four leaflets each. It has small yellow flowers above the ground. After a flower blooms, a stalk called a **peg** grows down from it and pushes into the soil. Underground, the tip of the peg swells into a pod with seeds inside. So a peanut is not a nut and not a root: it is a seed in a pod, like a pea. Open a peanut seed and you will find two thick **seed leaves** full of stored food, oil and protein, and a tiny baby plant tucked at one end.

In the world today. Once farmers grew peanuts, they needed people to buy them, so Carver worked in his laboratory to find uses. In 1916 he published a booklet of 105 ways to prepare peanuts to eat, and over the years he listed about three hundred things that might be made from them. Most of these were experiments rather than products for sale. And no, he did not invent peanut butter; people were already making it before his work became famous. Today peanuts are an important crop across the South, and Georgia grows more than any other state.

God’s handiwork. Carver was a Christian who taught a Bible class for his students at Tuskegee for many years. He called his laboratory “God’s little workshop,” and he said he asked the Creator to show him the secrets hidden in the plants He made. Carver believed that every plant was made for a purpose and that a scientist’s job is to find it and use it to serve his neighbors.



A peanut flower blooms above the ground, but its pod grows below.

PICTURE STUDY



George Washington Carver, Standing in a Field, Frances Benjamin Johnston, 1906 · Photograph · Library of Congress, Washington, D.C.

Frances Benjamin Johnston was one of the first well-known women photographers in America. She visited Tuskegee Institute in Alabama and took many pictures of its teachers and students at work. In this photograph she shows George Washington Carver outdoors among growing plants, the place where he did so much of his teaching.

Carver taught that a farmer or scientist must look closely at plants in the field, not only in books. A photograph like this one lets us see him at work in the place he loved.

Look closely

- Find what Carver is holding in his hand. It is a piece of soil. Why would a plant scientist study soil so closely?
- Look at the field around him. What can you see growing or lying on the ground?
- Look at how Carver is dressed. Why do you think he dressed so neatly for a picture in a field?

Talk about it

1. If you could ask Carver one question about the soil in his hand, what would you ask?
2. Why might a photographer take a picture of a scientist outdoors instead of in a classroom?

Safety first. Peanut allergies can be very dangerous. If anyone in your home or group has a peanut allergy, do not use peanuts at all; use dried lima beans soaked overnight for the seed study and a spoonful of cooking oil for the oil test. Use only plain peanuts in the shell (raw or roasted) and wash hands and the table afterward. An adult should handle any stove or oven.

EXPERIMENT: CARVER'S PEANUT LAB: SEEDS AND OIL

Carver spent hours in “God’s little workshop” finding out what is inside a peanut. You will do two small experiments. First, open a peanut and find its parts. Second, test this question:

Which foods store oil? Oil leaves a see-through spot on brown paper that does not dry away, while water dries and disappears.

You will need

- 6 peanuts in the shell (see the safety note), or soaked lima beans
- A magnifying glass
- A brown paper grocery bag cut into a flat sheet
- Test foods: a peanut, a slice of apple, a slice of raw potato, a few drops of water, and a dab of butter
- A pencil, a centimeter ruler and your science notebook

Steps

1. **Part 1: Inside a peanut.** Count the seeds in each of your 6 pods and write the numbers. Find the shell (the pod), the thin papery seed coat, the two seed leaves, and at one end the tiny baby plant. Use the magnifying glass to look for its tiny first leaves.
2. **Part 2: Predict.** Write which test foods you think will leave an oil spot.
3. With a pencil, draw five circles on the brown paper and label them Peanut, Apple, Potato, Water and Butter.

4. Rub each food firmly in its own circle for about 10 seconds. Crush the peanut a little first so it rubs well. Put a few drops of water in the Water circle.
5. **What we change:** the kind of food. **What we keep the same:** the same paper, the same rubbing time, the same waiting time. **What we measure:** whether a spot is left and how wide it is.
6. Wait 1 hour so that any water can dry. Then hold the paper up to a window. A spot that light shines through means oil.
7. Measure the width of each spot in centimeters and record it in a table with three columns: Food, Spot after 1 hour? (yes / no), Width (cm).
8. **Conclude.** Which foods store oil? Why do you think a seed stores so much oil and food?

Tips

- Water is our control. It shows what a wet spot looks like after it dries, so you can tell water from oil.
- Butter is a fat that we already know leaves a greasy spot, so it shows what an oil spot looks like.
- Most peanut pods hold 2 seeds, but you may find 1, 3 or even 4.

Check your work

- I found the seed coat, seed leaves and baby plant in a peanut.
- I recorded my oil test in a table and used water as a control.
- I can explain why a seed stores food and oil.

NATURE NOTEBOOK

1. Draw a peanut plant from its roots to its leaves. Show a flower, a peg growing down into the soil and a pod underground. Label the root nodules.
2. Draw an opened peanut seed, large, and label the seed coat, the two seed leaves and the baby plant.
3. Draw Carver's "movable school" wagon on a country road. Write one thing you would teach a farmer if you were riding in it.

From history. George Washington Carver died at Tuskegee in January 1943. That same year, Congress set aside the farm near Diamond, Missouri, where he had been born, as the George Washington Carver National Monument. It was the first national monument to honor an African American. Visitors can still walk the woods and stream where the young "plant doctor" first studied the plants God made.

WORKED EXAMPLES

Example 1. A farmer follows Carver's advice with three fields, A, B and C. In Year 1, Field A grows cotton, Field B grows peanuts and Field C grows sweet potatoes. Each year every crop moves to the next field: A to B, B to C, and C back to A. What grows in Field A in Year 3? How many years apart does cotton grow in Field A?

1. Year 1: A cotton, B peanuts, C sweet potatoes.
2. Year 2: each crop moves one field. Cotton goes to B, peanuts go to C, and sweet potatoes go back to A. So A sweet potatoes, B cotton, C peanuts.
3. Year 3: move again. Cotton goes to C, peanuts go to A, sweet potatoes go to B. So Field A grows peanuts.
4. Year 4: cotton moves from C back to A. Cotton was in Field A in Year 1 and again in Year 4, so $4 - 1 = 3$ years apart.

Answer: Field A grows peanuts in Year 3. Cotton returns to Field A every 3 years, and in between, the peanuts help put nitrogen back into the soil.

Example 2. Carver's 1916 booklet gave 105 ways to prepare peanuts to eat. If a family tried 5 of the recipes every week, how many weeks would it take to try them all?

1. Count by 5s to 100: 5, 10, 15, ... 100. Counting by 5s to 100 takes 20 counts, so 20 weeks give 100 recipes.
2. Recipes left: $105 - 100 = 5$. That is 1 more week.
3. Add: $20 \text{ weeks} + 1 \text{ week} = 21 \text{ weeks}$. Check: $21 \times 5 = 105$.

Answer: 21 weeks.

PRACTICE

1. **EASY** Is a peanut really a nut? What plant family does it belong to?
2. **EASY** Peanut flowers bloom above the ground. Where do the peanut pods grow, and how do they get there?
3. **MEDIUM** A peanut leaf has 4 leaflets. How many leaflets are on 6 peanut leaves? Is a peanut leaf simple or compound?
4. **MEDIUM** Why did Carver tell cotton farmers to plant peanuts or cowpeas in their fields some years?
5. **HARD** Here are oil-test results after 1 hour on brown paper. Peanut: see-through spot 2 cm wide. Apple: no spot. Potato: no spot. Water: no spot. Butter: see-through spot 3 cm wide. Which foods store oil? Why did we wait 1 hour before looking?
6. **CHALLENGE** Carver did not only tell farmers to grow peanuts. He also spent years finding ways to use them. In two or three sentences, explain why both parts of his work were needed.

COMMON MISTAKES

- Thinking Carver invented peanut butter. People were making peanut butter before Carver became famous; his work was teaching crop rotation and finding many new uses for peanuts and sweet potatoes.
- Thinking peanuts are nuts that grow on trees. Peanuts are legume seeds that grow in pods underground.
- Thinking peanuts are roots, like carrots. The pods form from flowers whose pegs push into the soil; the roots are separate, with nodules on them.

Make it a game · Carver's Kitchen. Players take turns naming something that can come from a plant: a food, a dye, a medicine, a building material or a fabric (peanut butter, cotton shirts, wooden chairs, sweet potato pie, maple syrup, rope). For each one, you must also name the plant part it comes from (seed, stem, root, leaf, flower or fruit). Score one point for the use and one point for the right plant part. The first player to 10 points wins and gets the title "Plant Doctor."

Scripture. "He causeth the grass to grow for the cattle, and herb for the service of man: that he may bring forth food out of the earth;" (Psalm 104:14, KJV)

God made plants "for the service of man." Carver spent his life finding how the peanut and the sweet potato could serve hungry families and help tired soil bring forth food again.

Practice answers

1. No. A peanut is a seed in a pod, so it belongs to the legume (pea and bean) family.
2. Under the ground. After the flower blooms, a stalk called a peg grows down and pushes into the soil, and the pod forms at its tip.
3. 24 leaflets ($4 + 4 + 4 + 4 + 4 + 4 = 24$). It is a compound leaf.
4. Growing cotton year after year wore out the soil. Peanuts and cowpeas are legumes with root nodules that take nitrogen from the air and leave it in the soil, so rotating crops helps the soil get healthy again.
5. The peanut and the butter contain oil. We waited 1 hour so that any water (from the apple, potato and water drops) would dry and disappear; a spot that is still there and lets light through is oil.
6. Peanuts helped the worn-out soil, but farmers also needed to sell or use their crop to feed their families. If no one wanted peanuts, farmers would go back to planting only cotton. By finding foods and other uses for peanuts, Carver helped make the healthy-soil plan work for the farmers.

UNIT 1 REVIEW

A parent may read each question aloud. Answer by naming, labeling or writing one or two complete sentences. Show your work for any adding or subtracting. The quiz is worth 40 points, 4 points for each question.

1. (4 pts) Name the four main parts of a plant, and tell the job of the root.
2. (4 pts) Which plant part do we eat in each food: carrot, spinach, broccoli, potato?
3. (4 pts) A bean seedling has a root 5 inches long and a part above the ground 7 inches tall. How long is the whole plant? Which part is longer, and by how much?
4. (4 pts) What are xylem, and what is transpiration?
5. (4 pts) Two celery stalks stood in blue water overnight. The one with leaves had color 7 inches up; the one with no leaves had color 3 inches up. Which drank higher, by how much, and what does this show?
6. (4 pts) Label these leaf parts: the flat part, the stalk, and the lines that carry water. Then tell the difference between a simple leaf and a compound leaf.
7. (4 pts) Name a plant with parallel veins and a plant with net veins.
8. (4 pts) Why did Carl Linnaeus give a name to each leaf shape?
9. (4 pts) Where does a peanut pod grow, and how does it get there?
10. (4 pts) What is crop rotation, and why did Carver tell cotton farmers to plant peanuts?

UNIT PROJECT: MY WHOLE-PLANT FIELD BOOK

Make a small field book of plant parts, the kind John Bartram or Linnaeus might have kept. Include your pressed, labeled weed from Lesson 1.1; your celery data table and a drawing of the colored dots from Lesson 1.2; your leaf rubbings and your yes-or-no leaf key from Lesson 1.3; and your peanut drawing and oil-test table from Lesson 1.4. Finish with a cover page and a paragraph telling which plant part you think does the most important job and why. Date every page and write where you found each specimen.

- **Accuracy:** Root, stem, leaf, flower, blade, petiole, veins, peg and nodules are labeled correctly.
- **Records:** Each experiment shows a prediction, what was changed, what was kept the same, what was measured, and results in inches or centimeters.
- **Explanation:** The paragraph clearly explains the job of a plant part and how it works with the other parts.
- **Care:** Pages are dated, neat and carefully drawn, with specimens taped down well.

Answer key

1. Root, stem, leaf and flower. The root holds the plant in the ground and soaks up water and minerals from the soil.
2. Carrot: root. Spinach: leaf. Broccoli: flower (flower buds). Potato: stem (an underground stem).
3. 12 inches long ($5 + 7 = 12$). The part above the ground is longer, by 2 inches ($7 - 5 = 2$).

4. Xylem are tiny tubes that carry water up through a plant. Transpiration is the way a plant lets water out of its leaves into the air as water vapor, which pulls more water up behind it.
5. The stalk with leaves drank 4 inches higher ($7 - 3 = 4$). It shows that leaves help pull water up the plant, because water leaving through the leaves draws more water up.
6. Blade, petiole and veins. A simple leaf has one blade; a compound leaf is split into leaflets on one petiole, like a clover.
7. Parallel: grass, corn or a lily (any one). Net: maple, oak or bean (any one).
8. So scientists everywhere could use the same words and picture the same leaf when they read a description.
9. Under the ground. After the yellow flower blooms above the ground, a stalk called a peg grows down into the soil, and the pod forms at its tip.
10. Crop rotation is planting different crops in a field from year to year. Peanuts are legumes whose root nodules put nitrogen, a plant food, back into the soil, so the worn-out cotton fields could become healthy again.

SEEDS AND GROWTH

A seed looks like a little brown pebble, but it is a living baby plant packed with its own lunch and waiting for the right moment to grow. In this unit you will watch seeds wake up in a germination jar, find out how seeds without legs travel across fields and oceans, and test what light does for a young plant. On the third day of creation God made “the herb yielding seed, and the fruit tree yielding fruit after his kind, whose seed is in itself” (Genesis 1:11). Every lesson shows a piece of that design.

You will meet Dr. William Beal, who buried bottles of seeds in 1879 to see how long they could stay alive; George de Mestral, who invented Velcro after his dog came home covered in burrs; Charles and Francis Darwin, who capped the tips of seedlings to learn how plants “see” light; and John Chapman, the real Johnny Appleseed. Like them, you will ask a question, make a prediction, change one thing at a time, measure in inches and centimeters, and record what you see.

The unit ends with Galatians 6:7: “whatsoever a man soweth, that shall he also reap.” A garden teaches that we reap the same kind we sow, more than we sow, and later than we sow, and Paul teaches that the same is true of our words and deeds. If your family is using *Gardening & Animals*, its planting lessons are a good “do it at home” companion to this unit.

BEFORE YOU BEGIN

- Can name the parts of a plant: root, stem, leaf and flower (Unit 1)
- Can measure with a ruler to the nearest inch and centimeter
- Can add and subtract numbers to 100 and read a simple bar graph
- Can keep a dated notebook entry with a drawing and a sentence

MASTERY CHECKLIST

- I can name the parts of a seed and the three things it needs to germinate.
- I can explain why plants spread their seeds and name ways seeds fly, float and hitch a ride.
- I can explain why a plant needs light and describe how a seedling grown in the dark looks different.
- I can plan a fair test that changes only one thing and keeps everything else the same.
- I can measure plant growth, record it in a table and read it from a bar graph.
- I can explain that seeds grow after their kind and what Galatians 6:7 teaches about sowing and reaping.

OPTIONAL BOOKS AND RESOURCES

- **USDA PLANTS Database** (<https://plants.usda.gov/>): Free. Look up the plants whose seeds you find on your sock walk (dandelion, burdock, maple, milkweed) to see photos

and where they grow. Best used with a parent.

- **Smithsonian Gardens** (<https://gardens.si.edu/>): Free. Articles and photographs about plants, seeds and gardens from the Smithsonian Institution. A parent can browse for pictures of seeds and seedlings to share.
- **Project Gutenberg** (<https://www.gutenberg.org/>): Free. Search for Charles Darwin's *The Power of Movement in Plants* to see the original drawings of bending seedlings (Lesson 2.3). The text is written for adults, so a parent may choose the pictures to show.

2.1 THE GERMINATION JAR ★

OBJECTIVES

- Name the three main parts of a seed (seed coat, baby plant and stored food) and find them in a soaked bean.
- Explain what a seed needs to germinate (water, air and warmth) and tell the story of Dr. Beal's buried seed bottles.
- Set up a germination jar, measure root growth in inches and centimeters, and record the results in a table.

Warm-up. Hold a dry bean in one hand and a small pebble in the other. They are about the same size and both feel hard. Which one is alive? How could you prove it without cutting either one open? Talk about your ideas, then drop the bean into a cup of water to soak overnight. Tomorrow you will look inside it.

Video. Coming soon. Bean seed germination time-lapse showing the root and shoot growing (search nature time-lapse channels, SciShow Kids, Homeschool Pop (Alternate), Smithsonian Gardens and university extension gardening channels).

KEY TERMS

seed coat

The tough outer skin of a seed that protects the baby plant inside.

embryo

The tiny baby plant inside a seed, with a beginning root and a beginning shoot.

seed leaves

The thick parts of a seed that hold stored food for the baby plant. A bean has two of them.

germination

The moment a seed wakes up and begins to grow, sending out its first root and shoot.

dormant

Resting and alive, but not growing yet. A dry seed is dormant until it gets water and warmth.

CORE IDEAS

The story. In the fall of 1879, a botany professor named William James Beal had a question nobody could answer quickly: how long can a seed stay alive in the ground? At Michigan Agricultural College (today Michigan State University), he filled twenty glass bottles with damp sand mixed with the seeds of common weeds. He buried the bottles upside down in a secret spot on the campus so that rain would not collect inside. His plan was to dig up one bottle every few years, plant the seeds and count how many still sprouted. Dr. Beal knew the

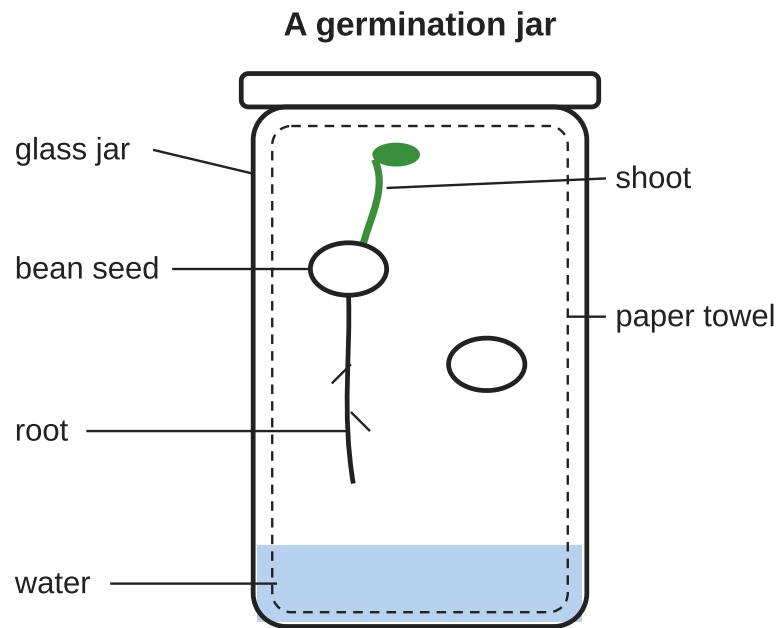
experiment would last far longer than his own life, so he trusted younger scientists to keep it going.

How they figured it out. And they have. Each time a bottle is due, scientists slip out in the dark before dawn, dig it up and carry the sand to a laboratory. They spread it on soil, give it water and warmth, and wait. In 2021, more than 140 years after Dr. Beal buried them, seeds of a plant called moth mullein still sprouted! Those seeds had been alive the whole time, only resting. The bottles teach a lesson every gardener can use: a seed is not a pebble. It is a living baby plant, packed with its own lunch, waiting for the right moment to grow.

The big idea. Every seed has three main parts. The **seed coat** is a tough skin that keeps the inside from drying out or getting hurt. Inside is the **embryo**, a tiny plant with a beginning root and a beginning shoot. The rest is **stored food**. In a bean, the food is packed into two thick **seed leaves** that split apart like the two halves of a book. A dry seed is **dormant**: alive but resting. When it gets **water, air and warmth**, it wakes up. This is called **germination**. The seed drinks water and swells, the seed coat splits, and the root pushes out first and grows down. Then the shoot grows up toward the surface. Most seeds do not need light or even soil to germinate. They carry everything else they need inside.

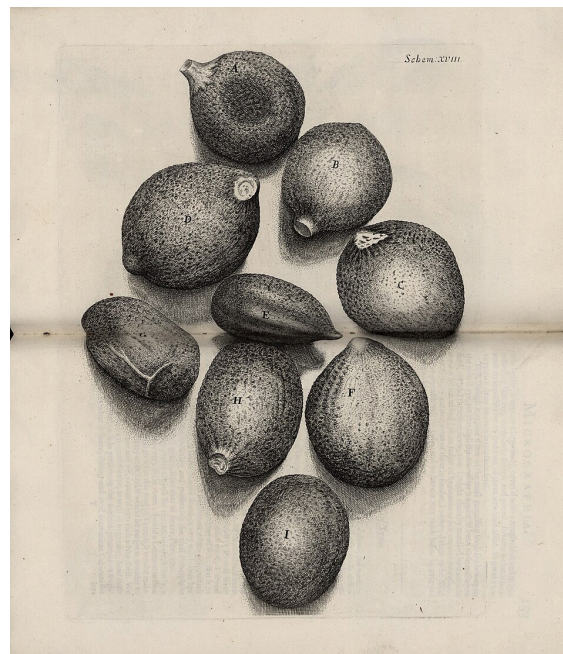
Try it and see. A germination jar lets you watch what usually happens underground. You line a clear jar with a paper towel, tuck soaked beans between the towel and the glass, and keep a little water in the bottom so the towel stays damp. In a few days you will see the seed coat wrinkle and split, and a white root poke out and turn downward. Here is a surprise to test: when a root is about an inch long, turn the bean upside down. Within a day or two, the tip of the root bends and grows down again. Roots can sense which way is down!

God's handiwork. A farmer plants seeds, but he cannot make one grow. Jesus told of a man who sowed seed and then slept and rose night and day, while "the seed should spring and grow up, he knoweth not how" (Mark 4:27). Scientists today know much more about how seeds work than people did long ago, yet every sprouting bean is still a small wonder. God tucked a whole plant, and a lunch box, inside a seed coat.



A germination jar. The damp paper towel holds the beans against the glass so you can watch the root grow down and the shoot grow up.

PICTURE STUDY



Seeds of Thyme, from Micrographia, Robert Hooke, 1665 · Copperplate engraving in a printed book · Published in London for the Royal Society; copies are kept in many libraries

Robert Hooke was an English scientist who built one of the best microscopes of his day. In 1665 he published *Micrographia* ("small drawings"), a book of careful pictures of things too small to see well with the eye alone: a flea, a fly's eye, cork, mold and seeds. Hooke drew everything himself first, and then engravers cut his drawings into copper plates for printing.

Hooke was amazed that a seed of the garden herb thyme, smaller than a grain of sand on your fingertip, had such a fancy shape when he looked closely. He said these little seeds looked like small fruits. His pictures taught people that God's work is just as beautiful up close as it is far away.

Look closely

- Find the seeds. How are they alike, and how is each one a little different?
- Look at the surface of a seed. Is it smooth, or does it have ridges, bumps or wrinkles?
- Find the end of a seed where it was once attached to the plant.
- Hooke used only black lines and dots. How did he make the seeds look round instead of flat?

Talk about it

1. Why would a scientist draw something instead of just describing it in words?
2. What do you think is inside each of these tiny seeds?
3. What small thing in your kitchen would you like to see under a magnifying glass?

Safety first. Use a plastic cup or jar if a glass jar might get dropped. Dried beans are for growing, not eating: raw dried beans can make you sick. Wipe up spilled water right away so no one slips, and wash your hands after handling seeds and damp paper towels. If mold appears, let an adult throw it away.

EXPERIMENT: MY GERMINATION JAR EXPERIMENT

Gardeners often soak beans before planting them. Does soaking really help? You will set up two germination jars, one with soaked beans and one with dry beans, and keep everything else the same. Then you will measure and record like a real seed scientist.

You will need

- 2 clear jars or clear plastic cups, the same size
- Paper towels
- 8 dried lima or pinto beans from the grocery store
- A bowl of water for soaking
- A ruler with inches and centimeters
- Masking tape and a marker
- Notebook and pencil
- A magnifying glass (if you have one)

Steps

1. **Question.** Write in your notebook: Do soaked beans sprout sooner than dry beans?
2. **Prediction.** Write what you think will happen and why.
3. The night before, soak 4 beans in a bowl of water. Keep the other 4 dry.

4. The next day, open one extra soaked bean with your fingernail. Find the seed coat, the two seed leaves and the tiny embryo. Draw it.
5. Label one jar “Soaked” and one jar “Dry.” Line each jar with a folded paper towel and stuff a crumpled paper towel in the middle to press the lining against the glass.
6. Slide 4 soaked beans between the towel and the glass in the Soaked jar, and 4 dry beans in the Dry jar, about halfway up. Space them around the jar.
7. Pour water into the bottom of each jar until it is about 1 inch (about 2½ centimeters) deep. The towel will soak it up.
8. **What we keep the same:** the jars, towels, kind of beans, amount of water and the warm spot where they sit. **What we change:** soaked or dry. **What we measure:** the day each root appears and how long it grows.
9. Every day, check the water and write down what you see. When a root appears, measure it in centimeters every other day.
10. When a root is about 1 inch long, turn one bean upside down. Watch what the root tip does over the next two days.
11. After about 10 days, count how many beans sprouted in each jar and write your conclusion: Was your prediction right?

Tips

- Keep the jars somewhere warm, like a kitchen counter, but out of hot direct sun.
- If the paper towel starts to dry at the top, add a little more water to the bottom.
- Measure from where the root leaves the seed to the tip of the root.
- Save your strongest sprouts for Lesson 2.3, the light experiment.

Check your work

- I can point to the seed coat, seed leaves and embryo of a bean.
- I can name the three things a seed needs to germinate.
- I measured and recorded my roots in centimeters and wrote a conclusion.

NATURE NOTEBOOK

1. Draw a soaked bean split open. Label the seed coat, the seed leaves and the embryo (baby plant).
2. Make a germination diary: draw the same bean on Day 1, Day 3, Day 5 and Day 7, and write the date and root length under each drawing.
3. Draw Dr. Beal’s bottle buried upside down in the ground. Write one sentence about why he buried it that way.

From history. Thomas Jefferson was a careful gardener as well as a president. Beginning in 1766, he kept a “Garden Book” in which he wrote down when he planted seeds, when they came up and when vegetables were ready to eat. He kept notes like these for most of his life, and many of them describe his gardens at Monticello in Virginia. Today gardeners

still read his records to learn which plants he grew. Your germination diary is the same kind of record.

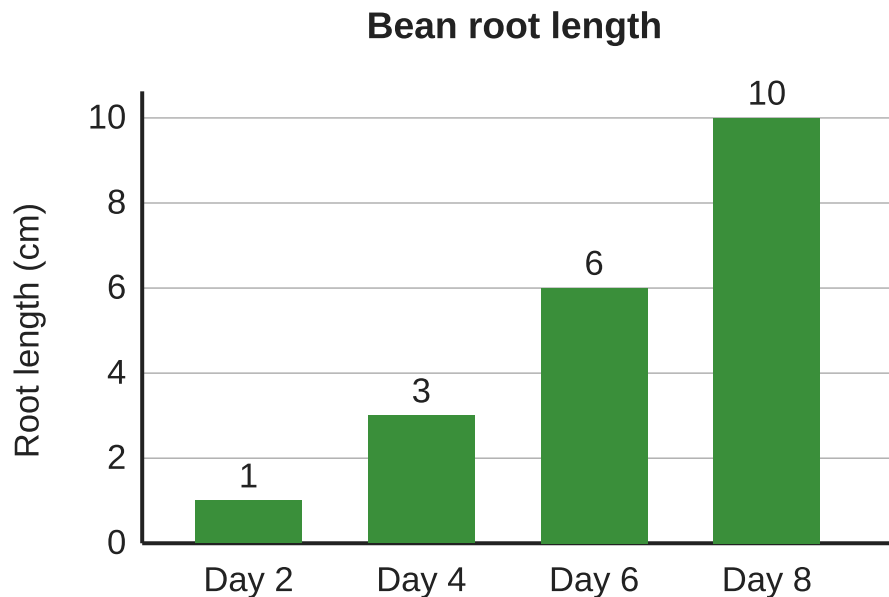
WORKED EXAMPLES

Example 1. Ben put 10 bean seeds in his germination jar. After 5 days, 7 of them had sprouted. How many did not sprout? If Ben planted 20 beans from the same bag, about how many would you expect to sprout?

1. Beans that did not sprout: $10 - 7 = 3$.
2. So 7 out of every 10 beans sprouted.
3. 20 beans is two groups of 10. Each group should give about 7 sprouts.
4. $7 + 7 = 14$.

Answer: 3 beans did not sprout. Out of 20 beans, we would expect about 14 to sprout.

Example 2. Grace measured the root of one bean every two days. Use the bar graph to answer: How long was the root on Day 6? How much did it grow from Day 4 to Day 8? About how many inches long was it on Day 8? (1 inch is about $2\frac{1}{2}$ centimeters.)



Grace's bean root, measured every two days.

1. Find the Day 6 bar. Its top lines up with 6, so the root was 6 cm long.
2. Day 4 bar: 3 cm. Day 8 bar: 10 cm.
3. Growth from Day 4 to Day 8: $10 - 3 = 7$ cm.
4. Each inch is about $2\frac{1}{2}$ cm. Count up: $2\frac{1}{2}$, 5, $7\frac{1}{2}$, 10. That is 4 jumps, so 10 cm is about 4 inches.

Answer: 6 cm on Day 6. It grew 7 cm from Day 4 to Day 8. On Day 8 it was 10 cm, or about 4 inches.

PRACTICE

1. **EASY** Name the three things a seed needs to germinate.
2. **EASY** When a bean germinates, which part comes out of the seed first: the root or the shoot? Which way does it grow?
3. **MEDIUM** Lily put 12 seeds in a jar and 9 of them sprouted. How many did not sprout?
4. **MEDIUM** A root was 2 cm long on Monday and 5 cm long on Thursday. How much did it grow?
5. **HARD** One inch is about $2\frac{1}{2}$ centimeters. A bean shoot is 4 inches tall. About how many centimeters tall is it?

6. **CHALLENGE** Sam thinks beans need water to sprout. Plan a fair test. What will you change? What will you keep the same? What will you look for? Explain in two or three sentences.

COMMON MISTAKES

- Thinking a dry seed is dead. A dry seed is dormant: alive but resting, waiting for water and warmth. Dr. Beal's seeds rested in the ground for more than a hundred years.
- Thinking seeds need soil or sunlight to sprout. Most seeds germinate with just water, air and warmth, as the germination jar shows. The young plant needs light later, once its stored food runs low.
- Thinking the root grows whichever way the seed is pointing. Roots sense which way is down and turn to grow downward, even if the seed is upside down.

Make it a game · Seed or Pebble?. A parent hides a mix of dried beans, pebbles, buttons and other seeds (corn, peas, sunflower) in a bowl. Close your eyes, pick one, and guess by touch: seed or pebble? If it is a seed, name one part that is inside it to score a point. Score a bonus point if you can name what it needs to germinate. Play until the bowl is empty.

Scripture. "Verily, verily, I say unto you, Except a corn of wheat fall into the ground and die, it abideth alone: but if it die, it bringeth forth much fruit." (John 12:24, KJV)

Jesus used a seed to teach. A grain of wheat that stays in the bag stays alone, but one that is planted gives up its old shape and becomes a whole plant full of new grain. Jesus was speaking about His own death and the new life that would come from it.

Practice answers

1. Water, air and warmth.
2. The root comes out first, and it grows down.
3. $12 - 9 = 3$ seeds did not sprout.
4. $5 - 2 = 3$ cm.
5. $2\frac{1}{2} + 2\frac{1}{2} + 2\frac{1}{2} + 2\frac{1}{2} = 10$, so about 10 centimeters.
6. Set up two jars that are the same in every way (same jar, towel, kind and number of beans, warm spot), but give water to only one of them. Check both every day and count how many beans sprout in each. If the beans in the watered jar sprout and the dry ones do not, that shows the seeds need water to germinate.

2.2 SEEDS THAT FLY, FLOAT AND HITCH

OBJECTIVES

- Explain why plants need to spread their seeds away from the parent plant.
- Sort seeds by how they travel (wind, water, animals and bursting pods) and point to the part that helps each one move.
- Run a fair drop test, time seeds with a stopwatch, and find the average of three trials.

Warm-up. Put on an old, fuzzy sock over your shoe (or rub a fleece blanket) and walk across a lawn or along the edge of a field with a parent. Pull the sock off and look closely. Did anything stick to it? If not, blow on a dandelion puff, or drop a maple “helicopter” and watch how it falls. Why would a plant want its seeds to go on a trip?

Video. Coming soon. Seed dispersal for kids: dandelion parachutes, spinning maple seeds, floating coconuts and burrs, plus the burdock burr and Velcro invention story (search SciShow Kids, Homeschool Pop (Alternate), Smithsonian, BBC-style nature footage and slow-motion science channels).

KEY TERMS

seed dispersal

The ways seeds travel away from the plant that made them, such as by wind, water or animals.

parent plant

The plant that grew a seed.

fruit

The part of a flowering plant that holds and protects its seeds. Apples, pea pods, burrs and maple keys are all fruits.

burr

A seed case covered with hooks or spines that catch on fur and clothing, so animals carry it away.

samara

A seed with a flat, papery wing, like a maple key, that spins as it falls so the wind can carry it farther.

CORE IDEAS

The story. In 1941 a Swiss engineer named George de Mestral came home from a walk in the mountains with his dog. Both of them were covered with burrs, the prickly seed cases of a plant called burdock. Most people would have just pulled them off and grumbled. De Mestral got curious. Why did these burrs hold on so tightly? He put one under a microscope

and saw hundreds of tiny hooks. Each hook had caught a little loop in his wool pants or in his dog's fur.

How they figured it out. De Mestral spent years trying to copy the burr. At last he made two strips of cloth: one covered with tiny stiff hooks and one covered with soft loops. Press them together and they hold; pull hard and they rip apart with a scratchy sound. He named his invention *Velcro*, from two French words for velvet and hook. The idea came straight from a seed! Naturalists had long been doing the same kind of careful looking: they watched which seeds blew, which floated and which rode away on animals, and then they studied the parts that made each trip possible.

The big idea. A seed that drops straight down under its parent plant has a hard life. The big plant shades it, and its roots drink up the water first. So God gave plants many ways to send their seeds away. This is called **seed dispersal**. Some seeds **fly**: a dandelion seed hangs from a fluffy parachute, and a maple seed has a papery wing that spins like a helicopter blade, so it falls slowly and the wind can push it farther. Some seeds **float**: a coconut has a thick, airy husk, so it can drift on the sea and sprout on a faraway beach. Some seeds **hitch** a ride with hooks, like burdock burrs. Others ride *inside* animals: a bird eats a berry and drops the seeds somewhere else. And some, like the pods of jewelweed (touch-me-not), burst open and fling their seeds.

Try it and see. You can test a seed's design. Hold a maple seed and a bean at the same height and drop them together. Which lands first? The bean drops fast. The maple seed spins and drifts. A slow fall gives the wind more time to carry a seed sideways. Scientists use a stopwatch, drop each seed from the same height several times, and find the average time so one lucky drop does not fool them.

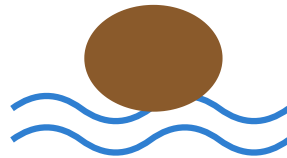
God's handiwork. A seed cannot walk, yet seeds travel across fields, rivers and even oceans. Each plant's fruit is made for its own kind of trip: silk for the wind, a husk for the sea, hooks for a passing fox. When an inventor like de Mestral copies a seed, he is learning from the Creator's designs.



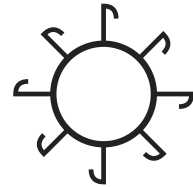
dandelion
flies (parachute)



maple
flies (wing)



coconut
floats



burdock
hitches (hooks)

Four seed travelers and the parts that help them move.

PICTURE STUDY



Dandelion (Taraxacum officinale), from Flora von Deutschland, Österreich und der Schweiz, Otto Wilhelm Thomé, 1885 · Color lithograph (printed botanical plate) · Published in Gera, Germany; copies are kept in many libraries

Otto Wilhelm Thomé was a German teacher and botanist who put together a big book of the plants of Germany, Austria and Switzerland. Each page was a careful, colored plate showing a whole plant along with small drawings of its parts, so students could learn to recognize it.

The dandelion is one of the most common plants in the world, but on Thomé's page it looks like a treasure.

Botanical plates like this one are drawn to teach, not just to decorate. The artist shows the plant at more than one stage of life on the same page, so you can see the flower and the seeds that come after it.

Look closely

- Find the yellow flower head and the round, white seed head. Which comes first in the life of a dandelion?
- Look at the leaves. Why do you think the name “dandelion” comes from French words meaning “lion’s tooth”?
- Look around the edges of the page for small drawings of single parts. Can you find a seed with its parachute?
- Find the hollow flower stalk. Is there a leaf on it?

Talk about it

1. Why would a botanist draw both the flower and the seed head on the same page?
2. How does the dandelion’s parachute help its seeds find new places to grow?
3. Where have you seen dandelions growing? How do you think they got there?

Safety first. Go on seed walks with an adult. Never eat wild seeds, berries or plants. Stay away from plants you do not know, especially poison ivy (“leaves of three, let it be”). After walking in tall grass, check your legs, socks and hair for ticks. For the drop test, an adult should do any dropping that needs standing on a step stool.

EXPERIMENT: THE GREAT SEED DROP

Which seed design falls the slowest? You will drop real seeds and a paper model from the same height and time them, just as a scientist would. A slow fall means the wind has more time to carry a seed away from its parent.

You will need

- 3 or 4 kinds of seeds: a maple key or other winged seed, a dandelion seed or milkweed seed (if in season), a dry bean and a sunflower seed
- A sheet of paper and scissors to make a paper “helicopter” model
- A stopwatch or a phone timer
- A tape measure or yardstick
- Masking tape
- Notebook and pencil
- An old fuzzy sock (for the bonus sock walk)

Steps

1. **Question.** Write: Which seed takes the longest to fall?
2. **Prediction.** Look at each seed's shape and write which one you think will fall slowest, and why.
3. Cut a paper helicopter: a strip of paper about 2 inches wide and 6 inches long, cut down the middle of one end about 3 inches, and fold the two flaps in opposite directions to make blades. Add a paper clip to the bottom.
4. Measure 6 feet (about 2 meters) up a wall and mark it with tape. An adult may hold the seeds at this height.
5. Make a table with a row for each seed and columns for Trial 1, Trial 2, Trial 3 and Average.
6. **What we keep the same:** the height, the place (indoors, no fan blowing) and the person dropping. **What we change:** the kind of seed. **What we measure:** the time from letting go to touching the floor, in seconds.
7. Drop each seed three times. Start the timer when it is let go and stop it when it lands. Write each time in the table.
8. Find the average for each seed: add the three times and divide by 3.
9. Circle the slowest seed. Was your prediction right? Write one sentence about which part of the seed slowed it down.
10. **Bonus sock walk:** pull an old sock over your shoe, walk through a weedy field or the edge of a lawn, then count and sort the seeds that hitched a ride.

Tips

- Round each time to the nearest whole second to keep the math simple.
- Drop seeds indoors so a breeze does not change the results. Afterward, try outside on a windy day and measure how far each one lands from where you dropped it.
- If you cannot find a maple key, your paper helicopter works the same way.

Check your work

- I can name four ways seeds travel and a plant for each one.
- I kept the height the same and changed only the kind of seed.
- I found the average of three trials.

NATURE NOTEBOOK

1. Draw a dandelion seed, a maple seed, a coconut and a burr. Under each, write how it travels: flies, floats or hitches.
2. Tape the seeds from your sock walk onto a page (or draw them). Label each with its shape: hooks, spines, wings or fluff.
3. Draw a burr hook next to a Velcro hook as you see them with a magnifying glass. How are they alike?

From history. Henry David Thoreau, the New England writer, spent years in the woods and fields around Concord, Massachusetts, watching how seeds traveled. He counted the

seeds in pine cones, followed milkweed silk on the wind and watched squirrels bury nuts and forget some of them. In 1860 he gave a talk to farmers called “The Succession of Forest Trees,” explaining how squirrels and wind plant new forests. His longer notes on seeds were finally published as a book more than a hundred years after his death, under the title *Faith in a Seed*.

WORKED EXAMPLES

Example 1. Noah dropped a dandelion seed from 6 feet three times. It took 5 seconds, 4 seconds and 6 seconds to land. A bean dropped from the same height landed in less than 1 second every time. What was the dandelion seed’s average time? Which seed would the wind carry farther?

1. Add the three times: $5 + 4 + 6 = 15$ seconds.
2. Divide by the number of trials: $15 \div 3 = 5$ seconds.
3. The dandelion seed stays in the air about 5 seconds; the bean, less than 1 second.
4. The longer a seed stays in the air, the longer the wind can push it sideways.

Answer: The dandelion seed’s average was 5 seconds. The wind would carry the dandelion seed farther, because it falls much more slowly than the bean.

Example 2. After a sock walk, Ava sorted the seeds stuck to her sock: 6 burdock burrs, 9 beggar’s-ticks and 4 grass seeds. How many seeds hitched a ride in all? Which kind was most common? How many more beggar’s-ticks than burrs were there?

1. Add all the seeds: $6 + 9 + 4 = 19$.
2. Compare the counts: 9 is greater than 6 and 4, so beggar’s-ticks were most common.
3. Subtract: $9 - 6 = 3$.

Answer: 19 seeds in all. Beggar’s-ticks were most common, with 3 more than the burdock burrs.

PRACTICE

1. **EASY** Match each seed to how it travels: (a) dandelion, (b) coconut, (c) burdock burr, (d) cherry pit. Choices: floats on water, flies with the wind, hooks onto fur, eaten by a bird and dropped somewhere else.
2. **EASY** Why is it bad for a seed to sprout right underneath its parent plant?
3. **MEDIUM** Look at a maple seed. Which part helps it travel, and how does that part work?
4. **MEDIUM** One dandelion seed landed 12 feet from its plant. Another landed 30 feet away. How much farther did the second seed travel?

5. **HARD** A meter is a little more than 3 feet. A maple seed landed 9 feet from the tree. About how many meters is that?
6. **CHALLENGE** George de Mestral invented Velcro after looking at burrs. Explain how a burr's hooks help the burdock plant, and how Velcro copies them.

COMMON MISTAKES

- Thinking all seeds just fall to the ground under the plant. Plants have many designs (wings, parachutes, hooks, floats, tasty fruit and bursting pods) that send seeds away.
- Thinking the heaviest seeds always travel farthest. A heavy coconut floats a long way, but in the air the light seeds with wings or fluff travel farthest because they fall slowly.
- Thinking a fruit is only something sweet to eat. To a botanist, a fruit is any part of a flowering plant that holds its seeds, so a burr, a pea pod and a maple key are all fruits.

Make it a game • How Do I Travel?. One player describes a seed without naming it ("I have a papery wing and I spin when I fall"). The other players act out how it travels: flap arms to fly, swim to float, grab a sleeve to hitch, or pretend to be a bird eating a berry. The first player to act it out correctly and name the seed scores a point. Take turns describing until each player has had three turns.

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 parachute, a wing, a float and a hook are four very different ways to solve the same problem. The more closely we look at seeds, the more we see the wisdom of the One who made them.

Practice answers

1. (a) dandelion: flies with the wind. (b) coconut: floats on water. (c) burdock burr: hooks onto fur. (d) cherry pit: eaten by a bird and dropped somewhere else.
2. The big parent plant would shade it and take most of the water and space, so the young plant would have a hard time growing.
3. The flat, papery wing. It makes the seed spin as it falls, so it falls slowly and the wind can carry it away from the tree.
4. $30 - 12 = 18$ feet farther.
5. $9 \div 3 = 3$, so about 3 meters (a little less, because a meter is a bit longer than 3 feet).
6. The burr's tiny hooks catch on loops of animal fur, so a passing animal carries the seeds away and drops them in a new place. Velcro copies this with one strip of tiny stiff hooks and one strip of soft loops that grab each other.

2.3 THE LIGHT EXPERIMENT

OBJECTIVES

- Explain that a young plant lives on the food stored in its seed at first, but needs light to make its own food once that runs low.
- Describe how seedlings grown in the dark differ from seedlings grown in the light, and how plants bend toward light.
- Run a fair test with one change, measure plant height in centimeters every two days, and read the results from a data table.

Warm-up. Lift up a board, a flowerpot or a doormat that has been lying on the grass for a week or more (or remember a spot where a toy was left on the lawn). What color is the grass underneath? Compare it with the grass in the sun. What do you think happened, and why?

Video. Coming soon. Plants growing toward light: bean seedlings in a shoebox maze, seedlings grown in the dark versus the light, and phototropism time-lapse (search SciShow Kids, Science Max, Homeschool Pop (Alternate), university botany and extension channels, and plant time-lapse footage).

KEY TERMS

seedling

A young plant that has just grown from a seed.

chlorophyll

The green coloring in leaves that catches sunlight so the plant can make its own food.

phototropism

A plant growing or bending toward light. “Photo” means light, and “tropism” means turning.

variable

Anything in an experiment that can change. In a fair test, you change only one variable on purpose.

control

The part of an experiment kept in the normal way, so you have something to compare against.

CORE IDEAS

The story. Charles Darwin, the English naturalist, loved experiments with plants. In the late 1870s, at his home called Down House in Kent, England, he and his son Francis grew tiny seedlings of canary grass in pots and watched them closely. When a pot sat near a window or a lamp, the young shoots bent toward the light within a few hours. The Darwins wanted to

know which part of the seedling “saw” the light. In 1880 they published what they found in a book called *The Power of Movement in Plants*.

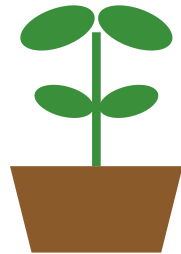
How they figured it out. The Darwins tried something clever. On some seedlings they covered just the very tip with a tiny cap that blocked the light. On others they left the tip open. The seedlings with open tips bent toward the light. Most of the seedlings with covered tips stayed straight! So the tip must sense the light, even though the bending happens lower down. The Darwins guessed that the tip sends some kind of message down the stem. Years later, other scientists found the message: a growth chemical, later named auxin, that makes the shady side of the stem grow longer, so the shoot leans toward the light.

The big idea. A seed carries enough stored food to get a young plant started, even in the dark. But once that food runs low, the plant must make its own. Green leaves do that with **light**. The green coloring in leaves, called **chlorophyll**, catches sunlight, and the leaf uses that light energy to turn water and air into sugar for food. A seedling growing in the dark makes very little chlorophyll, so it looks pale yellow or white. It also grows tall and thin very fast, as if it were stretching to find the light. It may look like a winner at first, but it is weak, and without light it will die when its stored food is gone. A plant near a window shows **phototropism**: it bends toward the light.

Try it and see. You can test this with two cups of bean seedlings. Put one in a sunny window and one in a dark closet. Keep everything else the same: same soil, same kind of bean, same water, same warm room. Light is the one **variable** you change. The plant in the window is your **control**. Measure both every two days and write down the height and the color. A scientist does not just say “the dark one looked weird.” She writes numbers and words in a table.

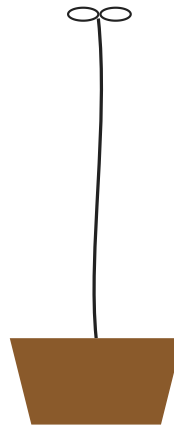
God’s handiwork. On the first day of creation, God said, “Let there be light” (Genesis 1:3). Every green plant on earth depends on it. A bean seedling is not able to think, yet it turns its leaves toward the window as surely as a sunflower bud follows the sun across the sky.

In the light



short, sturdy stem
green leaves

In the dark



tall, thin stem
small, pale yellow leaves

The same kind of bean, the same soil and the same water: only the light was different.

PICTURE STUDY



Sunflowers, Vincent van Gogh, 1888 · Oil on canvas · National Gallery, London

Vincent van Gogh was a Dutch painter who moved to the sunny town of Arles in the south of France. In the summer of 1888 he painted a vase of sunflowers to decorate the room where his friend, the painter Paul Gauguin, would stay. He used thick strokes of paint in many shades of yellow, the color of sunlight.

Sunflowers are a good flower for a lesson about light. While a young sunflower is still growing, its bud turns to face east in the morning and follows the sun westward during the day. Once the big flower opens, it usually stops turning and faces east.

Look closely

- Count the sunflowers. How many are fresh, and how many are drooping or dry?
- Find a flower that has lost its petals. What do you see in its center?
- How many different yellows can you find? Where did van Gogh use green, orange or brown?
- Look at the paint itself. Is it smooth, or can you see thick strokes and bumps?

Talk about it

1. Why do you think van Gogh painted flowers that were dying as well as fresh ones?
2. Why would yellow be a good color for a picture about sunshine?
3. If you planted a seed from the center of one of these sunflowers, what would grow?

Safety first. Water spills can make floors slippery, so water plants over a tray and wipe up spills. Do not eat the seeds or plants in this experiment. If you use a lamp instead of a window, let an adult set it up, keep paper and cardboard away from the bulb, and never touch a hot bulb.

EXPERIMENT: LIGHT OR DARK? A FAIR TEST

Does a bean seedling grow differently in the dark? You will grow two seedlings that are alike in every way except one: light. Then you will measure and record them like Charles and Francis Darwin did.

You will need

- 4 bean seeds, soaked overnight (or sprouted beans from your germination jar)
- 2 paper or plastic cups the same size, with a small hole poked in the bottom by an adult
- Potting soil
- A tray or plate to catch water
- A measuring spoon or small cup for water
- A dark closet or a large cardboard box
- A ruler with centimeters
- Notebook and pencil
- Bonus: a shoebox, two pieces of cardboard and tape for a maze

Steps

1. **Question.** Write: How does growing in the dark change a bean seedling?
2. **Prediction.** Write what you think the dark plant will look like after 10 days: taller or shorter, greener or paler?

3. Fill both cups with the same amount of soil. Plant 2 beans in each cup, about 1 inch (2½ centimeters) deep. Water each cup with the same amount.
4. Keep both cups together in a warm spot until the shoots poke through the soil. If both seeds sprout, keep the stronger one in each cup.
5. Label the cups “Light” and “Dark.” Put the Light cup in a sunny window. Put the Dark cup in a closet or under a big box.
6. **What we keep the same:** cups, soil, kind of bean, amount of water, room temperature. **What we change:** light. **What we measure:** height in centimeters and leaf color, every two days.
7. Make a table with columns for Day, Light height, Light color, Dark height, Dark color.
8. Every two days, give each cup the same small amount of water. Measure each plant from the soil to the top of the stem and write it in your table. Work quickly so the dark plant spends only a minute in the light.
9. After 10 days, compare. Which was taller? Which was greener? Which had the stronger stem?
10. Now move the dark plant to the window. Watch it for 3 more days. What happens to its color?
11. Write a conclusion: What did light do for the plant?

Tips

- Turn the Light cup once to see phototropism: in a day or two the stem will lean back toward the window.
- Bonus shoebox maze: tape two cardboard shelves inside a shoebox, cut a hole at the top of one end, put a seedling in the bottom of the other end, close the lid and watch the shoot find its way to the light.
- Taller does not always mean healthier. Look at the stem’s thickness and the leaf color too.

Check your work

- I changed only one thing (light) and kept everything else the same.
- I measured and recorded both plants every two days.
- I can explain why the dark plant was pale and tall.

NATURE NOTEBOOK

1. Draw the Light plant and the Dark plant side by side on the last day. Color them as truly as you can and label stem, leaves and seed leaves.
2. Draw the Darwins’ experiment: a seedling with an open tip bending toward a window, and a seedling with a cap on its tip standing straight.
3. Draw a houseplant near a window in your home. Draw an arrow showing which way its leaves face. Is the window on that side?

From history. In 1779 a Dutch-born doctor named Jan Ingenhousz, working in England, did hundreds of experiments with plants in water. He found that green leaves give off tiny bubbles of a gas that makes air good to breathe, but only when they are in sunlight. In the dark, they did not. He wrote about it in a book called *Experiments upon Vegetables*. Ingenhousz was one of the first people to show that plants need light to do their work, which scientists today call photosynthesis.

WORKED EXAMPLES

Example 1. Here are Mia's measurements. Light plant: Day 3, 2 cm; Day 6, 5 cm; Day 9, 8 cm. Dark plant: Day 3, 3 cm; Day 6, 9 cm; Day 9, 15 cm. On Day 9, how much taller was the dark plant? How much did each plant grow from Day 3 to Day 9? Does taller mean healthier?

1. Day 9 difference: $15 - 8 = 7$ cm. The dark plant was 7 cm taller.
2. Light plant growth: $8 - 2 = 6$ cm.
3. Dark plant growth: $15 - 3 = 12$ cm. The dark plant grew twice as much, because $6 + 6 = 12$.
4. But Mia's notes say the dark plant was pale yellow with a thin, floppy stem, and the light plant was green and sturdy.

Answer: The dark plant was 7 cm taller on Day 9. The light plant grew 6 cm and the dark plant grew 12 cm. Taller does not mean healthier: the dark plant stretched looking for light, and without light it cannot make food, so it will die when its seed food runs out.

Example 2. Jack set up the light experiment this way: the Light plant was in a big pot of garden soil and got water every day. The Dark plant was in a small cup of sand and got water once a week. The Dark plant grew poorly. Can Jack say the darkness caused it? Why or why not?

1. List what was different: light, pot size, soil and water. That is four variables, not one.
2. Any of those differences could have made the Dark plant grow poorly.
3. A fair test changes only one variable and keeps all the others the same.

Answer: No. Jack changed four things at once (light, pot size, soil and water), so he cannot tell which one made the difference. He should use the same pot, soil and water for both and change only the light.

PRACTICE

1. **EASY** What does a green plant need light for?
2. **EASY** A seedling grown in a dark closet is pale yellow. Why is it not green?

3. **MEDIUM** A bean plant was 4 inches tall on Day 5 and 7 inches tall on Day 8. How many inches did it grow?
4. **MEDIUM** One inch is about $2\frac{1}{2}$ centimeters. About how many centimeters is 4 inches?
5. **HARD** A plant on a windowsill leans toward the glass. What is this called? What could you do to make it grow straighter?
6. **CHALLENGE** In the Darwins' experiment, seedlings with a cap over their tips did not bend toward the light, but seedlings with open tips did. What did this show? Write two sentences.

COMMON MISTAKES

- Thinking the tallest plant is the healthiest. A seedling in the dark grows tall and thin very fast, but it is pale and weak and will die without light.
- Thinking plants get their food from the soil. Soil gives a plant water and some minerals, but the plant makes its food in its green leaves using light, water and air.
- Changing more than one thing in an experiment. If you change the light and the water, you cannot tell which one caused the result.

Make it a game · Sunflower Says. One player is the Sun and walks slowly around the room holding a flashlight (pointed at the floor, never in anyone's eyes). Everyone else is a seedling crouched in place. Seedlings must turn their faces and arms to follow the Sun, the way a young plant bends toward light. When the Sun calls "Night!" and switches off, seedlings stretch tall and droop. The Sun asks a question from the lesson; the first seedling with the right answer becomes the next Sun.

Scripture. "He causeth the grass to grow for the cattle, and herb for the service of man: that he may bring forth food out of the earth;" (Psalm 104:14, KJV)

The psalm says God causes the grass to grow. He does it through the sunlight, rain and soil He made. When a plant turns its leaves to the window, it is using the light God provides to make food that will one day feed cattle and people.

Practice answers

1. To make its own food. The green chlorophyll in its leaves catches the light, and the leaf uses that energy to turn water and air into sugar.
2. Without light, the seedling makes very little chlorophyll, the green coloring in leaves.
3. $7 - 4 = 3$ inches.
4. $2\frac{1}{2} + 2\frac{1}{2} + 2\frac{1}{2} + 2\frac{1}{2} = 10$, so about 10 centimeters.
5. It is called phototropism: bending toward light. Turn the pot a little every few days so each side of the plant gets light in turn.
6. It showed that the tip of the seedling is the part that senses the light. Because the bending happens lower down the stem, the tip must send a message down to the part that bends.

2.4 “WHATSOEVER A MAN SOWETH” (GALATIANS 6:7)

OBJECTIVES

- Explain that every seed grows into a plant of its own kind, as God said in Genesis 1:11, and that seeds of one kind can still vary.
- Tell the story of John Chapman (Johnny Appleseed) and explain why apple seeds grow apple trees whose fruit may differ from the parent.
- Use multiplication and counting to show how one seed sown can bring a harvest of many seeds, and explain what Galatians 6:7 means in a garden and in life.

Warm-up. Your parent pours a small handful of mixed seeds onto a plate: dried beans, popcorn kernels, sunflower seeds, dried peas and a few pumpkin seeds. Sort them into groups. For each group, say what plant would grow if you planted it. Could a popcorn kernel ever grow into a bean plant? How do you know?

Video. Coming soon. Johnny Appleseed history for kids and how apple trees are grown from seeds and by grafting, plus seed-to-harvest time-lapse of beans, corn and sunflowers (search Smithsonian, university extension orchards, Homeschool Pop (Alternate), Moody Science classics and farm and garden channels).

KEY TERMS

sow

To plant seeds by scattering them or putting them in the ground.

reap

To cut and gather a crop when it is ripe.

harvest

The ripe crop that is gathered, or the time of year when it is gathered.

after his kind

The Bible’s words for how living things make more of their own kind: bean seeds grow beans, and apple seeds grow apple trees (Genesis 1:11-12).

variety

A group within one kind of plant that has its own special look or taste, like different varieties of apples.

CORE IDEAS

The story. John Chapman was born in Massachusetts in 1774. As a young man he walked west into Pennsylvania and then into the wild new lands of Ohio and Indiana. Along the way he gathered apple seeds from the piles of crushed apples left over at cider mills. He carried the seeds west, cleared small patches of ground, planted them and fenced them in to keep deer and cattle out. Years later he came back to sell the young trees to families who were

building farms. Settlers called him **Johnny Appleseed**, and his orchards fed many frontier families.

How they figured it out. Every farmer knows that if you sow apple seeds, you get apple trees, never oak trees or cornstalks. But apple seeds hold a surprise. A tree that grows from a seed does not give exactly the same apples as the tree the seed came from. Its apples might be small and sour, or big and sweet. Each seedling is a new **variety**. Many of Chapman's apples were good for cider, apple butter and drying. Apple growers learned long ago that the only way to get exactly the same apple again is to **graft**: to join a twig from the favorite tree onto a young apple tree. Every McIntosh or Golden Delicious apple you buy comes from grafted trees.

The big idea. 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 seed carries the instructions for its own **kind**. There is plenty of variety within a kind (sweet apples and sour apples, red beans and white beans), but an apple seed always grows an apple tree. The Apostle Paul used this garden fact to teach: "whatsoever a man soweth, that shall he also reap" (Galatians 6:7). A garden teaches three truths. You reap the **same kind** you sow. You reap **more** than you sow: one bean can make a plant with dozens of beans. And you reap **later**: the harvest comes weeks or months after planting.

Try it and see. Cut an apple across its middle and you will find a five-pointed star. Each point is a little room that can hold seeds. Count them! Then plant a few different seeds, label each pot with your prediction, and see whether every one comes up after its kind. Count the seeds in a pepper, a tomato or a pea pod, and you will see how one seed sown becomes a harvest of many.

God's handiwork. Paul was not only talking about gardens. Our words and deeds are seeds too. Kind words tend to grow friendships; lies and selfishness grow trouble. The harvest may be slow, so Paul adds, "let us not be weary in well doing: for in due season we shall reap, if we faint not" (Galatians 6:9).

PICTURE STUDY



The Sower, Jean-François Millet, 1850 · Oil on canvas · Museum of Fine Arts, Boston

Jean-François Millet grew up on a farm in Normandy, France, where he helped his family plow and sow. Later, as a painter living in the village of Barbizon, he painted farm workers as strong and honorable people doing important work. In *The Sower*, a farmer strides down a field, scattering grain by hand in wide sweeps, the way grain had been sown for thousands of years.

This painting became famous. The Dutch painter Vincent van Gogh admired Millet so much that he made his own copies and versions of the sower many times. When you look at it, remember Jesus' parable of the sower, in which some seed fell by the wayside and the birds came and ate it up (Matthew 13).

Look closely

- Find the sower's hand. Is he holding the seed or throwing it?
- Find the bag of seed. How does he carry it so that both hands are free?
- Look near the top right of the painting. Can you find birds? Why might birds follow a sower?
- Is the sower walking slowly or taking big steps? How can you tell?

Talk about it

1. What kind of plants will grow from this sower's seed? How do you know?
2. Why do you think Millet made a farmer look so strong and important?
3. What good "seeds" could you sow this week with your words and actions?

Safety first. Let an adult cut fruit with a sharp knife. Do not eat apple seeds or seeds from seed packets (some packet seeds are coated with chemicals). Wash your hands after handling soil and seeds, and wipe up water spills.

EXPERIMENT: SOW, PREDICT AND REAP

Does every seed grow after its kind? You will plant five different seeds, predict what each will become, and check. You will also count the seeds inside fruits to see how a single seed sown becomes a harvest.

You will need

- 5 kinds of seeds: dried bean, popcorn kernel, dried pea, sunflower seed (raw, in the shell) and a pumpkin or squash seed
- 5 small cups or pots with holes in the bottom, and potting soil
- Masking tape and a marker
- An apple, a green pepper and a tomato (an adult cuts them)
- A paper plate for each fruit
- Notebook and pencil
- A ruler with inches and centimeters

Steps

1. **Question.** Write: Will every seed grow into the same kind of plant it came from?
2. **Prediction.** For each seed, write the name of the plant you expect and draw what you think its first leaves will look like.
3. Fill each pot with soil. Plant one kind of seed in each, about 1 inch (2½ centimeters) deep. Label each pot with the seed's name.
4. **What we keep the same:** soil, pot size, water and the sunny spot. **What we change:** the kind of seed. **What we observe:** what plant comes up and what its leaves look like.
5. Water each pot the same small amount every two days. Write the day each seed comes up.
6. After about two weeks, draw each seedling and compare it with your prediction. Did any seed grow into a different kind of plant?
7. **Harvest count.** Have an adult cut the apple across its middle (to show the star), and cut the pepper and tomato in half. Count the seeds from each fruit on its own plate and write the totals in a table.
8. Write a conclusion of two or three sentences. Use the words “after his kind” and “harvest.”

Tips

- Bean, pea, corn, sunflower and pumpkin seeds sprout quickly and have very different first leaves, so they are easy to tell apart.

- Corn comes up with one narrow, grassy leaf. Beans and pumpkins open two broad seed leaves first.
- Tomato seeds are small and slippery. Count them in groups of 10 to keep your place.

Check your work

- I can show that each seed grew into a plant of its own kind.
- I counted the seeds in three fruits and recorded them in a table.
- I can explain Galatians 6:7 for a garden and for my own life.

NATURE NOTEBOOK

1. Draw an apple cut across its middle. Show the five-pointed star and the seeds, and write how many seeds you counted.
2. Draw a row of five seeds and, above each one, the plant it grows into. Write “after his kind” across the top of the page.
3. Draw a “seed of kindness” you sowed this week and what it might grow into. Copy Galatians 6:7 underneath.

From history. In the spring of 1621, the Pilgrims at Plymouth had survived a hard first winter. A Patuxet man named Squanto (Tisquantum), who had learned English, showed them how to plant Indian corn: set the seeds in little hills and put fish in the ground with them to feed the soil, then tend the young plants through the summer. William Bradford, the colony’s governor, wrote about it in his history, *Of Plymouth Plantation*. That fall the Pilgrims reaped a good harvest of corn and gave thanks to God.

WORKED EXAMPLES

Example 1. Suppose one pea seed grows into a plant with 10 pods, and each pod holds 6 peas. How many peas did one pea seed give? How many peas would 3 pea seeds give?

1. One plant: 10 pods with 6 peas in each pod.
2. Count by sixes ten times, or multiply: $10 \times 6 = 60$ peas.
3. Three plants: $60 + 60 + 60 = 180$ peas.
4. We reap the same kind we sow (peas), and we reap much more than we sow.

Answer: One pea seed gave 60 peas. Three pea seeds would give 180 peas.

Example 2. Hannah counted the seeds in four apples: 7, 8, 6 and 9. How many seeds did she find in all? Which apple had the most? An apple has 5 little seed rooms, and each room usually holds no more than 2 seeds. What is the most seeds you would usually expect in one apple?

1. Add: $7 + 8 + 6 + 9 = 30$ seeds.
2. Compare: 9 is the largest number, so the fourth apple had the most.
3. Most seeds expected: $5 \text{ rooms} \times 2 \text{ seeds} = 10 \text{ seeds}$.

Answer: 30 seeds in all. The apple with 9 seeds had the most. You would usually expect no more than 10 seeds in one apple.

PRACTICE

1. **EASY** You plant a sunflower seed. What will grow? Could it grow into a bean plant?
2. **EASY** Finish the verse: “Be not deceived; God is not mocked: for whatsoever a man soweth, that shall he also ____.” (Galatians 6:7)
3. **MEDIUM** Green beans are usually ready to pick about 2 months after planting. If you plant them on May 1, in which month will you probably reap them?
4. **MEDIUM** An ear of corn has 10 rows of kernels, with 20 kernels in each row. How many kernels are on the ear? Each kernel is a seed.
5. **HARD** A tree grown from the seed of a sweet red apple gives small, sour, yellow apples. Is this still “after his kind”? Explain.
6. **CHALLENGE** You plant bean seeds 6 inches apart in a row that is 3 feet long. You put the first seed right at the start of the row and the last seed at the very end. How many seeds do you plant? (1 foot = 12 inches.) About how many centimeters long is the row, if 1 foot is about 30 centimeters?

COMMON MISTAKES

- Thinking a seed might grow into any kind of plant. Every seed grows after its own kind: corn from corn, beans from beans, apples from apples.
- Thinking every apple seed grows the very same apple as its parent tree. It grows an apple tree, but the fruit can vary in size, color and taste. Growers graft to copy a favorite variety.
- Thinking the harvest is the same size as what was planted, or that it comes right away. One seed usually gives many seeds, and the harvest comes weeks or months later.

Make it a game · Sow and Reap Memory Match. Make 16 cards: 8 cards with a drawing or picture of a seed (bean, corn, pea, sunflower, pumpkin, apple, acorn, tomato) and 8 cards with the plant each one grows into. Lay them face down. Take turns flipping two cards. If the seed matches its plant, keep the pair and say “after his kind!” Bonus

point if you can name something the plant gives us at harvest. The player with the most pairs wins.

Scripture. “Be not deceived; God is not mocked: for whatsoever a man soweth, that shall he also reap.” (Galatians 6:7, KJV)

No farmer plants thistles and expects wheat. Paul uses this plain garden fact to warn us that our choices grow results of the same kind. Sowing kindness, honesty and hard work brings a good harvest in God’s time, and sowing selfishness brings a harvest of trouble.

Practice answers

1. A sunflower plant will grow. It cannot grow into a bean plant, because seeds grow after their own kind.
2. reap
3. July (May + 2 months = July).
4. $10 \times 20 = 200$ kernels. That is 200 seeds on one ear, all from a single kernel that was planted.
5. Yes. The seed grew into an apple tree that makes apples, so it stayed the same kind. The apples are a new variety: different size, color and taste. Variety within a kind is normal, and to get the same sweet red apple again, growers graft a twig from the parent tree.
6. 3 feet = 36 inches. $36 \div 6 = 6$ spaces between seeds. With a seed at both ends, there is one more seed than spaces: 7 seeds. The row is about $3 \times 30 = 90$ centimeters long.

UNIT 2 REVIEW

Answer each question. Show your work for any math, and use complete sentences for explanations. The quiz is worth 40 points, 4 points for each question.

1. (4 pts) Name the three main parts of a seed and tell what each one does.
2. (4 pts) What three things does a seed need to germinate? Which part of a bean comes out first?
3. (4 pts) Dr. Beal buried bottles of seeds in 1879. In 2021, some of the seeds still sprouted. What does this tell us about dry seeds?
4. (4 pts) A root was 3 cm long on Day 4 and 10 cm long on Day 8. How much did it grow? About how many inches long was it on Day 8? (1 inch is about 2½ cm.)
5. (4 pts) Identify how each seed travels: (a) dandelion, (b) coconut, (c) burdock burr, (d) maple key.
6. (4 pts) Why do plants need to send their seeds away from the parent plant? What invention came from studying burdock burrs?
7. (4 pts) A maple seed fell from 6 feet three times. It took 2 seconds, 3 seconds and 4 seconds. What was the average time?
8. (4 pts) Two bean seedlings were grown the same way, but one was kept in a dark closet. Describe how the dark seedling looks and explain why.
9. (4 pts) In a fair test about light, what should you change, and name three things you should keep the same.
10. (4 pts) Galatians 6:7 says, “whatsoever a man soweth, that shall he also reap.” Name two things a garden teaches about sowing and reaping, and explain why an apple seed can grow a tree with apples that taste different from its parent’s.

UNIT PROJECT: MY SEED SCIENTIST LAB BOOK

Gather your work from this unit into one lab book with a cover you design. Include your germination jar record with root measurements and a bar graph, your seed-drop table with averages, your light-and-dark table with drawings of both plants, and your Sow, Predict and Reap chart with seed counts. Add a page with drawings of at least four seeds and how each travels, and finish with a short paragraph explaining what Galatians 6:7 teaches about gardens and about life.

- **Experiments:** Each experiment shows a question, a prediction, what was changed, what was kept the same and a conclusion.
- **Measurements:** Measurements are dated, labeled with units (inches or centimeters, seconds) and correctly added, subtracted or averaged.
- **Observation drawings:** Drawings of seeds and seedlings are careful, true to life and labeled with the correct parts.
- **Explanation:** The paragraph explains that seeds grow after their kind and what sowing and reaping teach, in clear complete sentences.

Answer key

1. Seed coat: protects the inside of the seed. Embryo: the tiny baby plant with a beginning root and shoot. Stored food (in a bean, the two seed leaves): feeds the young plant until it can make its own food.
2. Water, air and warmth. The root comes out first and grows down.
3. Dry seeds are not dead. They are dormant (alive but resting), and some kinds can stay alive in the ground for a very long time until they get water, air and warmth.
4. $10 - 3 = 7$ cm. 10 cm is about 4 inches ($2\frac{1}{2} + 2\frac{1}{2} + 2\frac{1}{2} + 2\frac{1}{2} = 10$).
5. (a) Flies on the wind with a parachute. (b) Floats on water. (c) Hitches a ride on animal fur with its hooks. (d) Flies with a spinning wing.
6. Seeds that land under the parent plant get too little light, water and space, so traveling gives them a better place to grow. George de Mestral invented Velcro after studying the tiny hooks on burdock burrs.
7. $2 + 3 + 4 = 9$ seconds. $9 \div 3 = 3$ seconds.
8. It is tall, thin and pale yellow. Without light it makes very little green chlorophyll, and it stretches up fast using its seed's stored food as if searching for light. It cannot make its own food and will die when the stored food runs out.
9. Change only the light (one plant in light, one in the dark). Keep the same: the kind of seed, the soil, the cup size, the amount of water and the room temperature (any three).
10. Any two: you reap the same kind you sow; you reap more than you sow; you reap later than you sow. An apple seed always grows an apple tree (after its kind), but each seedling is a new variety, so its fruit can differ in size, color and taste. That is variety within a kind.

POLLINATORS

A flower cannot walk across the meadow to find another flower, yet it needs pollen from another flower of its own kind to make seeds. So God gave flowers helpers. In this unit you will meet the **pollinators**: animals that carry pollen from flower to flower while they look for food. You will see how a bee's fuzzy hairs and pollen baskets work, how a caterpillar becomes a butterfly or moth, how a hummingbird hovers at a red tube flower, how a bat drinks from a cactus flower in the desert night, and how a tiny white moth and the yucca plant cannot live without each other.

You will work like the scientists who first figured these things out. You will repeat Karl von Frisch's colored-card test with real bees, watch for moths at a lighted sheet as Maria Sibylla Merian might have, test which kind of "face" carries the most pollen, and model a yucca seed pod with beans and a die. Along the way you will make predictions, keep everything the same except one thing, count, graph and record. In every lesson, ask the same question: **how does this flower and this animal each help the other?**

BEFORE YOU BEGIN

- Can name the parts of a flower, including the stamen and pistil (Unit 1)
- Knows that plants grow from seeds (Unit 2)
- Can make tally marks and read a simple bar graph
- Can measure with a ruler to the nearest half inch

MASTERY CHECKLIST

- I can explain what pollination is and why flowers need pollinators to make seeds.
- I can tell how a bee carries pollen and what Karl von Frisch learned about how bees see color.
- I can name the four stages of complete metamorphosis and tell a butterfly from a moth.
- I can match a flower to its likely pollinator by its color, smell, shape and time of opening.
- I can explain the yucca and yucca moth partnership as an example of mutualism.
- I can plan a fair test that changes only one thing, and record my results in a table or bar graph.

OPTIONAL BOOKS AND RESOURCES

- **Journey North** (<https://journeynorth.org/>): Free. Families report sightings of monarch butterflies and hummingbirds each spring and fall and watch the maps fill in. A good way to connect Lessons 3.2 and 3.3 to real birds and butterflies near you.
- **Pollinator Partnership** (<https://www.pollinator.org/>): Free planting guides for your region showing which flowers feed bees, butterflies and hummingbirds. Useful for planting a small pollinator bed after this unit.

- **USDA Forest Service: Celebrating Wildflowers, Pollinators**
(<https://www.fs.usda.gov/wildflowers/pollinators/>): Free pages with photos of bees, butterflies, moths, hummingbirds and bats at work, and clear explanations of which flowers each one visits. Parents can read sections aloud.

3.1 BEES ★

OBJECTIVES

- Explain what pollination is and why flowers need pollinators to make seeds.
- Describe how a bee's fuzzy hairs and pollen baskets carry pollen from flower to flower.
- Tell how Karl von Frisch tested whether bees can see colors, and read a bar graph of bee visits.

Warm-up. Put a spoonful of cocoa powder in the middle of a cupcake liner. This is your “flower,” and the cocoa is its pollen. Pull a fuzzy sock over your hand and pretend to be a bee drinking from the flower. Now touch a clean cupcake liner. What came along for the ride? Try again with a smooth plastic bag over your hand. Which “bee” carried more pollen?

Video. Coming soon. Honey bees gathering pollen and nectar, close-ups of pollen baskets, and the waggle dance; search Smithsonian, USDA, SciShow Kids, Homeschool Pop (Alternate) and slow-motion nature footage of bees on flowers.

KEY TERMS

pollen

A fine powder, often yellow, made in a flower's stamens. A flower needs pollen from its own kind to make seeds.

pollination

Moving pollen to the stigma, the sticky top of a flower's pistil, so the flower can make seeds.

pollinator

An animal, such as a bee, butterfly, hummingbird or bat, that carries pollen from flower to flower.

nectar

A sweet liquid made by flowers. Animals come to drink it and pick up pollen while they do.

pollen basket

A smooth hollow ringed with stiff hairs on each back leg of a honey bee, where it packs pollen to carry home.

CORE IDEAS

The story. Long ago, some scientists said that bees could not see colors at all. A young Austrian scientist named Karl von Frisch did not think that made sense. Why would meadows be full of blue, purple and yellow flowers if the bees that visit them saw only gray? So he set up a test. He put a little dish of sugar water on a blue card and laid it among gray cards of every shade, from almost white to almost black. The bees soon learned to fly to the blue

card. Then he took the sugar water away. The bees still flew straight to the blue card! They could see blue. Von Frisch studied bees for the rest of his long life, and in 1973 he shared the Nobel Prize for discovering how honey bees “talk” to each other by dancing.

How they figured it out. Von Frisch tried other colors too. Bees found yellow and blue easily, but a red card looked dark to them, and they mixed it up with the dark gray cards. Later, scientists learned that bees can see *ultraviolet*, a color our eyes cannot see at all. Many flowers have ultraviolet lines that point like arrows toward the nectar. To us the flower looks plain yellow; to a bee it has a landing strip. Von Frisch also watched bees come home and do a *waggle dance* on the honeycomb. The direction and length of the dance tell the other bees which way to fly and how far to go.

The big idea. A flower cannot walk to another flower. To make seeds, it needs **pollen** from another flower of the same kind carried to its stigma, the sticky top of the pistil. Moving pollen this way is **pollination**, and an animal that does it is a **pollinator**. A bee visits flowers to drink sweet **nectar** and to gather pollen to feed its young. Its body is covered with branched, fuzzy hairs, so pollen sticks all over it. A honey bee combs much of the pollen into a **pollen basket** on each back leg. But some grains stay in its fuzz, and at the next flower a few rub off onto the stigma. The bee came for food, and the flower got pollinated.

In the world today. Honey bees were brought to America by English settlers in the early 1600s. But America already had about 4,000 kinds of native bees! Most of them, such as mason bees and sweat bees, do not live in hives or make honey. Each mother bee lives alone and nests in a little hole in the ground or in wood. Fuzzy bumblebees can grab a flower and buzz so hard that pollen shakes loose, which helps tomatoes and blueberries. Farmers bring hives of honey bees to apple, cherry and almond orchards in spring. Many fruits on your table began as a flower a bee visited.

God’s handiwork. On each trip, a honey bee usually visits only one kind of flower. That means clover pollen goes to another clover, not to a rose where it would be wasted. The flower gives food, and the bee gives the pollen a ride. Neither one planned it, but the One who made them both did.

PICTURE STUDY



The Beekeepers, Pieter Bruegel the Elder, about 1568 · Pen and brown ink on paper · Kupferstichkabinett (Museum of Prints and Drawings), Berlin

Pieter Bruegel the Elder was a painter from the Low Countries (today Belgium and the Netherlands) who loved to draw farm people at work. In his time, beekeepers kept their bees in *skeps*, dome-shaped hives woven from straw. To harvest honey, they covered their faces with woven masks to keep from being stung. In this drawing Bruegel shows beekeepers busy with their hives, and a boy who has climbed a tree, perhaps to find a wild bees' nest.

Look closely

- Find the beekeepers' masks. Why do you think their faces are covered?
- Find the straw hives. How are they different from the wooden box hives beekeepers use today?
- Find the boy in the tree. What might he be looking for?
- The drawing is made only with lines of ink. How did Bruegel show the round shape of the hives?

Talk about it

1. What do you think it would feel like to stand near a hive full of buzzing bees?
2. Beekeepers long ago did not know as much about bees as we do. What would you want to tell them from this lesson?
3. Besides honey, what good thing do the bees in this drawing do for the farm?

Safety first. Bees and wasps can sting. Do the color experiment only with an adult, and skip it if anyone in your family is allergic to stings. Wear shoes, sit quietly at least 6 feet

(about 2 meters) away, and never swat at a bee. Pour out the sugar water and pick up the cards when you finish.

EXPERIMENT: WHICH COLOR DO BEES CHOOSE?

Do the same experiment Karl von Frisch did. You will set out paper “flowers” of four colors, each with the same sugar water, and count which color the bees visit most. Our **question**: Do bees visit some colors more than others?

You will need

- Four squares of paper or index cards, about 4 inches (10 cm) on a side: blue, yellow, white and red
- Four plastic bottle caps
- Sugar water: 1 tablespoon of sugar stirred into 1/4 cup of water
- Four small stones to hold the cards down
- A timer or clock
- Science notebook and pencil

Steps

1. Write your **prediction** in your notebook: Which color will the bees visit most? Which least?
2. On a warm, sunny day, choose a spot near flowers where you have seen bees.
3. Lay the four cards in a row about 1 foot (30 cm) apart. Hold each down with a stone.
4. Set a bottle cap in the middle of each card and fill each cap with the *same* amount of sugar water.
5. Sit at least 6 feet (about 2 meters) away. Watch for 10 minutes. Each time a bee lands on a card, make a tally mark under that color.
6. Mix up the order of the cards and watch for 10 more minutes, so no color gets the best spot both times.
7. Add up the tally marks for each color and draw a bar graph like the one in Worked Example 1.
8. Write one sentence: Was your prediction right? What did the bees seem to choose?

Tips

- **What we change:** only the color of the card. **What we keep the same:** the sugar water, the caps, the card size and the distance apart. **What we measure:** the number of bee landings on each color.
- Bees may need a day to find your cards. If no bees come, leave the cards out and try again tomorrow at the same time.
- Count only bees. Flies and wasps may come too; you can keep a separate tally for them.

Check your work

- I wrote a prediction before I started.
- I kept everything the same except the color.
- I made a tally chart and a bar graph of my results.
- I can explain why bees might visit some colors more than others.

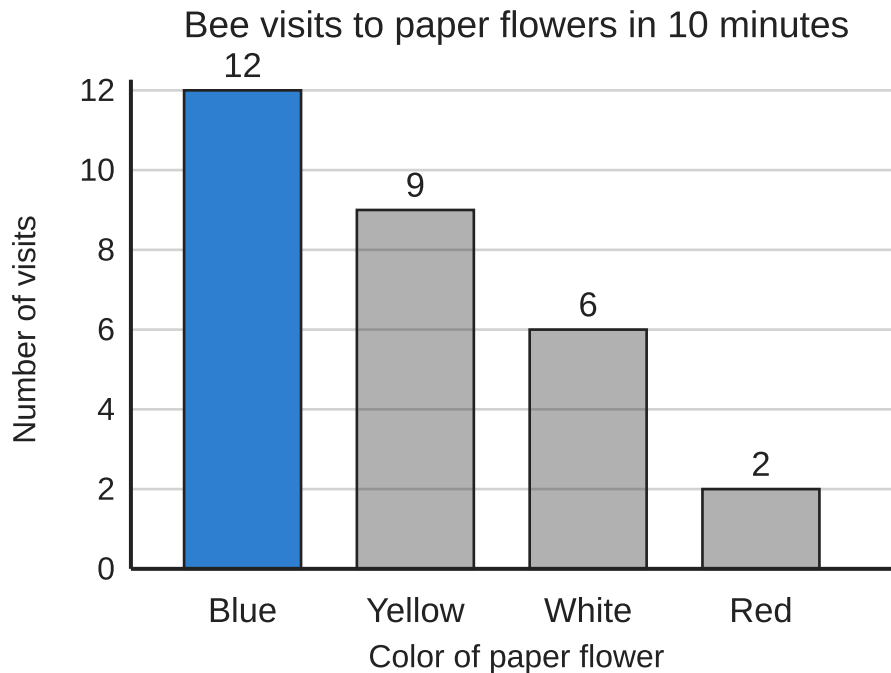
NATURE NOTEBOOK

1. Draw a large honey bee with its head, thorax and abdomen, six legs, four wings and two antennae. Color the pollen baskets on its back legs yellow and label them.
2. Watch a bee on a real flower for two minutes (from a safe distance). Draw the flower and write how many flowers the bee visited and whether they were all the same kind.
3. Draw two flowers side by side: one as you see it, and one with lines drawn on its petals pointing to the center, the way a bee might see it.

From history. In 1851 a minister named Lorenzo Langstroth, who kept bees in Philadelphia, noticed something important. Bees seal small gaps with sticky bee glue and fill big gaps with honeycomb, but they leave a space of about $\frac{3}{8}$ inch (about 1 centimeter) open as a walkway. Langstroth built a wooden hive with frames hung exactly that far apart, so a beekeeper could lift out each frame to check the bees and take honey without tearing the comb. He patented his hive in 1852, and the box hives with hanging frames that beekeepers use today come from his idea. He is often called the father of American beekeeping.

WORKED EXAMPLES

Example 1. A family did the color experiment and made this bar graph of bee visits in 10 minutes. Which color did the bees visit most? How many more visits did blue get than red? How many visits were there in all?



Bee visits to four paper flower colors in 10 minutes.

1. Find the tallest bar. The blue bar reaches 12, so blue got the most visits.
2. Read the red bar: it reaches 2. Subtract: $12 - 2 = 10$ more visits for blue.
3. Read every bar: blue 12, yellow 9, white 6, red 2.
4. Add them: $12 + 9 = 21$, then $21 + 6 = 27$, then $27 + 2 = 29$.

Answer: Blue got the most visits. Blue had 10 more visits than red. There were 29 visits in all.

Example 2. In her whole life, one worker honey bee makes only about $1/12$ of a teaspoon of honey. About how many worker bees does it take to make 1 teaspoon of honey? How many to make 1 tablespoon, which is 3 teaspoons?

1. Each bee makes $1/12$ of a teaspoon, so it takes 12 bees to make $12/12$, or 1 whole teaspoon.
2. A tablespoon is 3 teaspoons. Each teaspoon takes 12 bees.
3. Multiply: $3 \times 12 = 36$ bees.

Answer: About 12 bees for 1 teaspoon, and about 36 bees for 1 tablespoon. Every spoonful of honey is the life's work of many bees.

PRACTICE

1. **EASY** What is pollination? Why does a flower need it?
2. **EASY** Where on its body does a honey bee pack pollen to carry home, and what else on its body catches pollen?
3. **MEDIUM** Use the bar graph in Worked Example 1. How many more visits did yellow get than white? How many visits did white and red get together?
4. **MEDIUM** A worker honey bee is about $1/2$ inch long, which is about 12 millimeters. If 4 bees lined up nose to tail, about how long would the line be in inches? In millimeters?
5. **HARD** Sam wants to test whether bees like blue or red better. He puts sugar water on the blue card but only plain water on the red card. Why is this not a fair test? How should he fix it?
6. **CHALLENGE** A garden has red flowers and blue flowers. The bees visit the blue flowers much more often. Use what Karl von Frisch discovered to explain why.

COMMON MISTAKES

- Thinking all bees live in hives and make honey. Most of America's native bees live alone and nest in the ground or in holes in wood.
- Thinking bees carry pollen on purpose to help the flower. Bees gather pollen and nectar for food; the flower is pollinated by the grains that rub off along the way.
- Thinking bees see colors just as we do. Bees cannot see red well, but they can see ultraviolet, which we cannot see.

Make it a game · Waggle Dance Treasure Hunt. One player hides a small treat (the "flower patch") somewhere in the room or yard. That player comes back and does a bee dance: point your body in the direction of the treat and waggle your hips once for every three steps to walk. The other players must find the treat from the dance alone. Take turns being the scout bee.

Scripture. “More to be desired are they than gold, yea, than much fine gold: sweeter also than honey and the honeycomb.” (Psalm 19:10, KJV)

David is speaking of God’s words and judgments. He knew how sweet honey is, made by thousands of bees from thousands of flowers, and he said God’s Word is sweeter still.

Practice answers

1. Pollination is moving pollen to the stigma (the sticky top of the pistil) of a flower of the same kind. The flower needs it so it can make seeds.
2. It packs pollen into the pollen baskets on its back legs. Its fuzzy, branched body hairs catch pollen too.
3. Yellow had 3 more visits than white ($9 - 6 = 3$). White and red together had 8 visits ($6 + 2 = 8$).
4. About 2 inches ($1/2 + 1/2 + 1/2 + 1/2 = 2$). About 48 millimeters ($4 \times 12 = 48$), which is a little less than 5 centimeters.
5. He changed two things at once, the color and the drink, so he cannot tell which one the bees were choosing. He should put the same amount of the same sugar water on both cards so that only the color is different.
6. Von Frisch found that bees see blue and yellow well, but red looks dark to them, almost like gray or black. The blue flowers stand out to the bees, so they find them and visit them more. (Red flowers are often visited by other pollinators, such as hummingbirds.)

3.2 BUTTERFLIES AND MOTHS ★

OBJECTIVES

- Name the four stages of complete metamorphosis in order: egg, larva, pupa, adult.
- Tell a butterfly from a moth using clues such as antennae, resting wings and time of day.
- Explain how butterflies and moths drink nectar with a proboscis and carry pollen, and tell how Maria Sibylla Merian studied them.

Warm-up. Blow into a paper party blower, the kind that unrolls when you blow and curls back up when you stop. A butterfly's tongue works a lot like that! Then sip water through a straw from the bottom of a tall glass. How is the straw like a butterfly's tongue reaching into a deep flower?

Video. Coming soon. Monarch caterpillar forming a chrysalis and a butterfly coming out, butterfly proboscis close-up, and moths at a night light; search Smithsonian, U.S. Fish and Wildlife Service, SciShow Kids, Homeschool Pop (Alternate) and time-lapse nature footage of metamorphosis.

KEY TERMS

metamorphosis

A big change in body shape as an animal grows. Butterflies and moths change from egg to larva to pupa to adult.

larva

The young, worm-shaped stage of an insect that eats and grows. The larva of a butterfly or moth is called a caterpillar.

pupa

The resting stage when a caterpillar's body is rebuilt into an adult. A butterfly pupa is a chrysalis; many moth pupae are wrapped in a silk cocoon.

proboscis

The long, hollow tongue of a butterfly or moth. It stays coiled up until the insect unrolls it to sip nectar like a straw.

antennae

The two feelers on an insect's head, used to smell and feel. Their shape helps tell butterflies from moths.

CORE IDEAS

The story. In the German city of Frankfurt, a girl named Maria Sibylla Merian loved to gather caterpillars. She raised silkworms, fed them leaves, and watched them spin cocoons and come out as moths. In her day, many people believed small creatures like moths sprang

up by themselves from mud or rotting things. Merian watched carefully and painted what she saw: every moth came from an egg, then a caterpillar, then a pupa. When she was grown, she did something bold. In 1699 she and her daughter Dorothea sailed across the ocean to Suriname, in South America, to study the insects of the rain forest. In 1705 she published a great book of 60 pictures, *Metamorphosis of the Insects of Suriname*.

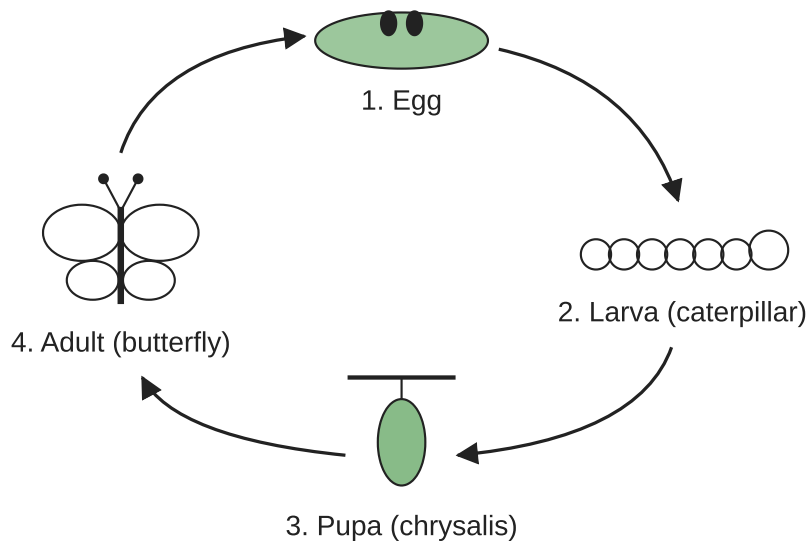
How they figured it out. Merian's secret was patience. She did not just catch a pretty butterfly. She kept the caterpillar, gave it the leaves it ate in the wild, and waited, sometimes for weeks. She learned that each kind of caterpillar eats only certain plants. So she painted the plant, the eggs, the caterpillar, the pupa and the grown insect together on one page. Scientists still use her method: watch the whole life of a living thing, not just one moment.

The big idea. Butterflies and moths grow through four stages, a change called complete **metamorphosis**: egg, **larva** (the caterpillar), **pupa**, and adult. The caterpillar eats and grows. Then it becomes a pupa. A butterfly pupa is a hard case called a chrysalis; many moth caterpillars spin a silk cocoon. Inside, the body is rebuilt, and an adult with wings comes out. The adult cannot chew. It drinks nectar through its **proboscis**, a tongue that stays coiled like a garden hose and unrolls into a flower like a straw. As it drinks, pollen sticks to its head, legs and body and rides along to the next flower.

Try it and see. How can you tell a butterfly from a moth? Look at the **antennae**. A butterfly's are thin with little clubs at the tips. A moth's are feathery, or thin with no club. Butterflies usually rest with wings folded up over their backs; moths usually rest with wings flat or like a tent. Most butterflies fly by day, and most moths fly at night. Night flowers made for moths, such as evening primrose and moonflower, are often white so they show up in the dark, and they smell sweet in the evening. The wings of both are covered with tiny scales, like shingles on a roof. That "dust" on your fingers when you touch a wing is really scales.

God's handiwork. A mother butterfly tastes with her feet. When she lands on a leaf, she can tell whether it is the right plant for her caterpillars. A monarch lays her eggs only on milkweed, the one food her caterpillars eat. She never sees her young hatch, yet their dinner is waiting for them.

Complete metamorphosis of a butterfly



Complete metamorphosis: egg, larva, pupa, adult, and back to egg.

PICTURE STUDY



Pomegranate with Butterfly and Caterpillar, from Metamorphosis of the Insects of Suriname (Metamorphosis insectorum Surinamensium), Maria Sibylla Merian, 1705 · Hand-colored engraving · Published in Amsterdam; copies are kept in many libraries and museums

Maria Sibylla Merian drew from life in Suriname, then went home to Amsterdam, where engravers cut her pictures into copper plates. Each printed page was painted by hand. Before Merian, most insect pictures showed one dead insect on a blank page. Merian showed

a whole life story on one page: the plant the caterpillar ate, the caterpillar itself, the pupa, and the grown insect with its wings spread.

Look closely

- Find the caterpillar. What is it doing, and what plant is it on?
- Find the pupa. Is it a hard chrysalis or wrapped in a cocoon?
- Find the grown insect. Look at its antennae and wings. Is it a butterfly or a moth?
- Find the flowers or fruit of the plant. Why do you think Merian painted the plant, too?

Talk about it

1. How many stages of the insect's life can you find on this one page?
2. Merian waited weeks to see each change. What would you need to raise a caterpillar yourself?
3. Why is a painting from life more useful to a scientist than a painting made from memory?

Safety first. Do the night watch only with an adult. Do not touch a hot light bulb, and keep lamp cords away from water. Watch moths and butterflies without grabbing them, because rubbing their wings knocks off scales they need. A few kinds of fuzzy or spiny caterpillars can sting, so do not pick up a caterpillar unless an adult says it is safe, and wash your hands afterward.

EXPERIMENT: DAY VISITORS AND NIGHT VISITORS

Are the insects that come at night different from the ones that come by day? You will count butterflies in the daytime and moths at a lighted sheet at night, then compare. Our

question: Do more moths come out at night than in the daytime?

You will need

- An old white bedsheet
- A clothesline, or two chairs, to hang the sheet
- A porch light, lamp or bright flashlight
- A magnifying glass
- A timer or clock
- Science notebook and pencil

Steps

1. Write your **prediction:** Will you see more moths at night or in the day? More butterflies at night or in the day?
2. Make a chart with two rows (Day, Night) and two columns (Butterflies, Moths).
3. On a warm, sunny afternoon, sit near a flower garden or field for 20 minutes. Tally every butterfly and every moth you see.

4. That night, about an hour after dark, hang the white sheet near the same place and shine the light on it.
5. Watch the sheet for 20 minutes. Tally every butterfly and moth that lands on it. Use the magnifying glass to check antennae: clubbed tips mean butterfly; feathery or no club means moth.
6. Draw one or two night visitors in your notebook, showing their antennae and how they hold their wings.
7. Compare your counts. Write one sentence telling whether your prediction was right.

Tips

- **What we change:** the time of day. **What we keep the same:** the place and the length of watching (20 minutes). **What we measure:** the number of butterflies and moths.
- Warm, still, cloudy nights in summer usually bring the most moths. A rainy or windy night may bring very few.
- Some moths fly by day, such as the hummingbird moth that hovers at flowers. Check antennae, not just the time.

Check your work

- I wrote a prediction and made my chart before I started.
- I watched for the same amount of time, in the same place, day and night.
- I used antennae and wings to tell butterflies from moths.
- I wrote whether my prediction was right.

NATURE NOTEBOOK

1. Draw the four stages of a butterfly's life in a circle with arrows, the way Merian might have, and draw the plant the caterpillar eats in the middle.
2. Draw a butterfly antenna and a moth antenna side by side, large, and label each one.
3. Find a flower outside that a butterfly visits. Draw it and write its color and shape, and whether it is open in the day or at night.

From history. In 1862 Charles Darwin received a white orchid from Madagascar whose nectar hid at the bottom of a tube nearly a foot long. He reasoned that somewhere in Madagascar there must be a moth with a tongue long enough to reach it, and many people doubted him. In 1903, after Darwin had died, scientists described a hawk moth from Madagascar with an enormously long proboscis, just the kind of moth Darwin had predicted. Its scientific name even ends with the word *praedicta*, which means "predicted."

WORKED EXAMPLES

Example 1. A family raised a monarch and kept a record. The egg hatched after 4 days. The caterpillar ate and grew for 14 days. The chrysalis stage lasted 10 days. How many days did it take from egg to butterfly? About how many weeks is that? Which stage was longest?

(Use the map or drawing “The four stages the family recorded.” shown earlier in this lesson.)

1. Add the days for each stage: $4 + 14 = 18$, then $18 + 10 = 28$ days.
2. A week has 7 days. Count by sevens: 7, 14, 21, 28. That is 4 weeks.
3. Compare the stages: 4, 14 and 10. The biggest is 14, the caterpillar stage.

Answer: 28 days, which is 4 weeks. The caterpillar (larva) stage was the longest.

Example 2. A monarch butterfly’s wingspan (tip to tip with wings open) is about 4 inches. A cecropia moth, the largest moth in North America, has a wingspan of about 6 inches. How much wider is the cecropia? Use $1 \text{ inch} \approx 2.5 \text{ centimeters}$ to give both wingspans in centimeters.

1. Subtract the inches: $6 - 4 = 2$ inches wider.
2. Monarch: $4 \text{ inches} \times 2.5 = 10 \text{ centimeters}$ ($2.5 + 2.5 + 2.5 + 2.5 = 10$).
3. Cecropia: $6 \text{ inches} \times 2.5 = 15 \text{ centimeters}$ ($10 + 2.5 + 2.5 = 15$).
4. Check: $15 - 10 = 5 \text{ centimeters}$, which is about 2 inches. The answers agree.

Answer: The cecropia is about 2 inches wider. The monarch is about 10 centimeters across and the cecropia about 15 centimeters, a difference of about 5 centimeters.

PRACTICE

1. **EASY** Name the four stages of complete metamorphosis in order.
2. **EASY** You find an insect resting on a porch at night with its wings spread flat. Its antennae look like tiny feathers. Is it a butterfly or a moth? Give two clues.
3. **MEDIUM** A flower has white petals, opens in the evening and smells very sweet at night. Which pollinator from this lesson is it probably made for? Why does white help?
4. **MEDIUM** A butterfly came out of its chrysalis on June 20. The chrysalis stage lasted 10 days. On what date did the caterpillar form its chrysalis?
5. **HARD** A newly hatched monarch caterpillar is about 2 millimeters long. A full-grown one is about 50 millimeters long (about 2 inches). How many times longer is the full-grown caterpillar?
6. **CHALLENGE** A student counted insects for 20 minutes at each time. Daytime garden: 8 butterflies, 1 moth. Night sheet: 0 butterflies, 12 moths. How many insects were

counted in all? At which time were most of the moths seen? What does this data suggest?

COMMON MISTAKES

- Thinking a caterpillar is a worm. A caterpillar is a young insect with six true legs near its head, and it will become a butterfly or moth.
- Thinking a small butterfly is a baby that will grow bigger. Adult butterflies and moths do not grow; all the growing happens in the caterpillar stage.
- Thinking all moths are dull brown and only fly at night. The luna moth is pale green, and some moths, such as the hummingbird moth, fly by day.

Make it a game · Butterfly or Moth?. A parent calls out a clue, such as “clubbed antennae,” “wings flat like a tent,” “flies at night,” “wings folded up over its back,” or “spins a silk cocoon.” If the clue fits a butterfly, stand tall and clap your hands over your head like folded wings. If it fits a moth, spread your arms out flat. A right answer earns a point; first to ten points wins.

Scripture. “Therefore if any man be in Christ, he is a new creature: old things are passed away; behold, all things are become new.” (2 Corinthians 5:17, KJV)

A caterpillar becoming a butterfly is not the same thing as a person being made new by Christ, but it is a beautiful picture of it. God loves to make things new.

Practice answers

1. Egg, larva (caterpillar), pupa (chrysalis or cocoon), adult.
2. A moth. Clues: feathery antennae with no clubs, wings held flat while resting, and it is out at night.
3. A moth. Most moths fly at night, and white petals are easier to see in the dark than dark colors. The strong evening smell also helps moths find it.
4. June 10 ($20 - 10 = 10$).
5. 25 times longer. Count by twos to 50, or think $2 \times 25 = 50$. All that growth comes from eating milkweed leaves.
6. $8 + 1 + 0 + 12 = 21$ insects. Most moths (12 of 13) were seen at night. The data suggests that most butterflies fly by day and most moths fly at night. (One count is not proof; the student should repeat it on other days.)

3.3 HUMMINGBIRDS AND BATS

OBJECTIVES

- Describe how hummingbirds hover and drink nectar, and name the clues of a flower made for hummingbirds.
- Explain how nectar bats pollinate night-blooming flowers such as the saguaro cactus, and define nocturnal.
- Use a flower-clue chart to match a flower to its likely pollinator, and solve simple wing-beat and nectar-recipe problems.

Warm-up. Hold your arms out and flap them as fast as you can for 10 seconds while someone counts your flaps. Write the number down. A hummingbird beats its wings about 50 times in just one second! Could you hover in one spot like that? Talk about why a hummingbird needs so much food.

Video. Coming soon. Slow-motion hummingbirds hovering and drinking from flowers, and nectar bats visiting saguaro or agave flowers at night; search Smithsonian, National Park Service, U.S. Fish and Wildlife Service, SciShow Kids and nature footage filmed with night cameras.

KEY TERMS

hover

To stay in one place in the air by beating the wings very fast, the way a hummingbird does in front of a flower.

nocturnal

Active at night and resting in the day. Bats and most moths are nocturnal.

tube-shaped flower

A flower whose petals form a long, narrow tube with nectar at the bottom, often visited by hummingbirds and moths with long tongues or beaks.

saguaro

A giant cactus of the Sonoran Desert in Arizona and Mexico. Its big white flowers open at night and are pollinated by bats, birds and bees.

CORE IDEAS

The story. In 1863 an American painter named Martin Johnson Heade sailed to Brazil, in South America, to paint hummingbirds. Hummingbirds live only in the Americas, and Brazil is home to many kinds that glitter green, ruby, violet and gold. Heade painted a set of small pictures he called *The Gems of Brazil*. For the rest of his life he kept painting hummingbirds beside tropical flowers such as orchids and passionflowers, with misty forest behind them.

He looked so carefully that you can often tell one kind of hummingbird from another in his paintings.

How they figured it out. Watchers like Heade noticed that hummingbirds visit certain flowers again and again. These flowers are usually red or orange, shaped like long tubes, full of nectar, and have little or no smell. A hummingbird does not land on the flower. It **hovers**, beating its wings about 50 times a second, and pushes its long beak deep inside. Its tongue is split at the tip, and it laps up nectar many times a second. While it drinks, pollen dusts its forehead or chin, and some rubs off on the next flower. Because bees cannot see red well, a red tube flower is a bit like a sign that says “For birds.”

The big idea. Some flowers wait until dark. In the deserts of Arizona and Mexico, the giant **saguaro** cactus opens big white flowers at night. They have a strong, musty smell and plenty of nectar. Their night visitors are bats! The lesser long-nosed bat pokes its long nose into the blossom and laps nectar with a long, brushy tongue. Pollen sticks to its furry face, and the bat carries it to the next cactus. Animals that are active at night are **nocturnal**. Flowers made for bats are usually large, pale, strong smelling and sturdy enough for a bat to grab. The saguaro flowers stay open into the next day, so birds and bees visit them too.

In the world today. There are more than 1,400 kinds of bats. Most eat insects, some eat fruit, and a smaller number drink nectar. Bats are not blind; they can see, and many also find their way by listening to echoes. Nectar bats help pollinate many cacti and agaves in the Americas and trees such as the baobab in Africa. You can watch hummingbirds at home by planting red tube flowers such as bee balm or trumpet honeysuckle, or by hanging a feeder.

God’s handiwork. The ruby-throated hummingbird, the only hummingbird that nests in most of the eastern United States, weighs about 3 grams, a little more than a penny. Yet each fall many of them fly across the Gulf of Mexico, about 500 miles, without stopping. A tiny bird and a red tube flower, a furry bat and a pale night flower: each one fits the other.

Flower clues: who is this flower made for?

Pollinator	Flower color	Smell	Flower shape	Open
Bee	blue, yellow, purple	sweet	place to land	day
Butterfly	red, orange, pink	light, sweet	flat cluster	day
Moth	white or pale	strong, sweet	deep tube	night
Hummingbird	red, orange	little or none	long tube	day
Bat	white or pale	strong, musty	large, sturdy	night

Flower clues: each kind of pollinator tends to visit flowers with these features.

PICTURE STUDY



Hummingbird and Passionflowers, Martin Johnson Heade, about 1875–1885 · Oil on canvas · The Metropolitan Museum of Art, New York

Martin Johnson Heade was an American painter who traveled to Central and South America to see hummingbirds in the wild. Most painters of his time showed birds alone, like specimens in a museum. Heade showed them alive, in their own homes, close to the flowers they visit. In this painting he paints a passionflower vine as carefully as the birds, because in the forest the two belong together.

Look closely

- Count the hummingbirds. Where is each one, and what is it doing?
- Find the passionflowers. What colors are they? Find a bud that has not opened yet.
- Find the curling tendrils that help the vine climb.
- Look at the background. Is it sharp or misty? Why might the painter have done that?

Talk about it

1. How did Heade make the birds and flowers stand out from the background?
2. If you were a hummingbird in this picture, where would you go first, and why?
3. What could a scientist learn from a painting made this carefully?

Safety first. Ask an adult to heat any water on the stove; hot water can burn. If you hang a feeder, an adult should help you wash it and change the nectar every few days, before it spoils. Never touch a bat, even one that seems sick or is lying on the ground; tell an adult, because bats can carry rabies.

EXPERIMENT: FUR, FEATHERS OR SMOOTH? THE POLLEN CARRIER TEST

Bees have fuzz, bats have fur, and hummingbirds have tiny feathers on their faces. Does a fuzzy face carry more pollen than a smooth one? Our **question**: Which kind of “face” carries the most pollen from one flower to the next?

You will need

- Three paper cups or cupcake liners for “flowers”
- Cocoa powder or colored chalk dust for “pollen”
- A pom-pom or piece of fuzzy sock (bat fur), a craft feather (hummingbird feathers) and a plastic spoon (a smooth face)
- Clear tape
- White index cards (the “stigmas”)
- Science notebook and pencil

Steps

1. Write your **prediction**: Which will carry the most pollen: fur, feather or smooth spoon?
2. Put 1/2 teaspoon of cocoa in the bottom of each cup.
3. Make a sticky “stigma”: stick a strip of tape on an index card, sticky side up, taping down only the ends.
4. Dip the pom-pom into a cup the same way each time: push it down once and lift it out. Then tap it once on the sticky tape.
5. Repeat with the feather and with the back of the spoon, each on its own fresh card.
6. Rate the pollen on each card: 0 = none, 1 = a little, 2 = some, 3 = a lot. Do three tries of each and record all the numbers in a table.
7. Add up the three scores for each carrier. Which carried the most pollen? Write one sentence about your prediction.

Tips

- **What we change**: the kind of surface. **What we keep the same**: the amount of cocoa, the way you dip and the way you tap. **What we measure**: the pollen score on the tape.
- Do this over a tray or newspaper; cocoa dust spreads.
- In spring and summer you can also hang a hummingbird feeder. Mix 1 part sugar with 4 parts water, with no red dye and no honey. Keep a tally of visits for 15 minutes each morning for a week.

Check your work

- I wrote a prediction before I started.
- I did each test the same way three times.
- I recorded my scores in a table and added them up.
- I can explain why furry bats and fuzzy bees make good pollen carriers.

NATURE NOTEBOOK

1. Draw a hummingbird hovering at a red tube flower. Draw a yellow dot of pollen on its forehead and label the beak, tongue and pollen.
2. Draw a saguaro cactus at night with a bat visiting one of its white flowers. Write the word nocturnal and what it means.
3. Copy the flower-clue chart into your notebook. Then find one real flower outside, draw it, and guess which pollinator it is made for.

From history. In 1988 the lesser long-nosed bat, the saguaro's night pollinator, was listed as endangered in the United States because so few were left. People went to work. Caves where the mother bats raise their young were protected and gated so the bats would not be disturbed, and landowners in Mexico and the American Southwest let more agave plants bloom so the bats had food along the route they travel each spring. The bats came back, and in 2018 the lesser long-nosed bat was taken off the endangered list, the first bat ever removed from that list because it had recovered.

WORKED EXAMPLES

Example 1. A ruby-throated hummingbird beats its wings about 50 times every second while it hovers. It hovers at a flower for 4 seconds. About how many times do its wings beat?

1. Each second has about 50 wing beats.
2. Count by fifties for 4 seconds: 50, 100, 150, 200.
3. Or multiply: $4 \times 50 = 200$.

Answer: About 200 wing beats in 4 seconds. Compare that with your own arm flaps from the warm-up!

Example 2. The usual recipe for hummingbird nectar is 1 part sugar to 4 parts water. That means $\frac{1}{4}$ cup of sugar for every 1 cup of water. How much sugar do you need for 2 cups of water? In metric cups, how much water goes with 50 milliliters of sugar?

1. Each cup of water needs $\frac{1}{4}$ cup of sugar.
2. For 2 cups of water: $\frac{1}{4} + \frac{1}{4} = \frac{2}{4} = \frac{1}{2}$ cup of sugar.
3. In milliliters, water is 4 times the sugar: $4 \times 50 = 200$ milliliters of water.
4. Check: in both cases there is 4 times as much water as sugar.

Answer: $\frac{1}{2}$ cup of sugar for 2 cups of water, and 200 milliliters of water for 50 milliliters of sugar.

PRACTICE

1. **EASY** Name two clues that a flower is made for hummingbirds.
2. **EASY** What does nocturnal mean? Name one nocturnal pollinator.
3. **MEDIUM** Use the flower-clue chart. A large, sturdy, pale flower opens at night and has a strong, musty smell. Which pollinator is it most likely made for?
(Use the map or drawing “Use the chart to match the flower to its pollinator.” shown earlier in this lesson.)
4. **MEDIUM** A ruby-throated hummingbird weighs about 3 grams. A U.S. nickel weighs 5 grams. About how much would 5 hummingbirds weigh? How many nickels is that?
5. **HARD** Using 1 part sugar to 4 parts water, how much sugar goes with 3 cups of water?
6. **CHALLENGE** Plan a fair test: Do hummingbirds visit a feeder with red on it more than a feeder with no red? Tell what you would change, what you would keep the same, and what you would measure.

COMMON MISTAKES

- Thinking bats are blind. Bats can see; many also use echoes to find their way and their food in the dark.
- Thinking hummingbirds suck nectar up through their beaks like a straw. They lap it up very fast with a long tongue that is split at the tip.
- Thinking hummingbird nectar needs red dye or honey. Plain white sugar and water (1 part to 4 parts) is best; the red on the feeder is enough to draw the birds, and honey can spoil and make them sick.

Make it a game • Who’s Visiting My Flower?. A parent describes a flower: “I am red and shaped like a long tube, and I have no smell,” or “I am big and white, I open at night, and I smell musty.” The child acts out the pollinator: hover and hum for a hummingbird, flap slowly with arms wide for a bat, buzz for a bee, flutter for a butterfly, or tiptoe in the dark for a moth. Then switch and let the child describe a flower.

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

A hummingbird needs food many times every hour, and God has filled the world with flowers full of nectar for it. Jesus says that if our Father feeds the birds, we can trust Him to care for us.

Practice answers

1. Any two: it is red or orange; it is shaped like a long tube; it has lots of nectar; it has little or no smell; it is open in the daytime.
2. Nocturnal means active at night and resting in the day. Nocturnal pollinators include bats such as the lesser long-nosed bat, and most moths.

3. A bat. Bat flowers are large, pale, sturdy, strong and musty smelling, and open at night. (A moth flower is pale too, but it smells sweet and is usually a deep, narrow tube.)
4. $5 \times 3 = 15$ grams, which is the same as 3 nickels ($5 + 5 + 5 = 15$).
5. $\frac{3}{4}$ cup of sugar ($\frac{1}{4} + \frac{1}{4} + \frac{1}{4} = \frac{3}{4}$).
6. Change only the color: one feeder with red, one with no red (for example, white or clear).
Keep the same: the same kind of feeder, the same nectar made the same way, the same height, sun or shade, and the same watching time each day; switch the feeders' places halfway through. Measure the number of hummingbird visits to each feeder, and repeat for several days.

3.4 THE YUCCA MOTH PARTNERSHIP

OBJECTIVES

- Describe, in order, what a female yucca moth does inside a yucca flower.
- Explain mutualism and tell how the yucca and the yucca moth each help the other.
- Tell how George Engelmann and Charles Valentine Riley discovered the partnership, and solve seed-count problems about yucca pods.

Warm-up. Think of two things that work best together, such as a lock and its key, or a bat and a ball. What happens if you lose one of them? Now try to tie your shoe with only one hand. Then try it with a partner, each of you using one hand. Some jobs need two partners, and in this lesson you will meet a plant and an insect that need each other.

Video. Coming soon. Yucca moths gathering pollen and pollinating yucca flowers at night, and yucca seed pods; search National Park Service, Smithsonian, university extension and botanical garden channels, and nature footage of desert plants.

KEY TERMS

mutualism

A partnership between two different kinds of living things in which both are helped.

stigma

The sticky top of a flower's pistil, where pollen must land for seeds to form.

ovary

The swollen bottom part of a flower's pistil, where seeds grow. It becomes the fruit or seed pod.

seed pod

The dry fruit that holds a plant's seeds. A yucca seed pod has rows of flat black seeds inside.

tentacles

Long, curling parts near the female yucca moth's mouth that she uses to gather and hold a ball of pollen.

CORE IDEAS

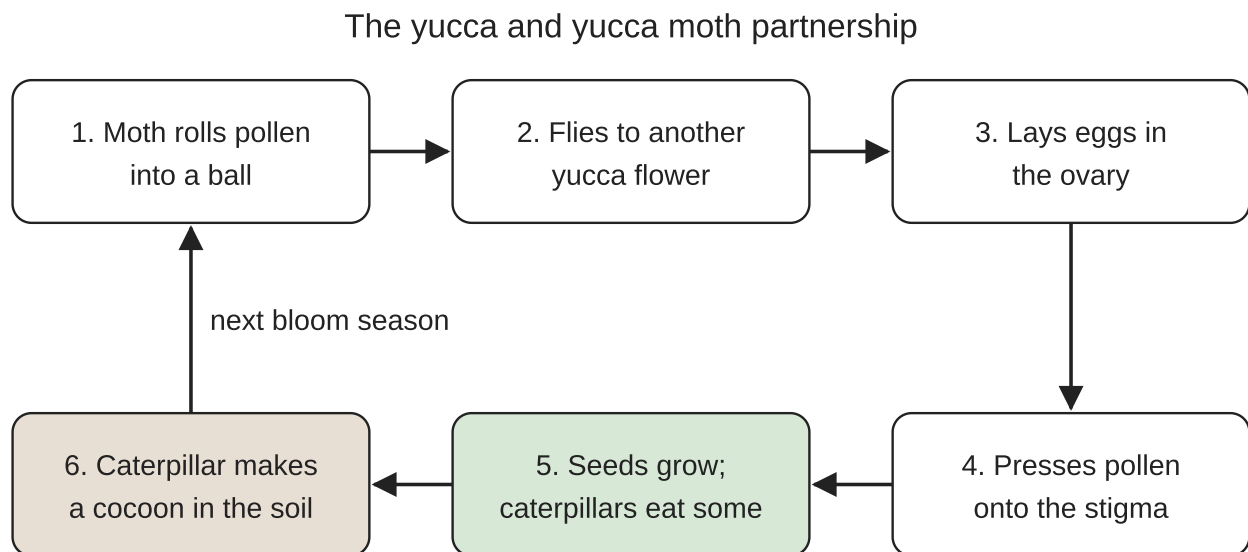
The story. In 1872, in St. Louis, Missouri, a botanist named George Engelmann puzzled over the yucca plant. Its creamy white, bell-shaped flowers hang down, and its sticky stigma is shaped so that pollen cannot simply fall onto it. Bees did not seem to pollinate it. Yet yuccas made seed pods. Something had to be carrying the pollen. Engelmann noticed small white moths in the blossoms and gave some to his friend Charles Valentine Riley, an insect scientist. Riley studied the moths and watched one do something no one had ever written down before.

How they figured it out. The female yucca moth has two curling **tentacles** near her mouth, which most moths do not have. With them she scrapes pollen from a yucca flower's stamens and rolls it into a sticky ball, which she tucks under her head. Then she flies to another yucca flower. There she lays her eggs inside the flower's **ovary**, where the seeds will grow. Next she climbs to the top of the pistil and presses the pollen ball into the **stigma**, as if she were planting a garden for her children. Riley published what he saw, and scientists around the world were amazed.

The big idea. A partnership in which two kinds of living things both gain is called **mutualism**. The yucca needs the moth: without it, its flowers make no seeds. The moth needs the yucca: its caterpillars eat only yucca seeds. When the eggs hatch, each tiny caterpillar eats some of the seeds in the growing **seed pod**, but many seeds are left to make new yucca plants. When the caterpillars are grown, they chew a hole out of the pod, drop to the ground and spin cocoons in the soil. They wait there until the yuccas bloom again, sometimes for more than a year. The grown moths do not eat at all. They live only a few days, long enough to lay eggs and pollinate.

Try it and see. Yuccas grow wild in deserts and prairies of the West and are planted in yards across much of the United States. In late spring or early summer, look for a tall stalk of white bells. With an adult, go out in the evening with a flashlight and peek inside the flowers for small white moths. Later in summer, find a seed pod and look for tiny round holes where the caterpillars chewed their way out. Count them.

God's handiwork. There is even a safety rule built in. If moths lay too many eggs in one flower, the yucca often drops that flower before the pod grows, so the caterpillars cannot eat up all of its seeds. The plant feeds the moth, and the moth plants the seeds. Partnerships like this make people wonder at the wisdom of the One who made them both.



The yucca gets pollinated; the moth's young get food.

The yucca and yucca moth partnership, step by step.

PICTURE STUDY



Yucca gloriosa, from *Les Liliacées*, Pierre-Joseph Redouté, 1802–1816 · Stipple engraving printed in color and finished by hand · Published in Paris in the book *Les Liliacées*; copies are kept in many libraries

Pierre-Joseph Redouté was a Belgian-born painter who worked in France and became one of the most famous flower painters who ever lived. People called him “the Raphael of flowers.” His great book *Les Liliacées* shows lilies and their relatives, painted life size from real plants, and among them is the yucca. Redouté had to be a careful scientist as well as an artist, so that botanists could name a plant from his picture.

Look closely

- Find the flowers. Which way do they point: up, out or down?
- Count the petals on one flower. (Yucca flowers have six.)
- Look at the leaves. Are they soft or stiff? How did Redouté show their sharp tips?
- Imagine a tiny white moth crawling inside one of these bells. Where would she put her pollen ball?

Talk about it

1. Why might a hanging flower be hard for pollen to fall into by itself?
2. If you painted a yucca for a science book, what parts would you be sure to show?
3. What would you add to this picture to tell the story of the yucca moth?

Safety first. Yucca leaves end in sharp, stiff points that can poke skin and eyes. Look at yuccas with an adult, keep your face well back from the leaves, and wear gloves if you handle a seed pod. Do not eat the dried beans used in the project, and keep them away from small children.

EXPERIMENT: SEEDS LEFT OVER: A YUCCA POD MODEL

Yucca moth caterpillars eat yucca seeds. Can the yucca still make plenty of seeds? You will use dried beans as seeds and a die to decide how many caterpillars hatch in each pod. Our **question**: Even when caterpillars eat some seeds, are most of the seeds left over?

You will need

- Dried beans (at least 50)
- A paper cup for the “seed pod”
- One number cube (die)
- Science notebook and pencil
- Optional: a real dried yucca seed pod, if you can find one

Steps

1. Write your **prediction**: In most pods, will more than half the seeds be left?
2. Count 50 beans into the cup. This is one seed pod with 50 seeds.
3. Roll the die. The number shows how many caterpillars hatched in this pod (1 to 6).
4. Each caterpillar eats 5 seeds. Take out 5 beans for each caterpillar.
5. Count the beans left in the cup and record: pod number, caterpillars, seeds eaten, seeds left.
6. Put all the beans back so there are 50 again, and repeat for 5 pods.
7. Look at your table. In how many pods were more than half the seeds (more than 25) left? Write one sentence about your prediction.
8. If you find a real yucca pod, open it with an adult, count the exit holes on the outside, and count the good seeds inside.

Tips

- **What we change**: the number of caterpillars (from the die). **What we keep the same**: 50 seeds in each pod and 5 seeds eaten by each caterpillar. **What we measure**: the seeds left in each pod.
- Check your counting with math: $\text{seeds left} = 50 - (\text{caterpillars} \times 5)$.
- This is a model, so the numbers are simpler than in a real pod, but the idea is the same.

Check your work

- I wrote a prediction before I started.
- I kept the number of seeds and the seeds per caterpillar the same every time.
- I recorded five pods in a table.
- I can explain why the partnership helps both the yucca and the moth.

NATURE NOTEBOOK

1. Draw the six steps of the yucca partnership as a comic strip, one box for each step. Give the moth a pollen ball under her head.
2. Draw a yucca plant from life, or from Redouté's picture. Label the flower stalk, the flowers and the sharp-tipped leaves.
3. Make a T-chart titled "Partners" with two columns: What the yucca gives the moth, and What the moth gives the yucca.

From history. Charles Valentine Riley went on to become the chief insect scientist for the U.S. Department of Agriculture. In the 1880s, a tiny scale insect was killing the orange and lemon trees of California. Riley sent a helper, Albert Koebele, to Australia, where the pest had come from, to look for its natural enemies. Koebele shipped back a little red-and-black ladybird beetle called the vedalia beetle. Released in the orchards in 1888 and 1889, the beetles ate the pests, and California's orange groves were saved. It was one of the first great successes of using one living thing to control another.

WORKED EXAMPLES

Example 1. A yucca seed pod grew 180 seeds. Three yucca moth caterpillars lived inside it, and each one ate about 20 seeds. How many seeds did the caterpillars eat in all? How many seeds were left to grow new yuccas?

1. Find the seeds eaten: $3 \text{ caterpillars} \times 20 \text{ seeds} = 60 \text{ seeds}$.
2. Subtract from the seeds in the pod: $180 - 60 = 120 \text{ seeds}$.
3. Check: $60 + 120 = 180$.

Answer: The caterpillars ate 60 seeds, and 120 seeds were left. The plant paid for its pollination with some seeds and still kept most of them.

Example 2. A student opened three yucca pods. Each one had grown 150 seeds. She counted the caterpillar exit holes: Pod A had 1 hole, Pod B had 2 holes and Pod C had 4 holes. Each hole means one caterpillar that ate about 20 seeds. How many seeds were left in each pod? Which pod lost the most?

1. Pod A: $1 \times 20 = 20$ eaten; $150 - 20 = 130$ left.
2. Pod B: $2 \times 20 = 40$ eaten; $150 - 40 = 110$ left.
3. Pod C: $4 \times 20 = 80$ eaten; $150 - 80 = 70$ left.
4. Compare: Pod C had the most caterpillars, so it lost the most seeds.

Answer: Pod A had 130 seeds left, Pod B had 110 and Pod C had 70. Pod C lost the most (80 seeds). This is why it helps the yucca to drop flowers that have too many eggs.

PRACTICE

1. **EASY** What is mutualism? Use the yucca and the yucca moth as your example.
2. **EASY** What does the female yucca moth carry from flower to flower, and how does she hold it?
3. **MEDIUM** Put these steps in order: (a) presses pollen onto the stigma, (b) rolls pollen into a ball, (c) caterpillars eat some seeds, (d) lays eggs in the ovary, (e) flies to another yucca flower.
(Use the map or drawing "Check your order against the diagram." shown earlier in this lesson.)
4. **MEDIUM** A yucca pod grew 200 seeds. Four caterpillars each ate about 20 seeds. How many seeds were left?
5. **HARD** A student measured a yucca flower stalk that was 4 feet tall. How many inches is that? One foot is about 30 centimeters; about how many centimeters tall is the stalk?
6. **CHALLENGE** Suppose all the yucca moths disappeared from a place where yuccas grow wild. What would happen to the yuccas there over many years? Explain your thinking.

COMMON MISTAKES

- Thinking the yucca moth visits the flower to drink nectar. The grown moth does not eat at all; she visits to gather pollen and lay her eggs.
- Thinking the caterpillars hurt the yucca so much that the partnership is bad for the plant. They eat only some of the seeds, and without the moth the yucca would make no seeds at all.
- Thinking any insect can pollinate a yucca. The yucca depends on yucca moths, which pack the pollen onto the stigma on purpose.

Make it a game • Partner Match. Make twelve cards, six pairs of partners: yucca and yucca moth, honey bee and blue flower, monarch caterpillar and milkweed, hummingbird and red tube flower, bat and saguaro, moth and white night flower. Lay them face down and take turns flipping two. If you find a pair, say one way the partners help each other to keep it. The player with the most pairs wins.

Scripture. "For the invisible things of him from the creation of the world are clearly seen, being understood by the things that are made, even his eternal power and Godhead; so that they are without excuse:" (Romans 1:20, KJV)

We cannot see God with our eyes, but Paul says we can see His power and wisdom in the things He made. A moth that plants seeds for the flower that feeds her children is one of those things.

Practice answers

1. Mutualism is a partnership in which two different kinds of living things both gain. The moth pollinates the yucca so it can make seeds, and the yucca feeds the moth's caterpillars with some of its seeds.

2. She carries a sticky ball of yucca pollen. She gathers it with the special tentacles near her mouth and holds it tucked under her head.
3. (b) rolls pollen into a ball, (e) flies to another yucca flower, (d) lays eggs in the ovary, (a) presses pollen onto the stigma, (c) caterpillars eat some seeds.
4. $4 \times 20 = 80$ seeds eaten. $200 - 80 = 120$ seeds left.
5. $4 \times 12 = 48$ inches. $4 \times 30 = 120$ centimeters, a little more than one meter.
6. The yucca flowers would not be pollinated, so they would make no seeds. The old plants might live for a while and some kinds can sprout new shoots from their roots, but no new yuccas would grow from seed, so over many years there would be fewer and fewer. Each partner needs the other.

UNIT 3 REVIEW

Answer each question. Show your work for any math and use complete sentences for explanations. The quiz is worth 40 points, 4 points for each question.

1. (4 pts) What is pollination? Why does a flower need it?
2. (4 pts) Name two parts of a honey bee's body that help it carry pollen.
3. (4 pts) Karl von Frisch put sugar water on a blue card among gray cards, then took the sugar water away. The bees still flew to the blue card. What did this show?
4. (4 pts) Name the four stages of complete metamorphosis in order. In which stage does the insect do all its growing?
5. (4 pts) Identify each insect as a butterfly or a moth: (a) thin antennae with clubs at the tips, resting with wings folded up over its back in the afternoon; (b) feathery antennae, resting with wings spread flat on a porch at night.
6. (4 pts) What did Maria Sibylla Merian do that helped people understand butterflies and moths?
7. (4 pts) A red, tube-shaped flower with lots of nectar and no smell is open in the daytime. Which pollinator is it most likely made for? Give one reason.
8. (4 pts) Which animal pollinates the saguaro cactus flowers at night? Name two clues that make the saguaro flower a good fit for this animal.
9. (4 pts) Tell, in order, three things the female yucca moth does in the yucca flowers.
10. (4 pts) The yucca and the yucca moth are an example of mutualism. Tell how each partner helps the other. Then solve: a pod grew 150 seeds and 2 caterpillars each ate 20 seeds. How many seeds were left?

UNIT PROJECT: MY POLLINATOR FIELD GUIDE

Make a small field guide of at least five pages, one for each pollinator in this unit: bee, butterfly, moth, hummingbird and bat, plus a page for the yucca and yucca moth partnership. On each page, draw the pollinator from life or from a good picture, draw a flower it visits, and write three facts: how it carries pollen, what kind of flower it likes (color, smell, shape, day or night), and one thing you observed or measured yourself. Add your bee color graph, your day-and-night insect chart, your pollen-carrier table and your yucca pod table at the back as your lab records.

- **Accuracy:** Facts about each pollinator and its flowers are correct, and body parts and flower parts are labeled correctly.
- **Observation:** Drawings are made carefully from life or from good pictures, and at least two pages include something the student saw or measured personally.
- **Records:** The lab records are complete, with a prediction, tallies or scores, and a sentence telling what the results showed.
- **Care:** The guide is neat, colorful and easy for someone else to use outdoors.

1. Pollination is moving pollen to the stigma (the sticky top of the pistil) of a flower of the same kind. The flower needs it to make seeds.
2. Its fuzzy, branched body hairs, which pollen sticks to, and the pollen baskets on its back legs.
3. It showed that bees can see the color blue and tell it apart from gray. (He also found that red looks dark to bees.)
4. Egg, larva (caterpillar), pupa (chrysalis or cocoon), adult. All the growing happens in the larva (caterpillar) stage.
5. (a) Butterfly. (b) Moth.
6. She raised caterpillars, fed them their real food plants, and painted every stage (egg, caterpillar, pupa, adult) with its plant. This showed that butterflies and moths come from eggs and caterpillars, not from mud. In 1705 she published her book of the insects of Suriname.
7. A hummingbird. Hummingbirds visit red or orange tube flowers in the day, reach deep with their long beaks, and do not need a smell to find flowers. (Bees cannot see red well.)
8. The lesser long-nosed bat. Clues (any two): the flowers open at night, they are large and white or pale, they have a strong musty smell, and they hold lots of nectar.
9. She gathers pollen with her tentacles and rolls it into a ball; she flies to another yucca flower and lays her eggs in the ovary; she presses the pollen ball onto the stigma.
10. The moth pollinates the yucca so it can make seeds; the yucca feeds the moth's caterpillars with some of its seeds. $2 \times 20 = 40$ eaten; $150 - 40 = 110$ seeds left.

FOOD CHAINS

Every living thing needs food, and in God's world every creature's supper connects to someone else's. In this unit you will learn to ask the naturalist's question: **who eats whom?** You will draw food chains with arrows that follow the sun's energy from a blade of grass to a grasshopper, a frog, a snake and a hawk. You will learn why green plants are the producers that start every chain, and why consumers must eat plants or animals to live.

You will sail to the Arctic with Charles Elton, who drew one of the first food webs on Bear Island in 1921. You will weigh a willow tree with Jan Baptist van Helmont, time hungry barn owls with Gilbert White, and watch earthworms with Charles Darwin. Then you will become a bone detective, taking apart a real owl pellet to find out what an owl ate, and you will run a mold race to see the decomposers that turn dead things back into rich soil. By the end you will see how the whole loop fits together: sun, producers, consumers, decomposers, and back to the soil again.

BEFORE YOU BEGIN

- Can name the parts of a plant: root, stem, leaf and flower (Unit 1)
- Knows that plants need light and water to grow (Unit 2)
- Can add and subtract numbers to 1,000 and read a simple bar graph
- Can measure length with a ruler in inches

MASTERY CHECKLIST

- I can draw a food chain that starts with a plant, with the arrows pointing toward the eater.
- I can explain the words predator, prey and food web, and why there are fewer animals at the top of a food chain.
- I can tell producers from consumers and sort consumers into herbivores, carnivores and omnivores.
- I can take apart an owl pellet safely and use skulls and jaws to count what the owl ate.
- I can explain how decomposers return nutrients to the soil, and run a fair test on bread mold.
- I can read and compare numbers in a data table and a bar graph.

OPTIONAL BOOKS AND RESOURCES

- **Barn Owl guide from All About Birds (Cornell Lab of Ornithology)** (https://www.allaboutbirds.org/guide/Barn_Owl): Free. Photos, calls and life history of the barn owl. Listen to its rasping scream before Lesson 4.3 and look at the heart-shaped face.
- **Project Gutenberg** (<https://www.gutenberg.org/>): Free. Search for Gilbert White's *The Natural History of Selborne* (Lesson 4.3) and Charles Darwin's book on earthworms

(Lesson 4.4). These are old books for grown-ups; a parent may choose short passages to read aloud.

4.1 WHO EATS WHOM ★

OBJECTIVES

- Tell how Charles Elton studied who eats whom on Bear Island and named the food chain.
- Build a food chain that starts with a plant and draw the arrows the right way, from the eaten to the eater.
- Explain the words predator, prey and food web, and show why a food chain has fewer animals at the top.

Warm-up. Write down four things you ate yesterday. Next to each one, draw an arrow back to where it came from. Milk → cow → grass. Toast → wheat. Did every arrow end at a plant? Keep your list for the lesson.

Video. Coming soon. Food chains and food webs for children, predator and prey (search SciShow Kids, Homeschool Pop (Alternate), Smithsonian's National Zoo, and nature footage of ospreys fishing, hawks hunting and arctic foxes).

KEY TERMS

food chain

A path that shows who eats whom, starting with a plant. Food energy moves along the chain from one living thing to the next.

predator

An animal that hunts and eats other animals. A hawk is a predator.

prey

An animal that is hunted and eaten by a predator. A mouse is prey for a hawk.

food web

Many food chains in one place, crossing and connecting like roads on a map.

energy

The power to move, grow and stay warm. Living things get energy from food, and the energy in food first came from the sun.

CORE IDEAS

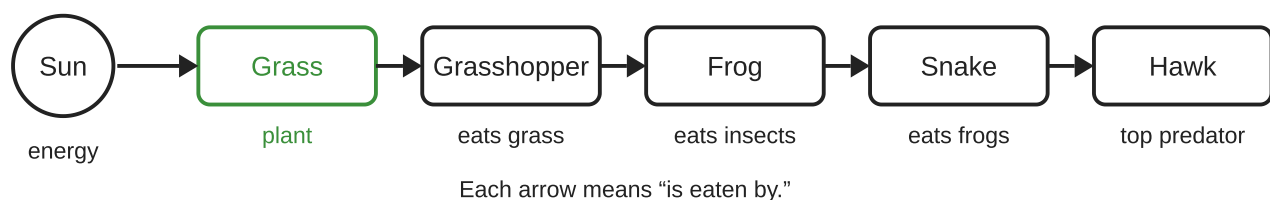
The story. In the summer of 1921, a young English scientist named Charles Elton sailed north with a team from Oxford University. They landed on Bear Island, a cold, rocky island in the Arctic Ocean between Norway and Spitsbergen. No trees grow there. The ground is covered with mosses, lichens and tiny flowers, and in summer the sea cliffs are crowded with nesting seabirds. Elton and his friend Victor Summerhayes, who studied plants, set out to list every living thing on the island. But Elton wanted to know more than names. He wanted to know *who eats whom*.

How they figured it out. Elton crawled over the moss looking for mites and springtails smaller than a grain of rice. He watched small birds peck at insects and seeds, and he saw arctic foxes hunting birds and stealing eggs. Back at Oxford, he and Summerhayes drew a chart with arrows joining every plant and animal to whatever ate it. They published it in 1923. It looked like a tangle of roads on a map. A few years later, in his book *Animal Ecology* (1927), Elton gave a name to each single road on that map: a **food chain**.

The big idea. A food chain shows how food **energy** moves from one living thing to the next. Here is one from a meadow: grass → grasshopper → frog → snake → hawk. The arrows point toward the eater. Read each arrow as “is eaten by.” Every food chain begins with a plant, because only plants can catch the sun’s energy and make food. An animal that hunts is a **predator**, and the animal it catches is its **prey**. The frog is a predator when it snaps up the grasshopper, and it is prey when the snake catches it. Most animals eat more than one thing, so real food chains cross and join into a **food web**, just like Elton’s tangled chart.

Try it and see. At each step up a food chain, most of the food energy is used up for moving, breathing and staying warm. Only a small part, about one tenth, is passed on to the next eater. That is why a field has thousands of grasshoppers, fewer frogs, still fewer snakes and only one or two hawks. Look out your window. Can you find a chain? A robin pulling an earthworm from the lawn is part of one. A squirrel nibbling acorns is part of another. Write down what you see and draw the arrows.

God’s handiwork. The psalm says, “The young lions roar after their prey, and seek their meat from God” (Psalm 104:21). God feeds every creature, from the springtail in the Arctic moss to the osprey diving for fish. The links of a food chain also keep one another in balance. Hawks and owls keep mice from eating all the grain, and so wise farmers are glad to see them. When we learn who eats whom, we learn to care for the whole web God made, not just one creature in it.



A meadow food chain. Read each arrow as “is eaten by.” The energy started in the sun.

PICTURE STUDY



Fish Hawk, or Osprey (Plate 81 from The Birds of America), John James Audubon, published 1827–1838 · Hand-colored engraving and aquatint, engraved by Robert Havell from Audubon's watercolor · Copies in many libraries and museums; Audubon's original watercolors are at the New-York Historical Society

John James Audubon traveled the woods, rivers and coasts of America to paint every bird he could find, life-size. His paintings were engraved and printed as *The Birds of America*, one of the largest and most famous bird books ever made. Audubon liked to show birds doing what they really do: hunting, feeding and caring for their young.

In this plate an osprey, also called a fish hawk, has just plunged into the water and come up with its dinner. The osprey is a predator, and the fish is its prey. You are looking at one link of a food chain.

Look closely

- Find the fish. How is the osprey holding it? Look closely at the feet and claws.
- Look at the wings. Is the osprey resting or working hard?
- Look at the fish's size compared with the bird. Would that be a big meal or a small one?
- Find the water. Where do you think the osprey caught the fish?

Talk about it

1. What did the fish eat before the osprey caught it? Can you make a food chain that ends with the osprey?
2. Why do you think Audubon painted the osprey carrying a fish instead of sitting still on a branch?
3. Is the osprey a predator, prey or both? Explain.

Safety first. Watch birds and squirrels at the feeder from indoors or from a distance. Never try to touch or hand-feed wild animals. Wash your hands with soap after handling birdseed.

EXPERIMENT: THE BIRD FEEDER CHOICE TEST

Birds are consumers, and many of them are near the bottom of a food chain because they eat seeds. In this small experiment you will find out which seed your backyard birds choose when they are given two kinds. While you watch, look for predators too: a hawk or a cat watching the feeder is part of the same food web.

You will need

- 2 identical shallow dishes, pie tins or plastic lids
- 1 cup (about 240 milliliters) of black-oil sunflower seed
- 1 cup (about 240 milliliters) of white millet or a mixed seed
- Measuring cup and a tablespoon
- Masking tape and a marker
- Notebook, pencil and a clock
- Binoculars and a bird guide (optional)

Steps

1. **Question:** Write it at the top of your page: “Do the birds in my yard eat more sunflower seed or more millet?”
2. **Prediction:** Write which seed you think the birds will eat more of, and why.
3. Label one dish “Sunflower” and one dish “Millet” with tape. Put exactly 1 cup of seed in each dish.
4. **What we change:** only the kind of seed. **What we keep the same:** the dishes, the amount of seed, the place and the time. Set the two dishes side by side, about 1 foot (30 centimeters) apart, on a porch rail, stump or flat spot where you can see them from a window.
5. **What we measure:** Watch for 15 minutes in the morning. Make a tally mark each time a bird visits a dish. If you can, write the kind of bird.
6. The next morning, measure how much seed is left in each dish with the measuring cup and tablespoon. Subtract to find how much was eaten.
7. **Record:** Make a table with three columns: Seed, Visits in 15 minutes, Seed eaten in one day. Then draw a bar graph of the visits.
8. Write a conclusion: Which seed did the birds choose? Was your prediction right? Draw one food chain that starts with your seed and ends with a predator you saw or know lives nearby.

Tips

- Squirrels may raid the dishes. That is not a ruined experiment; it is a discovery. Write it down, because squirrels are seed eaters too.
- Rain or wind can spill seed. If it does, run the test again on a calm day.
- Scientists repeat tests. If you can, run your test for three mornings and add up the visits.

Check your work

- I wrote a question and a prediction before I started.
- I changed only the kind of seed and kept everything else the same.
- I recorded my visits in a table and a bar graph.
- I drew a food chain with the arrows pointing toward the eater.

NATURE NOTEBOOK

1. Draw the meadow food chain from the lesson: grass, grasshopper, frog, snake, hawk. Draw the arrows pointing toward the eater and color the sun at the start.
2. Sketch one living thing you saw outdoors today. Around it, draw one thing it eats and one thing that might eat it.
3. Copy the title “Bear Island, 1921.” Draw moss, a small bird, a seabird egg and an arctic fox, and join them with arrows to make a food web.

From history. In *Animal Ecology* (1927), Charles Elton also noticed that the animals at the bottom of a food chain are small and very many, while the hunters at the top are large and few. He called this the “pyramid of numbers.” Think of a summer field: countless insects, many spiders and birds, and only one fox. Scientists still use Elton’s pyramid today, and his Bear Island chart was one of the first food webs ever drawn.

WORKED EXAMPLES

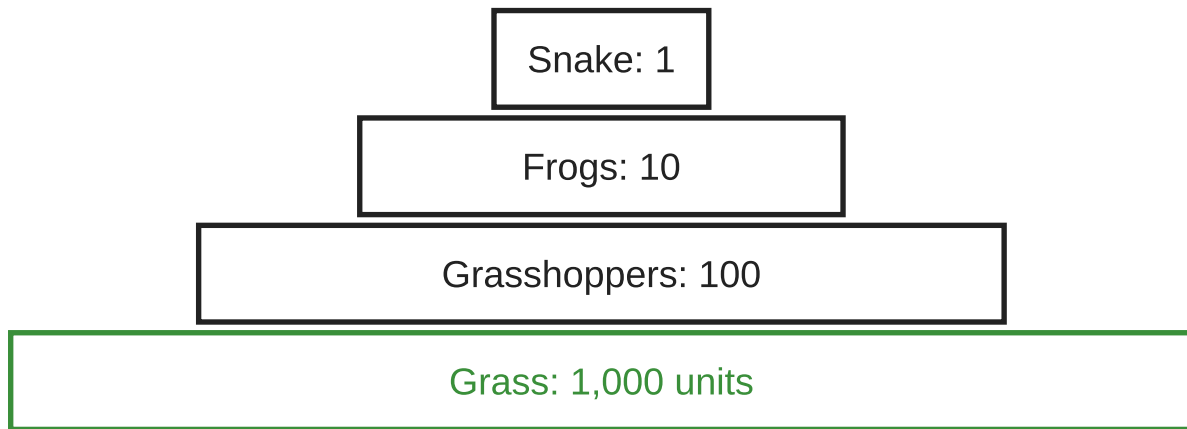
Example 1. Put these four cards in order to make a food chain, and draw the arrows: hawk, grass seeds, snake, mouse.

1. Find the plant first. Every food chain starts with a plant: **grass seeds**.
2. Ask, “Who eats grass seeds?” A **mouse** does: grass seeds → mouse.
3. Ask, “Who eats the mouse?” A **snake** does: mouse → snake.
4. Ask, “Who eats the snake?” A **hawk** does: snake → hawk.
5. Check the arrows. Each one points toward the eater, the way the food energy moves.

Answer: grass seeds → mouse → snake → hawk

Example 2. In a meadow, the grass holds 1,000 units of food energy. At each step up the food chain, only about one tenth of the energy is passed on. How much energy reaches the grasshoppers, the frogs and the snake?

About one tenth passes up each step



Each step up keeps only about one tenth of the energy. (Not drawn to scale.)

1. One tenth of a number is that number divided by 10.
2. Grass to grasshoppers: $1,000 \div 10 = \mathbf{100 \text{ units}}$.
3. Grasshoppers to frogs: $100 \div 10 = \mathbf{10 \text{ units}}$.
4. Frogs to snake: $10 \div 10 = \mathbf{1 \text{ unit}}$.
5. Notice how fast the energy shrinks. That is why there are many grasshoppers and only a few snakes.

Answer: Grasshoppers get 100 units, frogs get 10 units, and the snake gets 1 unit.

PRACTICE

1. **EASY** In the food chain seeds → mouse → owl, which animal is the predator and which is the prey?
2. **EASY** In a food chain drawing, which way should the arrows point?
3. **MEDIUM** Put these in order to make a food chain: fox, clover, rabbit.
4. **MEDIUM** Sam watched a feeder for 15 minutes. Birds visited the sunflower dish 14 times and the millet dish 6 times. How many visits were there in all? How many more visits did the sunflower dish get?
5. **HARD** A farmer's field has grass → mouse → snake. One year almost all the snakes leave the field. What will probably happen to the mice and to the grass? Explain.
6. **CHALLENGE** The plants in a pond hold 500 units of food energy. About one tenth is passed on at each step. Tiny animals eat the plants, small fish eat the tiny animals, and a heron eats the small fish. How much energy reaches the heron?

COMMON MISTAKES

- Drawing the arrows backward, from the hawk to the snake. The arrow points to the eater because it shows where the food energy goes.
- Starting a food chain with an animal. Every food chain starts with a plant (or with the sun that feeds the plant).
- Thinking predators are bad animals. Predators and prey both have a place in God's design, and predators keep animals like mice from growing too many.

Make it a game · Food Chain Line-Up. Write plants and animals on index cards: grass, acorn, grasshopper, mouse, squirrel, frog, snake, owl, hawk, fox. Shuffle and deal four cards. Race a parent or sibling to lay your cards in a row that makes a true food chain, starting with a plant. Say each link aloud: "The acorn is eaten by the squirrel..." Score one point for every correct arrow. If a card does not fit, trade it from the pile.

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

Even the strongest predator depends on God for its food. Psalm 104 is a whole song about God feeding His creatures, from the grass to the lions.

Practice answers

1. The owl is the predator. The mouse is the prey. (The seeds come from a plant.)
2. Toward the eater. Each arrow means "is eaten by" and shows the way the food energy moves.
3. clover → rabbit → fox
4. $14 + 6 = 20$ visits in all. $14 - 6 = 8$ more visits to the sunflower dish.
5. With fewer snakes eating them, the mice will probably grow in number. More mice will eat more grass seeds and grain, so the grass and the farmer's crop may suffer. A change in one link changes the others.
6. $500 \div 10 = 50$ units for the tiny animals; $50 \div 10 = 5$ units for the small fish; $5 \div 10 =$ one half of a unit for the heron. Very little energy reaches the top, which is why there are few herons.

4.2 PRODUCERS AND CONSUMERS

OBJECTIVES

- Tell how Jan Baptist van Helmont weighed a willow tree and its soil, and read his results from a bar graph.
- Explain that producers (green plants) make their own food from sunlight, water and air, and that consumers must eat to get food.
- Sort consumers into herbivores, carnivores and omnivores by looking at what they eat.

Warm-up. Hold a houseplant or a leaf from outside in one hand and a cracker in the other. Which one made its own food? Which one had to be made from something else? Trace the cracker back: cracker → flour → wheat plant. Then talk about it: where does the plant get *its* food?

Video. Coming soon. Producers and consumers, herbivores, carnivores and omnivores, how plants make food from sunlight (search SciShow Kids, Homeschool Pop (Alternate), Science Max, Smithsonian, and time-lapse footage of plants growing).

KEY TERMS

producer

A living thing that makes its own food. Green plants are producers: they use sunlight, water and air to make food in their leaves.

consumer

A living thing that cannot make its own food and must eat plants or other animals. All animals are consumers.

herbivore

A consumer that eats only plants, such as a rabbit, a deer or a caterpillar.

carnivore

A consumer that eats other animals, such as an owl, a hawk or a spider.

omnivore

A consumer that eats both plants and animals, such as a black bear, a raccoon or a person.

CORE IDEAS

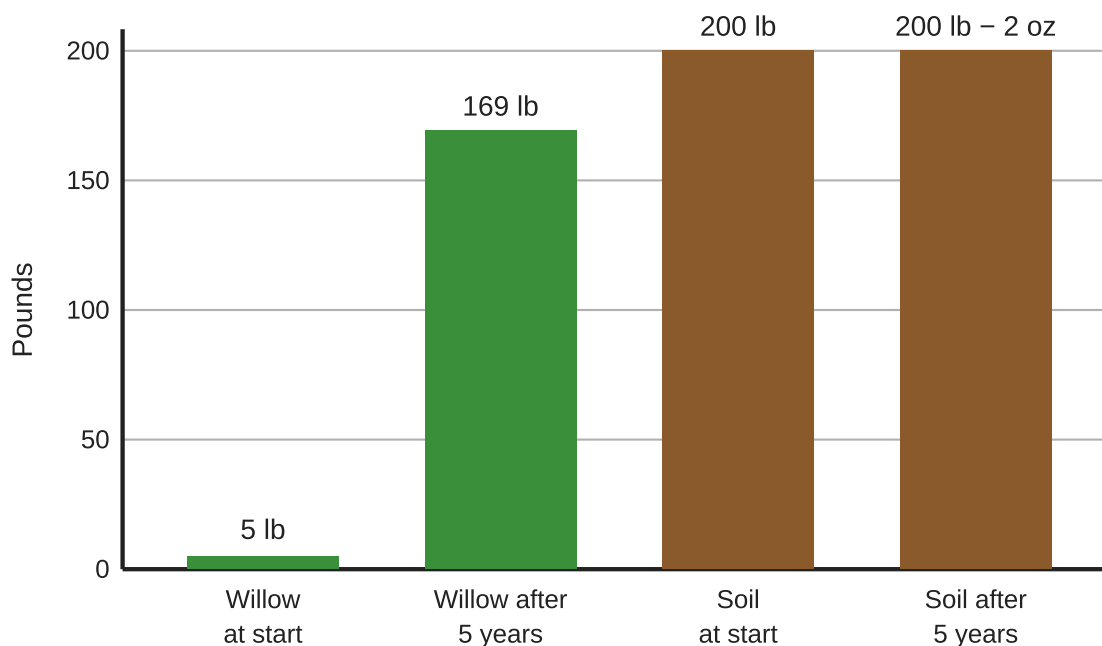
The story. Long ago, in what is now Belgium, a doctor and chemist named Jan Baptist van Helmont asked a simple question: where does a tree get the stuff it is made of? Most people thought plants “eat” soil. Van Helmont decided to find out with a scale. He dried 200 pounds of soil in an oven, put it in a big clay pot, and planted a little willow tree that weighed 5 pounds. He covered the pot with a metal lid full of small holes, so that air could get in but blowing dust could not. Then for five years he gave the tree nothing but rainwater. His report was printed in 1648.

How they figured it out. After five years, van Helmont pulled up the willow and weighed it: 169 pounds and 3 ounces, and that was without the leaves that had fallen each autumn. Then he dried the soil and weighed it again. It had lost only about 2 ounces! The tree had gained more than 160 pounds, but the soil was almost the same. Van Helmont decided the tree had been made from water alone. He was partly right. Later scientists, such as Joseph Priestley and Jan Ingenhousz, found that plants also take in a gas from the air, and that they need sunlight to do their work. Most of the willow's new wood came from the air!

The big idea. Green plants are **producers**. In their leaves they use the energy of sunlight to turn water and a gas from the air called carbon dioxide into sugar, their food. This is called *photosynthesis* (foe-toe-SIN-thuh-sis), which means "putting together with light." The soil gives plants water and a few minerals, but not their food. Animals cannot make food this way, so they are **consumers**: they must eat. A **herbivore** eats only plants. A **carnivore** eats other animals. An **omnivore** eats both. In a food chain, the producer always comes first.

In the world today. Every meal you eat begins with a producer. Bread comes from wheat. A hamburger comes from a cow that ate grass and hay. An egg comes from a hen that ate corn and bugs. Farmers are really tenders of producers: they care for the plants that feed the cows, the chickens and us. Even the hawk at the top of a food chain is eating sunlight that a plant caught first and passed along.

God's handiwork. On the sixth day of creation, God said that He had given "every green herb for meat" to the beasts, the birds and every creeping thing (Genesis 1:30). Quietly, without a sound, every leaf in your yard is making food from light, water and air. No factory in the world can do what one blade of grass does every sunny day.



Van Helmont's willow gained 164 pounds while the soil lost only about 2 ounces.

PICTURE STUDY



The Large Piece of Turf (Das große Rasenstück), Albrecht Dürer, 1503 · Watercolor and gouache on paper · Albertina, Vienna, Austria

Albrecht Dürer was a German artist from Nuremberg. Most painters of his day painted kings, saints and battles. But one day Dürer dug up, or knelt down beside, an ordinary clump of grass and weeds and painted it as carefully as a portrait. You can see every blade and every leaf.

Every plant in this painting is a producer. Each leaf is busy making food from sunlight, water and air. A clump like this one could feed a rabbit, a grasshopper, a caterpillar and a snail.

Look closely

- Find the dandelion leaves with their jagged, toothed edges.
- Count how many different kinds of leaves or grasses you can find.
- Look at the bottom of the painting. What is the ground like? Is it dry or damp?
- Find one leaf that would make a good meal for a caterpillar or a rabbit.

Talk about it

1. Why do you think Dürer painted something as plain as a patch of weeds?
2. Which consumers might live in or visit this little patch of grass?
3. What three things do these plants need to make their food?

EXPERIMENT: TRACE IT TO THE SUN

Is it true that *every* food we eat begins with a producer? Scientists test big ideas by checking many examples. You will check every food your family eats in one day.

You will need

- Notebook and pencil
- Colored pencils (green for producers)
- Food packages or a list of the day's meals
- Ruler for drawing a bar graph

Steps

1. **Question:** "Does every food we eat in one day come from a producer?"
2. **Prediction:** Write yes or no, and name any food you think might not come from a plant.
3. **What we change:** the food we look at. **What we keep the same:** the rule for tracing. For each food, keep asking "What did this come from?" or "What did it eat?" until you reach a plant.
4. List every food at breakfast, lunch, supper and snacks. Aim for at least 12 foods.
5. For each food, write a chain that ends at a plant, and color the plant green. Examples: toast → wheat. Cheese → milk → cow → grass. Honey → bees → flower nectar.
6. **What we measure:** Count the steps back to a plant. Toast is 1 step. Cheese is 3 steps.
7. **Record:** Make a table: Food, Chain back to a plant, Number of steps. Then draw a bar graph showing how many foods took 1 step, 2 steps and 3 or more steps.
8. Write a conclusion: Did every food lead back to a producer? Was your prediction right? Which food had the longest chain?

Tips

- Salt and water are not foods from living things. They are minerals, so leave them off your count, and write down that you did.
- Mushrooms are not plants. Put a star by them and wait for Lesson 4.4 to find out what they are.
- If you are stuck, ask a parent where a food comes from, or read the package.

Check your work

- I traced at least 12 foods back to a plant.
- I counted the steps for each food and made a bar graph.
- I can explain why every food chain starts with a producer.

NATURE NOTEBOOK

1. Draw a leaf with three arrows going into it labeled sunlight, water and air, and one arrow coming out labeled food (sugar).
2. Make three columns titled Herbivore, Carnivore and Omnivore. Draw or write two animals in each.
3. Draw van Helmont's pot and willow tree. Write 5 pounds beside the little tree and 169 pounds beside the big one.

From history. In 1771 the English minister and scientist Joseph Priestley put a burning candle in a closed glass jar, and soon the flame went out: the air was “used up.” Then he put a sprig of mint in the jar of used-up air. Some days later, a candle could burn in that air again. The plant had made the air fresh! A few years later, in 1779, the Dutch doctor Jan Ingenhousz showed that plants do this only when sunlight shines on their green parts. Step by step, these scientists found how producers work.

WORKED EXAMPLES

Example 1. Use the bar graph. How many pounds did van Helmont’s willow gain in five years? How much did the soil lose?

(Use the map or drawing “Van Helmont’s results.” shown earlier in this lesson.)

1. Read the willow bars: 5 pounds at the start and 169 pounds at the end (plus 3 ounces, which we will leave aside).
2. Subtract to find the gain: $169 - 5 = \mathbf{164 \text{ pounds}}$.
3. Read the soil bars: 200 pounds at the start and almost 200 pounds at the end. The soil lost only about **2 ounces**.
4. Compare: there are 16 ounces in 1 pound, so 2 ounces is only one eighth of a pound. The tree gained far, far more than the soil lost.
5. Conclusion: the tree did not grow by eating soil. Its new wood came mostly from water and air.

Answer: The willow gained 164 pounds (about 74 kilograms). The soil lost only about 2 ounces (about 57 grams).

Example 2. Use this table to sort each animal as a herbivore, carnivore or omnivore. Rabbit: clover, grass. Hawk: mice, snakes. Black bear: berries, fish, insects. Caterpillar: leaves.

1. Ask for each animal: does it eat plants, animals or both?
2. Rabbit eats only plants: **herbivore**.
3. Hawk eats only animals: **carnivore**.
4. Black bear eats berries (plants) and fish and insects (animals): **omnivore**.
5. Caterpillar eats only leaves: **herbivore**.
6. Count: 2 herbivores, 1 carnivore, 1 omnivore.

Answer: Herbivores: rabbit and caterpillar. Carnivore: hawk. Omnivore: black bear.

PRACTICE

1. **EASY** Is an oak tree a producer or a consumer? How do you know?

2. **EASY** A cow eats grass and hay. Is it a herbivore, a carnivore or an omnivore?
3. **MEDIUM** A bean seed weighed 1 ounce when it was planted. A few weeks later the bean plant weighed 9 ounces, and its pot of soil weighed the same as before. How many ounces did the plant gain? Where did most of that new weight come from?
4. **MEDIUM** A trail camera recorded what a raccoon ate in one week: blackberries, crayfish, corn, beetles. Is the raccoon a herbivore, carnivore or omnivore? Use the data to explain.
5. **HARD** Van Helmont covered his pot with a lid full of small holes. Why was that a smart thing for a scientist to do?
6. **CHALLENGE** Van Helmont said his willow was made from water alone. Write two sentences telling what he got right and what he missed.

COMMON MISTAKES

- Thinking plants get their food from the soil. Soil gives water and a few minerals, but plants make their own food in their leaves.
- Thinking an omnivore eats “anything.” An omnivore eats both plants and animals, but each kind still has its own favorite foods.
- Calling mushrooms plants or producers. Mushrooms cannot make food from sunlight. They are fungi, and you will meet them in Lesson 4.4.

Make it a game · Stand Up, Sit Down. A parent calls out a living thing. If it is a producer, stand tall with your arms up like branches catching the sun. If it is a consumer, sit and pretend to eat. Then, for consumers, call out herbivore, carnivore or omnivore for a bonus point. Try these: maple tree, deer, owl, corn, raccoon, spider, grass, person, rabbit, sunflower. Play until someone reaches ten points.

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)

“Meat” in the King James Bible means food. From the beginning, God made green plants to feed the creatures of the earth. Producers are His first gift in every food chain.

Practice answers

1. A producer. It is a green plant that makes its own food from sunlight, water and air.
2. A herbivore, because it eats only plants.
3. $9 - 1 = 8$ ounces. It came mostly from water and from carbon dioxide in the air, which the plant turned into food using sunlight.
4. An omnivore. Blackberries and corn are plants, and crayfish and beetles are animals, so it eats both.
5. The lid kept dust and dirt from blowing in and adding weight to the soil. It kept the soil the same, so the only thing added was water. That made his weighing fair.
6. He was right that the tree was not made from the soil, and right that water was part of it. He missed that the tree also took in carbon dioxide from the air and used sunlight to make its

food, and most of the wood came from that air.

4.3 OWL PELLET DISSECTION

OBJECTIVES

- Explain what an owl pellet is, how an owl makes it, and why it is a record of a food chain.
- Take apart an owl pellet safely, sort the bones, and identify skulls of rodents, shrews and birds.
- Count the prey animals in a pellet using skulls and jawbones, and read the class results from a bar graph.

Warm-up. Eat a few grapes or an orange slice, and spit the seeds into a cup. Your body knows some parts are not good to swallow. Now imagine you had no teeth and had to swallow your whole supper in one gulp, bones and all. What would you do with the parts you could not digest? Talk about your guess, then find out what an owl does.

Video. Coming soon. Owl pellet dissection for kids and how barn owls hunt by sound (search SciShow Kids, Homeschool Pop (Alternate), Cornell Lab of Ornithology, Smithsonian, and nature footage of barn owls hunting at night).

KEY TERMS

owl pellet

A small, tight bundle of fur, feathers and bones that an owl cannot digest and coughs up through its mouth.

regurgitate

To bring food back up from the stomach and out through the mouth. Owls regurgitate their pellets.

gizzard

A strong, muscular part of a bird's stomach. In an owl it squeezes the fur and bones into a pellet.

skull

The bones of the head, which hold and protect the brain. One skull means one animal.

rodent

A small mammal with long, curved front teeth for gnawing, such as a mouse, a vole or a rat.

CORE IDEAS

The story. In the 1770s, a country minister named Gilbert White lived in the village of Selborne, England. He loved to watch the animals around his home and wrote long letters about them, which became a famous book, *The Natural History of Selborne* (1789). A pair of barn owls nested under the eaves of the village church. On summer evenings White stood in

the dusk with his pocket watch and timed them. He found that one parent or the other came back to the nest with a mouse about once every five minutes! Those owls were catching a great many mice for their young.

How they figured it out. Where does all that mouse go? An owl has no teeth, so it swallows small prey whole or in a few big pieces. Its stomach digests the soft meat. But fur, feathers and bones cannot be digested. The muscular **gizzard** squeezes them into a tight, smooth bundle. Several hours later the owl stretches its neck and **regurgitates** the bundle out of its mouth. That is an **owl pellet**. A barn owl often coughs up one or two pellets a day, usually 1 to 3 inches (about 3 to 8 centimeters) long. Farmers have found them under owl roosts in barns and church towers for hundreds of years.

The big idea. An owl pellet is a food chain you can hold in your hand. Grass and seeds fed a vole, and the vole fed the owl. Inside a pellet you can find tiny **skulls**, jawbones, ribs, backbones, hip bones and leg bones. Each skull stands for one animal the owl ate. A **rodent** skull has two pairs of long, curved front teeth with a gap behind them. A shrew's skull is long and pointed, and its little teeth often have dark red tips. A bird skull has a beak and no teeth at all. Scientists study pellets to learn which small animals live in a field without ever setting a trap.

Try it and see. In this lesson you will take apart a real pellet with a toothpick and tweezers, just as a scientist would. Go slowly. The bones are as thin as a pencil lead and break easily. Sort them by shape onto a bone chart, count the skulls and lower jaws, and decide how many animals your owl ate. When the whole class or family puts their counts together, you can make a bar graph of the owl's menu.

God's handiwork. The barn owl is made for hunting in the dark. Its heart-shaped face works like a dish that gathers sound toward its ears. One ear opening sits a little higher than the other, which helps the owl tell exactly where a rustle came from, up or down as well as left or right. Soft, fringed edges on its wing feathers make its flight almost silent. A barn owl can catch a mouse by sound alone. God has given every creature what it needs for its place in the food chain.

PICTURE STUDY



Barn Owl (Plate 171 from The Birds of America), John James Audubon, published 1827-1838 · Hand-colored engraving and aquatint, engraved by Robert Havell from Audubon's watercolor · Copies in many libraries and museums; Audubon's original watercolors are at the New-York Historical Society

John James Audubon painted the birds of America life-size, and he often showed them with their food. In this plate he painted a pair of barn owls in the night. Look closely and you will see that the owls are not just sitting: one of them has caught its supper.

Barn owls hunt over fields and meadows at night and sleep by day in barns, hollow trees and towers. That is where people find their pellets.

Look closely

- Find the heart-shaped faces. Why might a face shaped like a dish help an owl hear?
- Look at the owls' feet. How many toes and claws can you see?
- Find the small animal one owl is holding. What kind of animal do you think it is?
- Look at the colors of the feathers. Would this owl be easy or hard to see at night over a field?

Talk about it

1. If this owl swallowed its prey whole, what would end up in its pellet the next day?
2. Make a food chain that ends with this barn owl.
3. Why do you think farmers are glad to have barn owls living in their barns?

Safety first. Use only owl pellets bought from a science supply company that says they were heat-sterilized. Do not take apart pellets found outdoors. Cover the table, keep food and drinks away, wear disposable gloves if you have them, and do not touch your face.

Toothpicks and tweezers are pointed; work slowly with an adult present. Wash your hands well with soap and warm water when you finish.

EXPERIMENT: WHAT DID THE OWL EAT?

You will be a bone detective. Your pellet holds the leftovers of the owl's meals. Your job is to find out how many animals it ate and what kinds they were.

You will need

- 1 heat-sterilized barn owl pellet (from a science supply company; many come with a bone chart)
- Paper plate and newspaper to cover the table
- Wooden toothpicks and tweezers
- Magnifying glass
- Ruler with inches and centimeters
- Disposable gloves (if you have them)
- A bone sorting chart (from the kit, or draw boxes labeled Skulls, Lower jaws, Ribs, Backbones, Hip bones, Leg and arm bones, Shoulder blades)
- White glue and dark paper (optional)

Steps

1. **Question:** "What did my owl eat, and how many animals were in this pellet?"
2. **Prediction:** Write how many animals you think you will find, and what kind.
3. **What we measure:** Measure the pellet's length in inches and in centimeters. Draw it in your notebook.
4. Hold the pellet gently and pull it in half with your fingers or tweezers. Use a toothpick to tease the gray fur away from the bones. Work slowly so the bones do not snap.
5. Lay each bone you free on the matching box of your sorting chart. Put skulls and jaws in their own boxes.
6. Use the magnifying glass to study each skull. Look for long curved front teeth (rodent), red-tipped teeth (shrew) or a beak (bird).
7. **Record:** Count the skulls and the lower jaw halves. Each animal has one skull and two lower jaw halves. Write how many animals you think the owl ate and what kinds.
8. If others did pellets too, add up everyone's skulls by kind and make a class bar graph. Throw away the fur in a sealed bag, wipe the table, and wash your hands.

Tips

- Pellets can be taken apart dry. If yours is very hard, an adult may soak it for a few minutes in warm water first.
- Skulls are often broken. Count a broken skull only if you can see the front teeth or most of the head.

- Glue your best bones onto dark paper and label them to make a display for your portfolio.

Check your work

- I followed every safety rule and washed my hands.
- I sorted the bones by shape on a chart.
- I counted skulls and jaws and decided how many animals the owl ate.
- I can name at least one food chain that ends with my owl.

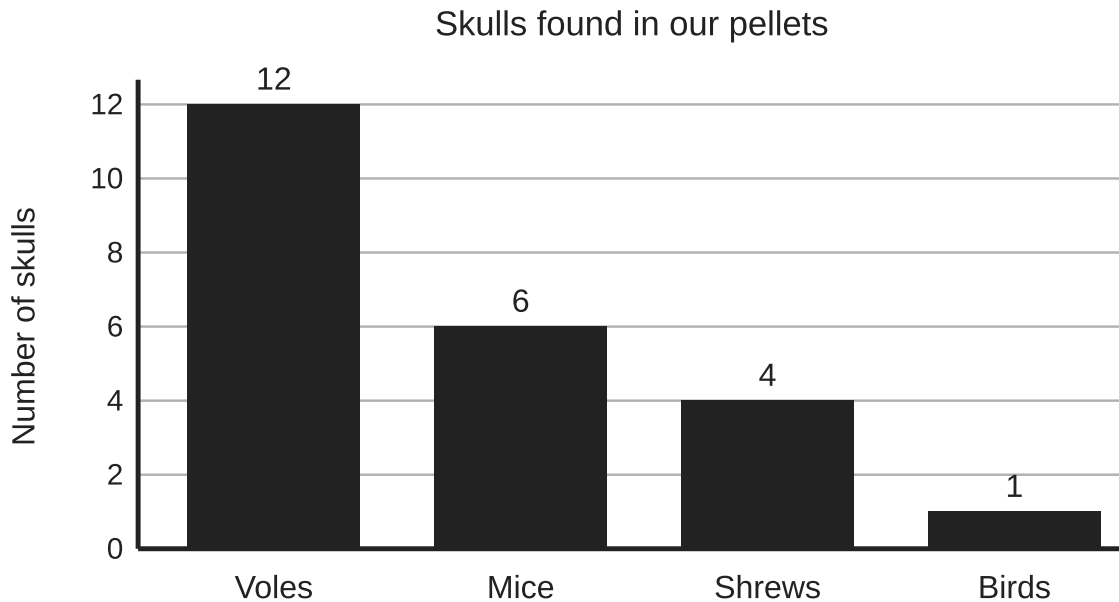
NATURE NOTEBOOK

1. Draw your owl pellet before you open it, at its real size. Write its length in inches and centimeters.
2. Draw one skull from your pellet, large and carefully, using the magnifying glass. Label the teeth and the eye holes.
3. Draw a food chain that ends with a barn owl. Write under it: "My pellet is the leftovers of this chain."

From history. The barn owl is one of the most widespread land birds in the world. It lives on every continent except Antarctica. For centuries farmers have welcomed barn owls into their barns, because a family of owls catches a great many mice and rats in a season. Today many farmers and families put up wooden barn owl nest boxes, and scientists use the pellets found beneath them to learn which small animals live in nearby fields.

WORKED EXAMPLES

Example 1. A family took apart several pellets and counted the skulls. Use the bar graph. How many animals did they find in all? How many more voles than mice?



Skulls found in one family's owl pellets.

1. Read each bar: voles 12, mice 6, shrews 4, birds 1.
2. Add them all: $12 + 6 = 18$, $18 + 4 = 22$, $22 + 1 = 23$ animals.
3. Compare voles and mice: $12 - 6 = 6$ more voles.
4. Notice that 12 is twice 6, so the owls ate twice as many voles as mice. Voles were their main food.

Answer: 23 animals in all; 6 more voles than mice.

Example 2. Mia's pellet had only 1 whole skull, but she found 5 lower jaw halves. What is the smallest number of animals the owl could have eaten?

1. Each animal has 2 lower jaw halves, a left one and a right one.
2. Pair the jaws: 2 halves make 1 animal, 2 more make a 2nd animal, and 1 half is left over.
3. The left-over half must belong to a 3rd animal.
4. The skull count says at least 1 animal, but the jaw count says at least 3. Use the bigger number, because skulls can be crushed while jaws survive.

Answer: At least 3 animals.

PRACTICE

1. **EASY** What is an owl pellet? Is it owl droppings?
2. **EASY** You find a skull with two pairs of long, curved front teeth and a gap behind them. What kind of animal was it?
3. **MEDIUM** A pellet is 2 inches long. One inch is about $2\frac{1}{2}$ centimeters. About how many centimeters long is the pellet?
4. **MEDIUM** A barn owl coughs up 2 pellets every day. How many pellets will it make in one week?
5. **HARD** A pellet has 3 skulls and 8 lower jaw halves. What is the smallest number of animals the owl ate? Explain.
6. **CHALLENGE** Scientists collect owl pellets to find out what small animals live in a field. Write two sentences: why does this work, and why might the count be a little too low?

COMMON MISTAKES

- Thinking a pellet is owl droppings. Pellets come up from the stomach and out of the mouth; droppings come out the other end.
- Counting every bone as a different animal. Each animal has many bones, so count skulls and pairs of jaws.
- Thinking owls chew their food. Owls have no teeth; they swallow small prey whole and let the gizzard sort out the leftovers.

Make it a game • Bone Detective. A parent draws or describes a mystery skull: “It has a beak and no teeth.” “It has long curved front teeth and a gap.” “Its tiny teeth have red tips.” Name the animal group (bird, rodent or shrew) to score a point. For a bonus, tell one food chain that animal belongs to. Then switch: you describe a skull and the parent guesses.

Scripture. “Who provideth for the raven his food? when his young ones cry unto God, they wander for lack of meat.” (Job 38:41, KJV)

God asked Job who feeds the hungry young birds. The answer is God Himself. Gilbert White’s barn owls, carrying mouse after mouse to their nest, are a picture of the Lord’s care for even the birds of the night.

Practice answers

1. It is a bundle of fur, feathers and bones the owl could not digest. It is not droppings: the owl coughs it up (regurgitates it) through its mouth.
2. A rodent, such as a mouse or a vole.
3. About 5 centimeters ($2\frac{1}{2} + 2\frac{1}{2} = 5$).
4. $2 \times 7 = 14$ pellets.
5. At least 4. Eight jaw halves make 4 pairs, and each animal has one pair. The jaws tell us more than the 3 skulls, because one skull may have been crushed.

6. It works because owls hunt the small animals of the field and leave their skulls in the pellets, so the skulls show which kinds live there. The count may be too low because tiny, thin bones (like shrew and bird skulls) can break, and some pellets are never found.

4.4 DECOMPOSERS

OBJECTIVES

- Tell how Charles Darwin studied earthworms and found that they slowly turn dead leaves into rich soil and bury things on the ground.
- Explain that decomposers such as fungi and bacteria, helped by worms and other small creatures, break down dead things and return nutrients to the soil for producers.
- Run a fair test on bread mold, record the results in a table, and compare the numbers.

Warm-up. Go outside and lift a flat stone, a board or a pile of old leaves (with a parent). What do you see underneath? Look for worms, roly-polies, white threads or soft, crumbly leaves. Put everything back the way you found it. Then talk about it: what happens to all the leaves that fall every autumn?

Video. Coming soon. Decomposers for kids: fungi, bacteria, earthworms and compost, with time-lapse of fruit and leaves rotting and mushrooms growing (search SciShow Kids, Homeschool Pop (Alternate), Science Max, Smithsonian, and nature time-lapse footage).

KEY TERMS

decomposer

A living thing that breaks down dead plants, dead animals and waste, and returns what they were made of to the soil.

fungi

Living things such as mushrooms and molds that cannot make their own food. Many feed on dead things and break them down. One is called a fungus.

bacteria

Living things so tiny that you need a microscope to see one. Many kinds break down dead things in soil and water.

nutrients

The materials in soil that plants need to grow strong and healthy.

compost

Rich, dark soil made when decomposers break down a pile of leaves, grass clippings and food scraps.

CORE IDEAS

The story. At Down House, his home in the English county of Kent, Charles Darwin kept pots of earthworms on a table in his study. He watched them for years. He tested whether they could hear: worms paid no attention to a shrill metal whistle or to the loud, low notes of a bassoon played right beside them. But when he set the pots on top of the piano and a note

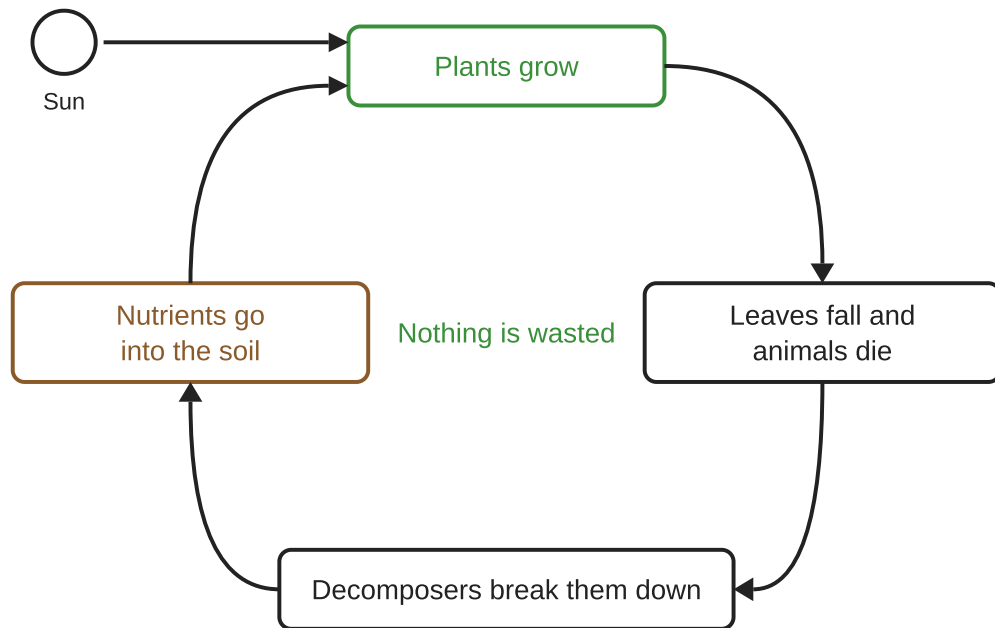
was struck, the worms quickly hid in their burrows. They could not hear, but they could feel the shaking! In 1881 Darwin published his last book, all about earthworms.

How they figured it out. Darwin found that worms pull dead leaves down into their burrows and eat them along with soil. They leave behind little piles called castings, which are dark, rich soil. Little by little the castings cover whatever lies on the ground. In one field near his home, broken chalk had been spread over the surface in 1842. When a trench was dug there 29 years later, the chalk lay buried about 7 inches (about 18 centimeters) deep, under soil the worms had made. Darwin's quiet worms had been rebuilding the field all along.

The big idea. When a leaf falls or an animal dies, it does not just disappear. **Decomposers** break it down. The most important decomposers are **fungi**, such as mushrooms and molds, and **bacteria**, which are too small to see without a microscope. Worms, roly-polies, millipedes, termites and some beetles help by eating dead things and breaking them into small pieces. Together they are nature's cleanup crew. They turn dead leaves, logs and bones back into **nutrients** in the soil, and producers take up those nutrients through their roots to grow new leaves. Decomposers are the last link of every food chain, and they lead right back to the first link.

Try it and see. You can watch decomposers at work in your own kitchen. Put a damp slice of bread in a sealed bag and wait. In a few days fuzzy spots of mold, a kind of fungus, will appear and spread. Gardeners put decomposers to work on purpose when they build a **compost** pile from leaves, grass clippings and vegetable scraps. A few months later, the pile becomes dark, sweet-smelling soil that makes a garden grow.

God's handiwork. In God's world, nothing is wasted. Every autumn, millions of leaves fall in the forest, yet the forest is not buried in them. The cleanup crew turns them into food for next spring's growth. Even the smallest creatures under a log have work to do. The Bible reminds us that our own bodies are made from the dust of the ground (Genesis 2:7), and that God, who made the soil, also made the creatures that keep it rich.



Decomposers close the loop: what dies feeds what grows.

PICTURE STUDY



Blue Mould (Observation XX, Schem. XII, from Micrographia), Robert Hooke, 1665 · Engraving, from Hooke's drawing made with a microscope · Published in London by the Royal Society; copies in many libraries

Robert Hooke was an English scientist who built one of the best microscopes of his day. In 1665 he published *Micrographia*, a book of large, careful drawings of tiny things: a flea, a fly's eye, a slice of cork and more. It amazed everyone who saw it.

In one picture Hooke drew the blue mold he found growing on the leather cover of a little book. Through his lenses the fuzzy spots turned into a forest of tiny stalks with round heads. He was looking at a decomposer at work.

Look closely

- Find the thin stalks. What do they remind you of?
- Look at the round knobs on top. Hooke thought they looked a bit like tiny mushrooms. Do you agree?
- Look at how the stalks are crowded together. Does this look like one living thing or many?
- Find a place where Hooke used fine lines to show shadow and roundness.

Talk about it

1. Mold was eating the leather book cover. What other things have you seen mold grow on?
2. Why do you think Hooke wanted to draw something as plain as mold?
3. Is mold a producer, a consumer or a decomposer? How do you know?

Safety first. Keep the mold bags sealed the whole time and look through the plastic. Never open or sniff a moldy bag. Anyone with mold allergies or asthma should not handle the bags. When you finish, throw the bags away still sealed. Wear gloves or wash your hands after touching soil, worms or rotting leaves, and never touch or eat mushrooms you find outdoors.

EXPERIMENT: THE MOLD RACE

Molds are decomposers. Do they need water to do their work? You will run a fair test with two slices of bread and find out.

You will need

- 2 slices of the same homemade or bakery bread (store bread with preservatives may take longer)
- 2 zip-top sandwich bags
- A spray bottle or spoon and water
- Masking tape and a marker
- Magnifying glass
- Notebook, pencil and ruler

Steps

1. **Question:** “Does bread mold faster when it is damp or when it is dry?”
2. **Prediction:** Write which slice you think will mold first, and why.

3. **What we change:** only the water. Sprinkle one slice with about 1 tablespoon of water so it is damp but not soggy. Leave the other slice dry.
4. **What we keep the same:** the kind of bread, the size of the slices, the bags and the place. Seal each slice in its own bag, label them Damp and Dry with the date, and put both bags side by side in the same dark, warm cupboard.
5. **What we measure:** Every day at the same time, look through the bag with the magnifying glass. Count the spots of mold on each slice and write the number. Note the colors you see.
6. **Record:** Make a table with three columns: Day, Spots on damp bread, Spots on dry bread. Keep going for 7 to 10 days.
7. Draw both slices on the last day. Then write a conclusion: Which slice molded first? Which had more spots? Was your prediction right?
8. Throw both bags away without opening them, and wash your hands.

Tips

- To add a third test, put a damp slice in the refrigerator. Does cold slow the decomposers down?
- If no mold appears after several days, your bread may have preservatives. Write that down; it is a real result.
- Compare with the mold Robert Hooke drew. Can you see tiny stalks or round heads with your magnifying glass?

Check your work

- I changed only one thing (the water) and kept everything else the same.
- I counted the mold spots every day and recorded them in a table.
- I followed the safety rules and never opened the bags.
- I can explain what molds and other decomposers do.

NATURE NOTEBOOK

1. Draw the decomposer loop: plants grow, leaves fall, decomposers break them down, nutrients go into the soil. Add arrows and a sun.
2. Draw one member of the cleanup crew you found outdoors (a worm, roly-poly, millipede or mushroom). Label where you found it.
3. Draw your two bread slices on the last day of the Mold Race and label the colors of the mold.

From history. In September 1928, the Scottish scientist Alexander Fleming came back to his laboratory at St. Mary's Hospital in London after a holiday. On one glass dish of germs, a spot of mold had grown, and all around the mold the germs had died. The mold was a kind of *Penicillium*, a decomposer. From that mold, other scientists later made penicillin, one of the first medicines that could cure dangerous infections. A humble decomposer saved millions of lives.

WORKED EXAMPLES

Example 1. Here is a Mold Race table. Damp bread spots on days 1 to 7: 0, 0, 0, 2, 5, 9, 14. Dry bread spots on days 1 to 7: 0, 0, 0, 0, 0, 1, 2. On which day did mold first appear on each slice? How many more spots did the damp bread have on day 7?

1. Find the first day the damp bread has a number bigger than 0: day 4 (2 spots).
2. Find the first day the dry bread has a number bigger than 0: day 6 (1 spot).
3. Read day 7: damp bread 14 spots, dry bread 2 spots.
4. Subtract: $14 - 2 = 12$.
5. Conclusion: the mold grew sooner and faster on the damp bread. Decomposers work best with water.

Answer: Damp bread: day 4. Dry bread: day 6. On day 7 the damp bread had 12 more spots.

Example 2. In October, a pile of raked leaves was 12 inches (about 30 centimeters) tall. By spring, the decomposers had worked on it, and the pile was only 3 inches (about 8 centimeters) tall. How many inches of the pile were broken down?

(Use the map or drawing “Where the leaves went.” shown earlier in this lesson.)

1. Start with the height in October: 12 inches.
2. Subtract the height in spring: $12 - 3 = 9$ inches.
3. In centimeters: about $30 - 8 = 22$ centimeters (a little more, because the numbers were rounded).
4. The leaves did not vanish. Fungi, bacteria and worms turned them into nutrients, water and air, and the bottom of the pile became dark, crumbly soil.

Answer: 9 inches (about 23 centimeters) of the pile were broken down.

PRACTICE

1. **EASY** Name two decomposers and two helpers in nature’s cleanup crew.
2. **EASY** What do decomposers give back to the soil? Who uses it?
3. **MEDIUM** Darwin’s chalk was buried about 7 inches deep. One inch is about $2\frac{1}{2}$ centimeters. About how many centimeters is that?
4. **MEDIUM** Ben put one damp slice of bread in a warm cupboard and one damp slice in the refrigerator. On day 7 the cupboard slice had 15 spots and the refrigerator slice had 3. What did Ben change? What can he conclude?
5. **HARD** Lucy wants to test whether bread molds faster in light or in dark. Name the one thing she should change, two things she should keep the same, and what she should measure.

6. **CHALLENGE** Imagine a forest with no decomposers at all. Write two or three sentences about what would happen over many years.

COMMON MISTAKES

- Thinking rotting things just disappear. They are broken into nutrients, water and gases that go back into the soil and air.
- Thinking all molds and bacteria are harmful germs. A few cause sickness, but most are helpful decomposers, and some even help make bread, cheese and medicine.
- Calling mushrooms plants. Mushrooms are fungi. They have no green leaves and cannot make food from sunlight, so they feed on dead things instead.

Make it a game • Cleanup Crew Tag. One player is the Decomposer. Everyone else is a falling leaf, twirling around the yard. When the Decomposer tags a leaf, that player must crouch down and become Soil. Soil can spring up as a new Plant when a free leaf runs by and says, “Nutrients!” Before each round, every player must name one decomposer or helper (mold, mushroom, bacteria, worm, roly-poly, millipede) to join the game.

Scripture. “All go unto one place; all are of the dust, and all turn to dust again.”
(Ecclesiastes 3:20, KJV)

Every living body returns to the dust, and decomposers are the workers God uses to do it. But the Bible does not end there: Christians trust the God who raised Jesus from the dead and who gives life that does not decay.

Practice answers

1. Decomposers: any two of mushrooms, molds (fungi) and bacteria. Helpers: any two of earthworms, roly-polies, millipedes, termites and beetles.
2. Nutrients. Producers (plants) take them up through their roots to grow.
3. $7 \times 2\frac{1}{2} = 17\frac{1}{2}$, about 18 centimeters.
4. He changed the temperature (warm or cold). Mold grew much more in the warm place, so molds decompose faster when it is warm and slower when it is cold.
5. Change: light or dark. Keep the same: any two of the kind of bread, the size of the slice, the amount of water, the bags, the temperature and the number of days. Measure: the number of mold spots each day (or the day mold first appears).
6. Dead leaves, logs and animals would pile up and never rot away. The nutrients would stay locked inside them, so the soil would grow poor and new plants could not grow well. With fewer producers, the animals that eat them would have less food too.

UNIT 4 REVIEW

A parent may read each question aloud. Answer in complete sentences, and show your work for counting and number questions. The quiz is worth 40 points, 4 points for each question.

1. (4 pts) Put these in order to make a food chain and draw the arrows: snake, grasshopper, grass, frog.
2. (4 pts) In the food chain acorn → squirrel → fox, which animal is the predator and which is the prey?
3. (4 pts) Who was Charles Elton, and what did he study on Bear Island in 1921?
4. (4 pts) Grass holds 1,000 units of food energy. About one tenth is passed on at each step. How much reaches the rabbits that eat the grass, and how much reaches the fox that eats the rabbits?
5. (4 pts) What is a producer? Name one, and tell the three things it uses to make its food.
6. (4 pts) Write herbivore, carnivore or omnivore for each: deer, owl, black bear.
7. (4 pts) Van Helmont's willow weighed 5 pounds at the start and 169 pounds after five years. The soil lost only about 2 ounces. How much did the tree gain, and what does that show?
8. (4 pts) What is an owl pellet, and how does an owl make one?
9. (4 pts) A pellet has 2 skulls and 6 lower jaw halves. What is the smallest number of animals the owl ate? Explain.
10. (4 pts) Name two decomposers and explain what decomposers do for producers.

UNIT PROJECT: MY FOOD WEB DISPLAY

Make a large poster that shows a real food web from your own yard, park or region. Draw or glue pictures of at least three producers, four consumers and two decomposers, and join them with arrows that point toward the eater. Label each living thing producer, herbivore, carnivore, omnivore or decomposer, and draw the sun at the start.

Beside the poster, add your owl pellet bone chart (with bones glued and labeled if you saved them), your bar graph of skulls, and your Mold Race table with a short conclusion. Finish with a paragraph explaining how energy moves up a food chain and how decomposers bring nutrients back to the soil.

- **Accuracy:** Every arrow points toward the eater, every food chain starts with a producer, and each living thing is labeled correctly.
- **Records:** The bone chart, skull bar graph and Mold Race table are complete, dated and correctly counted.
- **Explanation:** The paragraph explains producers, consumers and decomposers, the flow of energy from the sun, and the return of nutrients to the soil.
- **Care:** The display is neat, colorful and easy to read, with careful drawings like a real naturalist's.

Answer key

1. grass → grasshopper → frog → snake. The arrows point toward the eater.
2. The fox is the predator. The squirrel is the prey.
3. He was an English scientist from Oxford. On Bear Island in the Arctic he studied who eats whom, drew a chart of the island's food web, and later named the food chain.
4. Rabbits: $1,000 \div 10 = 100$ units. Fox: $100 \div 10 = 10$ units.
5. A producer is a living thing that makes its own food, such as a green plant (grass, an oak tree, corn). It uses sunlight, water and air (carbon dioxide).
6. Deer: herbivore. Owl: carnivore. Black bear: omnivore.
7. $169 - 5 = 164$ pounds. The tree was not made from the soil; its new wood came mostly from water and air.
8. It is a bundle of fur, feathers and bones the owl cannot digest. The owl swallows its prey whole, the gizzard packs the leftovers into a pellet, and the owl coughs it up (regurgitates it) through its mouth.
9. At least 3. Each animal has 2 lower jaw halves, and $6 \div 2 = 3$. The jaws show more animals than the skulls, because a skull may have been crushed.
10. Any two of mushrooms, molds (fungi) and bacteria (helpers such as worms also accepted for one). They break down dead plants and animals and return nutrients to the soil, which producers take up through their roots to grow.

HABITATS

Every creature God made has a home that fits it. “The high hills are a refuge for the wild goats; and the rocks for the conies” (Psalm 104:18). A **habitat** is the place where a plant or animal finds the four things it needs: **food, water, shelter and space**. In this unit you will visit three very different habitats, a grassy prairie, a steaming rainforest and a crowded coral reef, and then you will step out your own back door and discover that your yard is a habitat too.

You will travel up the Missouri River with Lewis and Clark as they pour barrels of water into a prairie dog hole, walk into the Amazon forest with Henry Walter Bates, and feel Captain Cook’s ship lurch onto the Great Barrier Reef. You will test how roots hold prairie soil, find out whether pointed drip-tip leaves shed rain faster, and use vinegar to discover what a coral skeleton is made of. Finally, like Frank Chapman’s Christmas bird counters, you will survey two squares of ground, tally every creature you find, and graph your data. In every habitat you will ask: **what helps this creature live here?**

BEFORE YOU BEGIN

- Can draw a food chain with arrows pointing toward the eater (Unit 4)
- Knows the parts of a plant and what plants need to grow (Units 1 and 2)
- Can add and subtract numbers to 1,000 and read a simple bar graph
- Can measure length in inches and feet with a ruler or yardstick

MASTERY CHECKLIST

- I can explain that a habitat gives a living thing food, water, shelter and space.
- I can describe a prairie, a tropical rainforest and a coral reef, and name animals that live in each.
- I can name the four layers of a rainforest and explain why coral needs clear, shallow, sunny water.
- I can give examples of adaptations, such as deep prairie roots, drip-tip leaves and a clownfish’s slimy coat.
- I can run a fair test that changes only one thing, and record my results in a table.
- I can survey a small plot, count with tally marks, make a bar graph and compare two microhabitats.

OPTIONAL BOOKS AND RESOURCES

- **Tallgrass Prairie National Preserve (National Park Service)**
(<https://www.nps.gov/tapr/>): Free. Photos and information about one of the last large tallgrass prairies, in the Flint Hills of Kansas, where a bison herd grazes again. Look at the pages on prairie plants and animals during Lesson 5.1.

- **Corals tutorial from NOAA Ocean Service** (https://oceanservice.noaa.gov/education/tutorial_corals/): Free. Clear pictures and short readings about coral polyps, the algae that live inside them, and the kinds of reefs. A parent can read sections aloud during Lesson 5.3.
- **Great Backyard Bird Count** (<https://www.birdcount.org/>): Free. Each February, families count birds for at least 15 minutes and report what they see. A good way to repeat your Lesson 5.4 survey as part of a real science project.

5.1 PRAIRIE ★

OBJECTIVES

- Tell how Lewis and Clark found and caught a prairie dog on the Great Plains in 1804, and name the four things every habitat gives: food, water, shelter and space.
- Describe a prairie and explain why it has grass and wildflowers but few trees.
- Run a fair test to show how grass roots hold soil, and name two adaptations that help prairie plants and animals live there.

Warm-up. Walk through your house and find four things you need to live: where you get food, where you get water, where you are sheltered from rain and cold, and where you have room to sleep and play. Write them down. Now pick a squirrel, a robin or a pet. Where does it find those same four things?

Video. Coming soon. Prairie habitat for children: tallgrass prairie, prairie dog towns and bison herds (search National Park Service Tallgrass Prairie National Preserve, Smithsonian's National Zoo, SciShow Kids, Homeschool Pop (Alternate), and nature footage of prairie dogs barking and bison grazing).

KEY TERMS

habitat

The place where a plant or animal lives and finds what it needs: food, water, shelter and space.

prairie

Wide, open land covered with grasses and wildflowers and only a few trees. The middle of North America was once one great prairie.

shelter

A safe place that protects an animal from weather and from predators, such as a burrow, a nest or a hollow log.

burrow

A hole or tunnel dug in the ground by an animal for a home.

adaptation

A body part or way of acting that helps a living thing live in its habitat, such as deep roots or a lookout bark.

CORE IDEAS

The story. On September 7, 1804, Meriwether Lewis and William Clark were traveling up the Missouri River with their Corps of Discovery, in what is now northern Nebraska. Near the river they came to a gentle slope covered with hundreds of little mounds of dirt. On top of the mounds sat small tan animals. They stood up straight, gave a sharp bark, and then

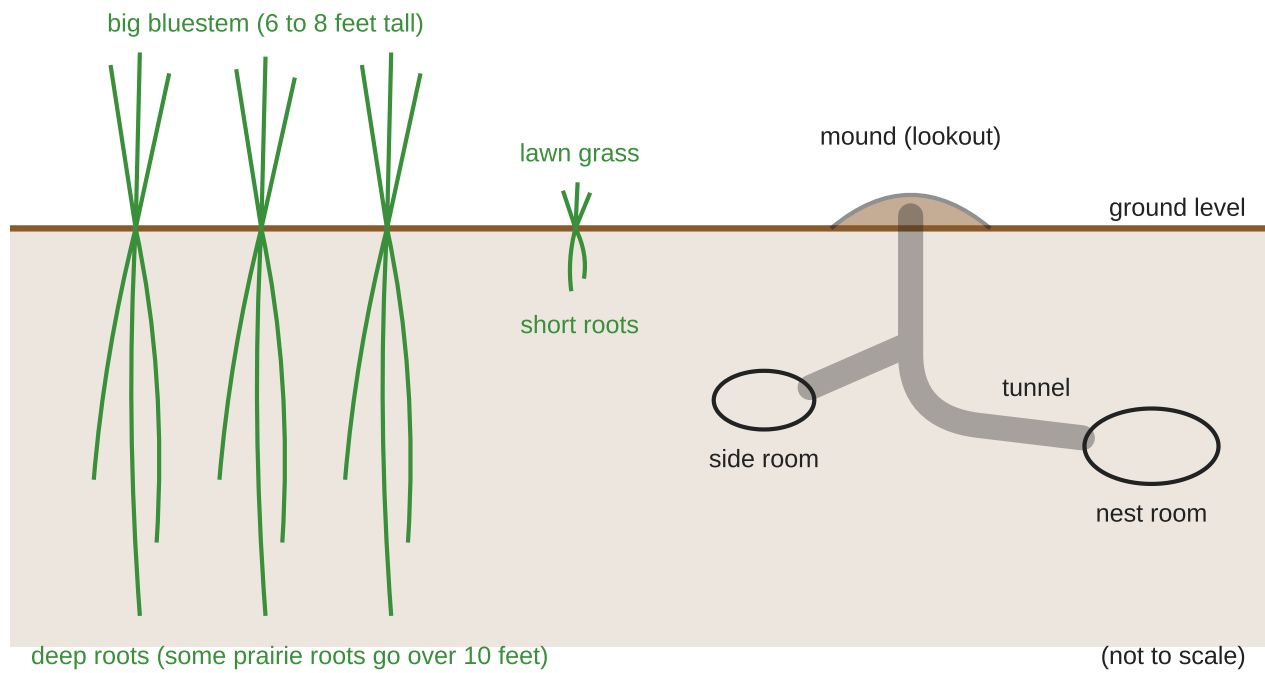
dove into holes. The French boatmen called them “little dogs.” Lewis called them barking squirrels. The men wanted one for President Thomas Jefferson, so they dug, then poured barrel after barrel of river water down one hole until a wet, surprised prairie dog came out. The next spring they sent a live prairie dog down the river, and it traveled all the way east and arrived alive.

How they figured it out. Lewis and Clark wrote down more than the animal’s name. They wrote what it ate, where it lived and how it hid. That is how a naturalist learns a creature’s **habitat**, the place where it finds four things: **food, water, shelter and space**. The prairie dog eats grasses and other plants, and it gets most of its water from the plants it eats. Its **burrow** is its **shelter**, with tunnels and rooms safe from hawks, coyotes and winter cold. The dirt mound by the door is a lookout post and keeps rainwater from rushing in. And a prairie dog town needs space: a wide, open field where the guards can see danger coming.

The big idea. A **prairie** is wide, open land covered with grasses and wildflowers, with only a few trees. Long ago the prairie stretched across the middle of North America, from Texas north into Canada. In most places there is not enough rain for a forest, and grass fires and grazing bison keep young trees from taking over. In the east, where more rain falls, big bluestem grass grows 6 to 8 feet tall. Farther west, near the Rocky Mountains, it is drier and the grass is short. Every prairie creature has **adaptations** that help it live there. Prairie dogs dig. Hawks have sharp eyes for spotting a mouse in the grass. Bison have thick, shaggy coats for the icy winter wind.

Try it and see. The most amazing part of a prairie is hidden. If you could lift a prairie like a carpet, you would find a second forest underground: roots. Many prairie plants have far more roots than leaves, and some send roots down more than 10 feet. Deep roots reach water in a dry summer, and when a fire burns the grass, the roots live and send up new green shoots. Roots also hold the soil in place. When too much prairie sod was plowed up and a long dry time came in the 1930s, wind blew the bare soil away in great dust storms. Farmers learned to plant windbreaks of trees and to plow along the curve of their hills.

God’s handiwork. The psalm says, “He causeth the grass to grow for the cattle” (Psalm 104:14). On the prairie, God feeds the bison, the pronghorn and the prairie dog with grass, and the grass with rain and sun. Each creature fits its home, and each one has a part to play in it.



Under the prairie: deep roots and a prairie dog burrow. (Not drawn to scale.)

PICTURE STUDY



Buffalo Bull, Grazing on the Prairie, George Catlin, 1832–1833 · Oil on canvas · Smithsonian American Art Museum, Washington, D.C.

George Catlin was a painter from Pennsylvania who wanted to record the people and animals of the West before they changed. In 1832 he rode a steamboat far up the Missouri River, the same river Lewis and Clark had traveled, and painted what he saw along the way. He painted bison, prairie dogs, wolves and the wide grassy land, often working quickly outdoors.

In this painting a bison bull, which people in Catlin's day called a buffalo, is doing what bison do most of the day: eating grass. Look at how much open space surrounds him. That open grassland is his habitat.

Look closely

- Look at the bison's shape. Where is his fur thickest? Why might that help him in a prairie winter?
- Find the horizon. Can you see any trees? What covers the ground instead?
- Look at the bison's head. Is it held high or low? What is he doing?
- Look at the sky and the land. How does Catlin show that the prairie is huge?

Talk about it

1. Name the food, water, shelter and space this bison needs. Which can you see in the painting?
2. Why do you think Catlin painted a bison standing alone in all that space?
3. How is this bison's habitat like a prairie dog's? How is it different?

Safety first. Dig the grass clump only with an adult, and only where you have permission. Keep fingers clear of the shovel blade. Wear gloves if you can, and wash your hands with soap after handling soil. Watch wild animals such as prairie dogs and bison only from a safe distance; never walk up to a bison.

EXPERIMENT: ROOTS AND RAIN: THE RUNOFF TEST

Prairie roots hold the soil when the rain pours down. In this small experiment you will pour the same "rainstorm" on soil with grass roots and on bare soil, and measure how much muddy water runs off each one.

You will need

- 2 identical aluminum loaf pans or shallow plastic tubs (an adult cuts a small V-shaped notch in the rim at one end of each)
- A clump of grass with its roots and soil, about the size of the pan, dug with an adult
- Bare garden soil, enough to fill the second pan to the same depth
- 2 books of the same thickness to tilt the pans
- 2 clear cups to catch the runoff
- A watering can or a cup with small holes poked in the bottom
- Measuring cup marked in ounces and milliliters
- Notebook, pencil and a ruler

Steps

1. **Question:** Write it at the top of your page: "Does grass with roots hold soil and water better than bare soil?"

2. **Prediction:** Write which pan you think will lose more water and more mud, and why.
3. Put the grass clump in one pan and pack bare soil to the same depth in the other. Use your ruler to check that both are the same depth.
4. **What we change:** only grass roots or no roots. **What we keep the same:** the pans, the depth of soil, the tilt and the amount of water. Set each pan on a book so the notched end hangs over the edge of a table, with a clear cup under the notch.
5. Measure 2 cups (16 ounces, about 480 milliliters) of water. Pour it slowly and evenly over the grass pan with the watering can. Do the same for the bare soil pan.
6. **What we measure:** Wait 5 minutes. Pour each cup of runoff into the measuring cup and read how many ounces ran off. Hold each cup up to the light and write whether the water is clear, a little cloudy or muddy.
7. **Record:** Make a table with three columns: Pan, Water that ran off (ounces), Color of the water.
8. Write a conclusion: Which pan lost more water and more soil? Was your prediction right? Explain what the roots did.

Tips

- Pour slowly, like a steady rain. A sudden splash will wash soil out of both pans.
- Let the cups stand for an hour after the test. Mud will settle to the bottom, and you can compare how much soil each pan lost.
- Put the grass clump back in the ground when you finish, and water it. It can keep growing.

Check your work

- I wrote a question and a prediction before I started.
- I changed only one thing: roots or no roots.
- I measured the runoff in ounces and wrote down its color.
- I explained how roots help hold the prairie soil.

NATURE NOTEBOOK

1. Draw a prairie dog standing on its mound like a lookout. Label its eyes, ears, front claws for digging and the mound.
2. Draw the cut-away view of a prairie: tall grass above the ground and long roots below. Under it write, "The hidden forest."
3. Make a habitat chart for a prairie dog with four boxes: Food, Water, Shelter, Space. Write or draw what it uses in each box.

From history. Bison once grazed the prairie in great herds, but by 1889 only about a thousand were left in all of North America. William Hornaday, director of the Bronx Zoo in New York, worked to save them. In 1905 he helped start the American Bison Society, with Theodore Roosevelt as its honorary president. In 1907 the Bronx Zoo sent 15 bison by train to the Wichita Mountains in Oklahoma to begin a new wild herd. Ranchers, parks

and Native American tribes raised bison too, and today about half a million bison live in North America.

WORKED EXAMPLES

Example 1. Big bluestem grass can grow 7 feet tall. Sam is 4 feet tall. How much taller is the grass than Sam? Give the answer in feet and in inches. About how tall is the grass in meters?

(Use the map or drawing “Big bluestem grows taller than a grown man, and its roots grow deep.” shown earlier in this lesson.)

1. Subtract the heights: $7 \text{ feet} - 4 \text{ feet} = \mathbf{3 \text{ feet}}$.
2. There are 12 inches in 1 foot. $3 \text{ feet} = 12 + 12 + 12 = \mathbf{36 \text{ inches}}$.
3. Check another way: $7 \text{ feet} = 84 \text{ inches}$ and $4 \text{ feet} = 48 \text{ inches}$. $84 - 48 = 36 \text{ inches}$. It matches.
4. One meter is a little longer than 3 feet. So 7 feet is a little more than 2 meters: **about 2 meters**.

Answer: The grass is 3 feet (36 inches) taller than Sam. It is about 2 meters tall.

Example 2. A rain gauge in the tallgrass prairie of eastern Kansas collects about 35 inches of rain in a year. A rain gauge in the shortgrass prairie of eastern Colorado collects about 15 inches. How much more rain falls on the tallgrass prairie? Which place has taller grass, and why?

1. Write the two amounts: tallgrass about 35 inches, shortgrass about 15 inches.
2. Subtract: $35 - 15 = \mathbf{20 \text{ inches}}$ more rain on the tallgrass prairie.
3. Think like a scientist: plants need water to grow. More rain means more water for the grass.
4. So the place with more rain, eastern Kansas, has the taller grass.

Answer: About 20 inches more rain falls on the tallgrass prairie. The grass grows taller there because it gets more water.

PRACTICE

1. **EASY** Name the four things every habitat must give a plant or animal.
2. **EASY** Give two reasons why a prairie has grass and wildflowers but few trees.
3. **MEDIUM** A prairie dog burrow goes 3 feet straight down before it turns. How many inches is that? About how many meters?
4. **MEDIUM** Maya did the runoff test. She poured 16 ounces of water on each pan. From the grass pan, 3 ounces of clear water ran off. From the bare soil pan, 10 ounces of muddy

water ran off. How many more ounces ran off the bare soil? What does this tell you about roots?

5. **HARD** Look at the diagram of the prairie underground. Why do deep roots help a prairie plant live through a dry summer and a grass fire? Write two or three sentences.
(Use the map or drawing “Compare the prairie grass roots with the lawn grass roots.” shown earlier in this lesson.)
6. **CHALLENGE** Jake did the runoff test, but he poured 1 cup of water on the grass pan and 3 cups on the bare soil pan. He said, “See, bare soil loses more water!” Is this a fair test? What should he change?

COMMON MISTAKES

- Thinking a habitat is just an animal’s house. A habitat gives food, water and space too, not only shelter.
- Thinking a prairie is empty land with nothing much in it. A prairie is full of grasses, wildflowers, insects, birds and burrowing animals, and much of its life is underground.
- Thinking an animal grows an adaptation because it wants one. A prairie dog does not decide to have digging claws; it is born with them, as God designed its kind, and passes them on to its young.

Make it a game · Prairie Dog Lookout. Lay pillows or towels around a room or yard as burrows. Everyone is a prairie dog nibbling grass except one lookout, who stands on a chair or step (the mound). A parent plays the hawk. When the lookout sees the hawk coming and gives a sharp “Yip!”, every prairie dog must dash to a burrow before being tagged. Anyone tagged becomes a hawk. Trade lookouts each round, and after each round name one thing a prairie dog’s habitat gives it.

Scripture. “He causeth the grass to grow for the cattle, and herb for the service of man: that he may bring forth food out of the earth;” (Psalm 104:14, KJV)

God makes the grass grow, and the grass feeds the grazing animals. A prairie is one great pasture that He waters and feeds.

Practice answers

1. Food, water, shelter and space.
2. Any two: there is not enough rain for a forest in most places; grass fires burn young trees; grazing animals such as bison eat or trample young trees.
3. 3 feet = 36 inches. That is almost 1 meter (a meter is a little longer than 3 feet).
4. $10 - 3 = 7$ more ounces ran off the bare soil. The roots held the soil and helped the water soak in instead of running away with the mud.
5. Deep roots can reach water far down in the soil after the top of the ground dries out. When a fire burns the leaves, the roots are safe underground, so the plant can send up new shoots. The roots also store food for regrowing.
6. No. He changed two things: roots and the amount of water. More water on the bare pan would make more runoff no matter what. He should pour the same amount of water, the same

way, on both pans so the only difference is roots or no roots.

5.2 RAINFOREST ★

OBJECTIVES

- Tell how Henry Walter Bates explored the Amazon rainforest and collected thousands of kinds of animals new to science.
- Name the four layers of a tropical rainforest from top to bottom and give an animal that lives in each.
- Test whether leaves with drip tips shed water faster than round leaves, and explain how this adaptation helps rainforest plants.

Warm-up. Fill a spray bottle with water. Spray a leaf from a houseplant or a tree outside five times, then hold it tipped downward. Watch where the water goes. Does it run off a point, drip from the edges, or sit in drops on top? Draw what you see.

Video. Coming soon. Tropical rainforest layers for children: emergent, canopy, understory and forest floor, sloths, toucans and leafcutter ants (search Smithsonian's National Zoo, SciShow Kids, Homeschool Pop (Alternate), Science Max, and nature footage of the Amazon rainforest canopy).

KEY TERMS

tropical rainforest

A thick forest near the equator where it is warm all year and rain falls almost every day.

layer

One level of the forest, from the treetops down to the ground. Each layer is a habitat with its own plants and animals.

canopy

The leafy roof of the rainforest, where the crowns of most of the tall trees meet. Most rainforest animals live here.

forest floor

The dark, damp ground of the forest, covered with fallen leaves. Very little sunlight reaches it.

drip tip

A long, pointed tip on a leaf that lets rainwater run off quickly.

CORE IDEAS

The story. In 1848 two young Englishmen, Henry Walter Bates and Alfred Russel Wallace, stepped off a sailing ship at Pará (today the city of Belém) in Brazil, where the great Amazon River meets the sea. Neither had much money. They planned to pay their way by collecting insects and birds and selling them to museums and collectors back home. Bates walked into the forest and could hardly believe it. Giant trees rose like pillars, and thick vines hung down

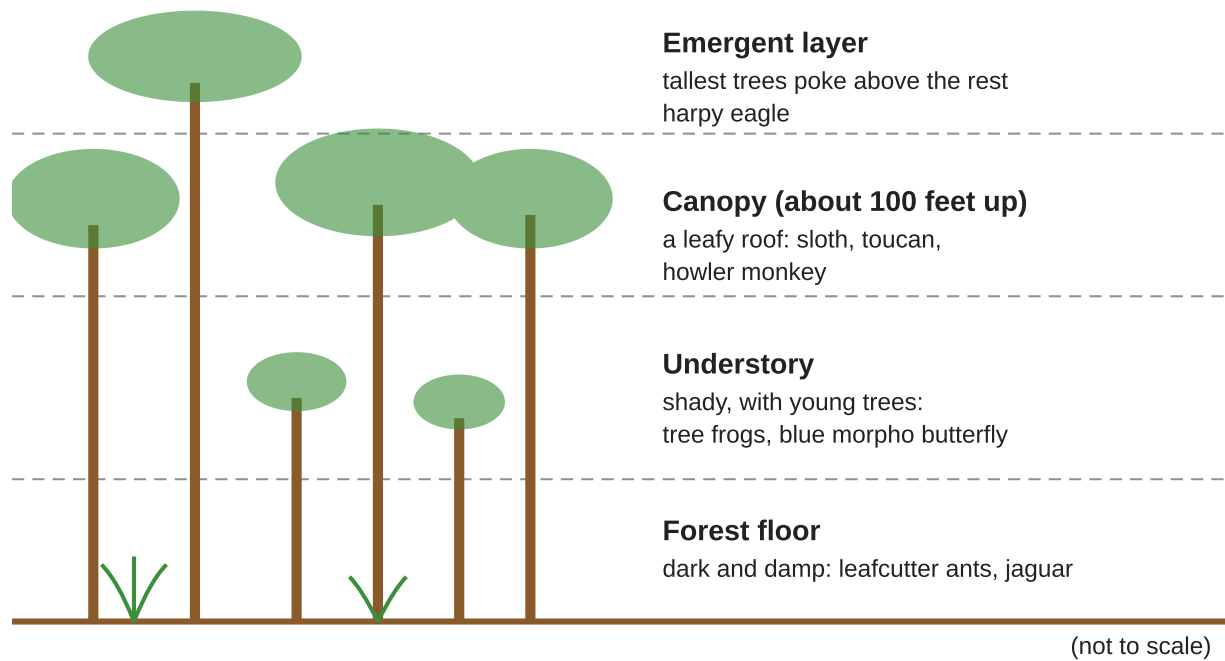
from far above. Bright butterflies drifted through the shade, and somewhere high overhead he heard monkeys and parrots he could not see. Wallace went home after four years, but Bates stayed in the Amazon for eleven.

How they figured it out. Bates collected every day. He pinned beetles and butterflies, wrote careful notes, and packed his boxes for the long voyage to England. By the time he came home in 1859, he had gathered specimens of more than 14,000 kinds of animals, mostly insects, and about 8,000 of them were new to science. Bates noticed that animals did not live just anywhere in the forest. Some butterflies flew only in the sunny treetops, others only in the shade near the ground. He saw that most of the forest's animals lived high up in the trees, where the leaves, flowers and fruit were. In 1863 he wrote a book about it all, *The Naturalist on the River Amazons*.

The big idea. A **tropical rainforest** grows near the equator, where it is warm all year and rain falls almost every day, often 80 inches or more in a year. The forest is built in **layers**, like the floors of a tall building. At the very top are the **emergent** trees, giants that poke up above the rest, where harpy eagles nest. Below them is the **canopy**, a leafy roof about 100 feet up, home to sloths, toucans and howler monkeys. Under the canopy is the shady **understory**, with young trees, tree frogs and blue morpho butterflies. At the bottom is the dark, damp **forest floor**, where leafcutter ants march and jaguars hunt. So little sunlight reaches the floor that many plants climb or perch high on branches to reach the light. Some, called bromeliads, hold little pools of rainwater in their leaves, where tree frogs raise their tadpoles.

Try it and see. When it rains this much, a wet leaf is a problem. Moss, mold and tiny algae grow fast on leaves that stay wet, and they block the sunlight the leaf needs. Many rainforest leaves have an adaptation called a **drip tip**: a long, pointed end that lets water run off quickly so the leaf can dry. Sloths have their own odd adaptation. They hang upside down and move so slowly that tiny green algae grow in their fur, which helps them blend in with the leaves. In this lesson you will build two leaves and test the drip tip yourself.

God's handiwork. Rainforests hold more kinds of plants and animals than any other habitat on land. The psalm says of God's trees, "Where the birds make their nests: as for the stork, the fir trees are her house" (Psalm 104:17). In the rainforest, a single tree can be a house for a whole crowd of creatures, each in its own layer.



The four layers of a tropical rainforest. (Not drawn to scale.)

PICTURE STUDY



Plate 18 from Metamorphosis of the Insects of Suriname: Spiders, Ants and Hummingbird on a Guava Tree,
Maria Sibylla Merian, 1705 · Hand-colored engraving made from Merian's watercolor · Published in
Amsterdam; copies are kept in many libraries and museums

You met Maria Sibylla Merian in the lesson on butterflies and moths. She sailed to Suriname, on the north coast of South America, and spent nearly two years in its hot, wet rainforest, drawing plants and animals from life. This page shows one guava branch as a busy habitat: ants on the march, spiders on the hunt, and a hummingbird's nest.

Later, some experts in Europe said Merian had made it up. A spider eating a bird? Nearly 150 years later, Henry Walter Bates found a huge hairy spider in the Amazon with two small birds caught in its web, and wrote it down. Merian had been right.

Look closely

- Find the big spider. What has it caught?
- Find the ants. Where are they going? Count how many you can see.
- Find the nest and the eggs. Who do you think built the nest?
- Look at the guava leaves and fruit. Which animals are using this one branch as part of their habitat?

Talk about it

1. Which layer of the rainforest do you think this branch came from? Why?
2. Why do you think people did not believe Merian at first? What finally showed she was right?
3. Make a food chain from the creatures in this picture.

Safety first. An adult should cut the plastic leaves, because cut milk-jug plastic can have sharp edges. Wipe up spilled water right away so no one slips.

EXPERIMENT: THE DRIP TIP TEST

Do leaves with long, pointed drip tips really shed water faster? You will make two plastic leaves, the same size and the same material, one round and one with a drip tip, give them the same “rain,” and count the drops left behind.

You will need

- A clean, empty plastic milk jug (an adult cuts out two flat pieces)
- Scissors (for the adult) and a marker
- Spray bottle filled with water
- 2 clothespins or binder clips and a stack of books, or tape and the edge of a table
- A protractor (optional) to set the same tilt for both leaves
- Paper towels, a timer and a notebook

Steps

1. **Question:** Write it at the top of your page: “Does a leaf with a drip tip shed water faster than a round leaf?”
2. **Prediction:** Write which leaf you think will be drier after 1 minute, and why.
3. Draw two leaf shapes on the milk-jug plastic, each about 4 inches (10 centimeters) wide. Make one round. Make the other the same size, but add a long, narrow point about 2 inches (5 centimeters) long at one end. An adult cuts them out.

4. **What we change:** only the shape of the leaf tip. **What we keep the same:** the material, the size, the tilt and the amount of water. Clip both leaves to the edge of a book stack so they tip downward at the same slant, with the drip tip pointing down.
5. Spray each leaf exactly 10 times from the same distance, about 1 foot (30 centimeters) away.
6. **What we measure:** Start the timer. Watch for 1 minute and count the drops that fall off each leaf. At the end of the minute, count the drops of water still sitting on each leaf.
7. Dry both leaves and repeat the test two more times, so you have 3 trials.
8. **Record:** Make a table with columns for Trial, Drops left on round leaf, and Drops left on drip-tip leaf. Add up each column. Then write your conclusion: Which leaf shed water better? Was your prediction right?

Tips

- Scientists repeat tests because one try can be a fluke. Three trials give you a better answer.
- If the drops are hard to count, press a paper towel square on each leaf after 1 minute and compare the size of the wet spots.
- Look at houseplants at home or at a garden store. Many plants from rainforests, such as the weeping fig and some philodendrons, have pointed leaf tips.

Check your work

- I wrote a question and a prediction before I started.
- I changed only the leaf tip and kept the size, material, tilt and water the same.
- I did 3 trials and added up my results in a table.
- I explained how a drip tip helps a rainforest leaf.

NATURE NOTEBOOK

1. Draw a tall rainforest from the bottom to the top and label the four layers. Draw one animal in each layer.
2. Draw a sloth hanging upside down from a branch. Color a little green in its fur and write why it is there.
3. Trace three real leaves from your yard or houseplants. Circle any leaf that has a pointed tip like a drip tip.

From history. Bates noticed something puzzling in the Amazon. Some butterflies tasted terrible to birds, and birds learned to leave them alone. Other butterflies were good to eat, yet they wore almost the very same colors and patterns as the bad-tasting ones, so birds left them alone too. After he came home, Bates explained this in a paper read in London in 1861. Today scientists still call it *Batesian mimicry*: a harmless animal that looks like a dangerous or bad-tasting one is protected by its look.

WORKED EXAMPLES

Example 1. A rainforest gets about 80 inches of rain in a year. A standard door in an American house is 80 inches tall. A town in Ohio gets about 40 inches of rain in a year. How many times as much rain does the rainforest get? About how much is 80 inches in feet?

1. Compare: $40 + 40 = 80$. So the rainforest gets **2 times** as much rain as the town.
2. Change 80 inches to feet. 6 feet = 72 inches, and $80 - 72 = 8$. So 80 inches = **6 feet 8 inches**.
3. Picture it: if none of the rain soaked in or ran away, one year of rainforest rain would stand as high as the top of a door.
4. In metric, 80 inches is about 200 centimeters, or 2 meters.

Answer: The rainforest gets 2 times as much rain. 80 inches is 6 feet 8 inches, as tall as a door, or about 2 meters.

Example 2. The canopy of a rainforest is about 100 feet high. A giant emergent tree reaches about 200 feet. A two-story house is about 20 feet tall. How many houses stacked up would reach the canopy? How many would reach the top of the emergent tree?

(Use the map or drawing “The emergent trees poke up above the canopy.” shown earlier in this lesson.)

1. Count by 20s to reach the canopy: 20, 40, 60, 80, 100. That is **5 houses**.
2. The emergent tree is 200 feet, which is twice as tall as 100 feet.
3. Twice 5 houses is $5 + 5 =$ **10 houses**.
4. Check: $10 \times 20 = 200$ feet.

Answer: 5 houses would reach the canopy, and 10 houses would reach the top of the emergent tree.

PRACTICE

1. **EASY** Name the four layers of a tropical rainforest, from the top down.
2. **EASY** Why is the forest floor of a rainforest so dark?
3. **MEDIUM** During a wet week in the rainforest, 2 inches of rain fell each day for 5 days. How much rain fell in all? About how many centimeters is that? (1 inch is about 2 and a half centimeters.)
4. **MEDIUM** Bates collected more than 14,000 kinds of animals. About 8,000 of them were new to science. About how many kinds were already known?
5. **HARD** Lily did the drip tip test. Drops left after 1 minute: Trial 1, round leaf 12, drip-tip leaf 3. Trial 2, round leaf 10, drip-tip leaf 4. Trial 3, round leaf 11, drip-tip leaf 2. Add up each leaf. How many more drops stayed on the round leaf? What is her conclusion?

6. **CHALLENGE** Put each animal in its layer: harpy eagle, three-toed sloth, leafcutter ants, toucan. Then explain in one or two sentences why so many rainforest animals live up high instead of on the ground.

COMMON MISTAKES

- Thinking a rainforest is a tangled jungle all the way to the ground. Under a thick canopy the forest floor is dark, and it is often more open than people expect. The tangles grow where sunlight breaks through, such as along rivers.
- Thinking most rainforest animals live on the ground. Most of them live up in the trees, where the food is.
- Thinking every rainforest is hot. Tropical rainforests are warm, but there are cool rainforests too. The Hoh Rain Forest in Olympic National Park, Washington, is cool and mossy and gets more than 10 feet of rain a year.

Make it a game • Layer Leap. Learn four poses: stretch up on tiptoes with arms high for the emergent layer, spread your arms wide like branches for the canopy, crouch halfway down for the understory, and touch the floor for the forest floor. A parent calls out a rainforest animal: harpy eagle, sloth, toucan, tree frog, blue morpho butterfly, leafcutter ant, jaguar. Strike the pose for that animal's layer as fast as you can. A right pose scores a point. Then trade places and you call the animals.

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)

God plants the trees, and the trees become homes. In the rainforest, each layer of the trees is a habitat for its own birds, frogs and insects.

Practice answers

1. Emergent layer, canopy, understory, forest floor.
2. The leaves of the canopy and emergent trees above block almost all of the sunlight, so very little reaches the ground.
3. $2 + 2 + 2 + 2 + 2 = 10$ inches. 10 inches is about 25 centimeters.
4. $14,000 - 8,000 =$ about 6,000 kinds were already known.
5. Round leaf: $12 + 10 + 11 = 33$ drops. Drip-tip leaf: $3 + 4 + 2 = 9$ drops. $33 - 9 = 24$ more drops stayed on the round leaf. Conclusion: the drip-tip leaf shed water faster and stayed drier.
6. Harpy eagle: emergent layer (it nests in the tallest trees). Sloth and toucan: canopy. Leafcutter ants: forest floor. Many animals live up high because that is where the sunlight reaches the leaves, so that is where most of the leaves, flowers and fruit are. That means more food up there.

5.3 CORAL REEF

OBJECTIVES

- Tell how Captain James Cook's ship struck the Great Barrier Reef in 1770, and explain that coral is made by tiny animals called polyps.
- Explain why reef-building corals need warm, clear, shallow, sunny water, and describe the partnership between coral and the tiny algae inside it.
- Use a vinegar test to find which objects are made of the same stuff as a coral skeleton.

Warm-up. Hold a seashell, an eggshell or a piece of white chalk. Is it hard or soft? Heavy or light? Rough or smooth? Write three words that describe it. Now guess: was it made by a living thing, or is it just a rock? Keep your guess for the lesson.

Video. Coming soon. Coral reefs for children: coral polyps feeding, clownfish and sea anemones, parrotfish making sand (search NOAA Ocean Service, NOAA Ocean Today, Smithsonian Ocean, SciShow Kids, Homeschool Pop (Alternate), and nature footage of the Great Barrier Reef and the Florida Keys).

KEY TERMS

coral reef

A huge underwater ridge of hard limestone built by corals in warm, shallow seas. It is a crowded habitat for fish and many other sea creatures.

polyp

One tiny coral animal: a soft tube with a mouth on top, ringed by stinging tentacles.

colony

A group of living things of one kind that live joined or close together. A coral is a colony of many polyps.

algae

Simple plant-like living things that make food from sunlight. Tiny algae live inside reef corals and share their food.

limestone

A hard, white rock made of a material called calcium carbonate. Coral skeletons, seashells and eggshells are made of this same material.

CORE IDEAS

The story. On the night of June 11, 1770, Captain James Cook's ship, the *Endeavour*, was sailing along the northeast coast of Australia. The sea was calm, and the sailors felt safe. At about eleven o'clock the ship gave a terrible lurch and stopped. She had run onto a coral reef. Water poured in through a hole in the bottom. The sailors threw overboard everything heavy they could spare, even their cannons, and pumped for their lives. When the high tide

came, they floated free. They pulled a sail under the hull to slow the leak and limped to the mouth of a river, where they spent weeks mending the ship. When they hauled the *Endeavour* onto the beach, they found a big chunk of coral stuck fast in the hole. The reef that nearly sank them had also helped plug the leak.

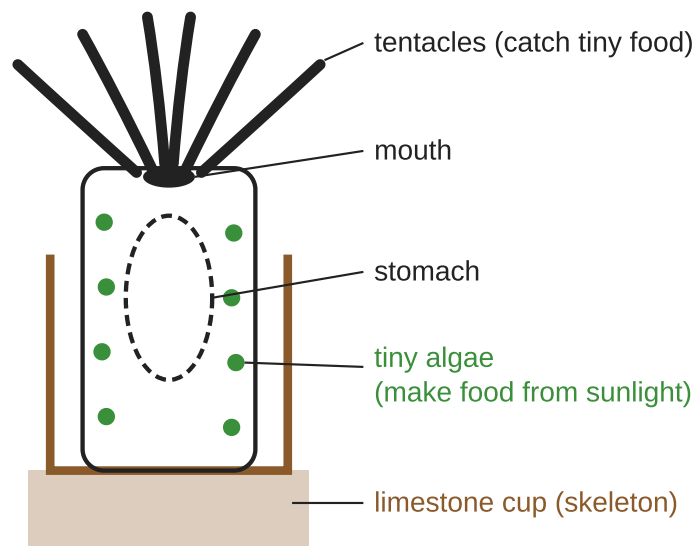
How they figured it out. The reef Cook struck was part of the Great Barrier Reef. What builds such a thing? For a long time people thought coral was a stone or a sea plant, because it branches like a little tree and has tiny “flowers.” In the 1720s a French doctor named Jean-André Peyssonnel watched red coral in a dish of seawater and saw its “flowers” open and close and catch food. He said coral is an animal. Many learned men did not believe him at first, but others later watched coral closely and found that he was right.

The big idea. A coral is a **colony** of tiny animals called **polyps**. Each polyp is a soft tube, often smaller than a pea, with a mouth on top ringed by stinging tentacles that catch bits of food at night. The polyp takes material from the seawater and builds a hard cup of **limestone** under itself. New polyps grow on top of the old cups, and little by little the cups pile up into a **coral reef**. Reef-building corals have a partner: tiny **algae** live inside each polyp and make food from sunlight. They share that food with the coral, and the coral gives them a safe home. That is why these corals grow only in warm, clear, shallow water where the sunlight can reach them.

In the world today. A reef is like a busy undersea city, full of cracks and caves for shelter. Coral reefs cover only a tiny part of the ocean floor, yet about one fourth of all kinds of sea creatures live on them. A clownfish hides among the stinging tentacles of a sea anemone, protected by a slimy coat. A parrotfish scrapes algae off the coral with its beak-like teeth, grinds up the bits of limestone, and leaves them behind as fine white sand. The Great Barrier Reef stretches about 1,400 miles (2,300 kilometers) and is made of nearly 3,000 separate reefs. It is the largest thing on earth built by living creatures. Divers who love reefs look but do not touch, because a polyp is easily hurt.

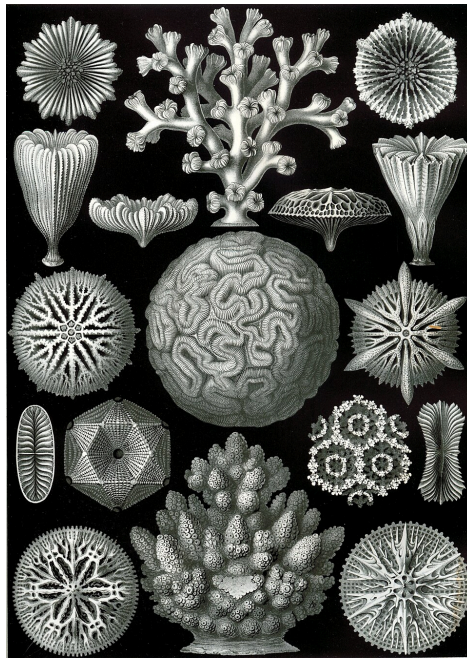
God’s handiwork. “So is this great and wide sea, wherein are things creeping innumerable, both small and great beasts” (Psalm 104:25). God made the polyp, smaller than a pea, and gave it the skill to build a wall that can stop a ship.

One coral polyp (drawn much bigger than life)



One coral polyp, drawn much bigger than life. Thousands of polyps together make one coral colony.

PICTURE STUDY



Hexacoralla (stony corals), from Kunstformen der Natur (Art Forms in Nature), Ernst Haeckel, published in parts, 1899-1904 · Color print (lithograph) made from Haeckel's drawings · Published in Leipzig, Germany; copies are kept in many libraries

Ernst Haeckel was a German scientist who spent long hours drawing sea creatures under his microscope and at the seashore. He made a book of one hundred pictures called *Art Forms in Nature*, showing jellyfish, shells, sea stars and corals arranged in patterns like stained-glass windows.

This page shows stony corals, the kind that build reefs. Haeckel drew the hard limestone skeletons, some seen from above and some from the side. Look for the thin walls that run out from the middle of each cup like the spokes of a wheel. In this group of corals they usually come in sixes and multiples of six.

Look closely

- Find a coral cup that looks like a star or a wheel. Count the spokes. Is the number six, twelve or more?
- Find a coral drawn from the side. How is it different from the ones seen from above?
- Look at how Haeckel arranged the corals on the page. Is the picture balanced from side to side?
- Find the smallest and the largest coral on the page.

Talk about it

1. These are empty coral skeletons. Where did the soft, living polyps once sit?
2. Why might a scientist draw a coral instead of only describing it in words?
3. If these cups grew together by the thousands, what would they build?

Safety first. Vinegar stings if it gets in your eyes, so keep your hands away from your face and wash them after the test. If you ever visit a real reef or tide pool, swim only with an adult, wear water shoes, and never touch coral: it can cut and sting you, and your touch can hurt the polyps.

EXPERIMENT: THE CORAL FIZZ TEST

Coral skeletons are made of limestone. Limestone has a secret sign: when vinegar touches it, it fizzes with tiny bubbles of gas. In this experiment you will test several objects to find out which ones are made of the same stuff as a coral skeleton.

You will need

- White vinegar, about 1 cup (8 ounces, about 240 milliliters)
- 5 small clear cups or jars, labeled with tape
- Test objects about the size of a thumbnail: a piece of clean eggshell, a seashell, a glass marble, a plastic bead, and a pebble from outside
- A small piece of real coral if you have one (from a shop or a family collection, never taken from a living reef)
- Measuring spoon, hand lens, notebook and pencil
- Timer

Steps

1. **Question:** Write it at the top of your page: "Which of these objects are made of limestone, like a coral skeleton?"

2. **Prediction:** Look at each object with the hand lens. Write “yes” or “no” beside each one to show whether you think it will fizz.
3. Put one object in each labeled cup.
4. **What we change:** only the object. **What we keep the same:** the size of the objects, the amount of vinegar and the time we watch. Pour 2 tablespoons of vinegar into each cup.
5. **What we measure:** Watch each cup with the hand lens for 2 minutes. Write whether you see bubbles, and whether there are none, a few or many.
6. **Record:** Make a table with three columns: Object, My prediction, What happened (no bubbles, a few bubbles, many bubbles).
7. Leave the eggshell cup overnight. In the morning, write what happened to the shell.
8. Write a conclusion: Which objects are made of limestone, like coral? What do these objects have in common?

Tips

- Bubbles may be tiny at first. Look at the edges of the object with the hand lens.
- If your pebble fizzes, that is a discovery, not a mistake. It may be a piece of limestone rock. Write it down.
- The bubbles are a gas called carbon dioxide, the same gas that makes the fizz in a baking soda and vinegar volcano.
- Notice that the objects that fizz were all made by living animals: hens, clams or snails, and coral polyps.

Check your work

- I wrote my predictions before I poured the vinegar.
- I used the same amount of vinegar and watched each cup for the same time.
- I recorded my results in a table.
- I can name which objects are made of limestone, like a coral skeleton.

NATURE NOTEBOOK

1. Draw one coral polyp, large, and label the tentacles, mouth, stomach, algae and limestone cup.
2. Draw a coral reef with at least four creatures: a clownfish in an anemone, a parrotfish, a sea turtle and one more of your choice. Draw a cave or crack where a small fish could hide.
3. Draw your eggshell before and after its night in vinegar. Write one sentence about what changed.

From history. In April 1836 the young naturalist Charles Darwin visited the Cocos (Keeling) Islands in the Indian Ocean aboard HMS *Beagle*. These islands are an atoll: a ring of low coral islands around a quiet lagoon. Captain Robert FitzRoy’s crew measured the depth of the sea around the reef by lowering a heavy lead weight with a lump of

sticky tallow on its bottom. Whatever the tallow touched stuck to it, so they could see what the sea floor was made of. Near the top they brought up living coral, and deeper down only dead coral and sand. The test showed that reef-building coral lives only in fairly shallow water.

WORKED EXAMPLES

Example 1. A branch of staghorn coral grows about 4 inches longer each year. Today the branch is 8 inches long. How long will it be after 3 more years? About how many centimeters does it grow in one year?

1. Find the growth in 3 years: $4 + 4 + 4 = 12$ inches (or $3 \times 4 = 12$).
2. Add it to the length now: $8 + 12 = \mathbf{20 \text{ inches}}$.
3. One inch is about 2 and a half centimeters. So 4 inches is about 2 and a half + 2 and a half + 2 and a half + 2 and a half = **about 10 centimeters**.
4. Staghorn is one of the fastest-growing corals. Big round brain corals grow much more slowly.

Answer: The branch will be about 20 inches long. It grows about 10 centimeters in one year.

Example 2. A diver counted fish for 10 minutes at two spots. At a spot with healthy living coral she saw 12 damselfish, 5 parrotfish and 8 butterflyfish. At a spot of broken coral rubble she saw 4 damselfish, 1 parrotfish and 1 butterflyfish. How many fish did she see at each spot? How many more at the living coral?

1. Living coral: $12 + 5 + 8 = \mathbf{25 \text{ fish}}$.
2. Rubble: $4 + 1 + 1 = \mathbf{6 \text{ fish}}$.
3. Subtract: $25 - 6 = \mathbf{19 \text{ more fish}}$ at the living coral.
4. Think like a scientist: living coral has more cracks and caves for shelter and more food, so more fish live there.

Answer: 25 fish at the living coral and 6 fish at the rubble; 19 more fish at the living coral.

PRACTICE

1. **EASY** Is a coral a plant, an animal or a rock? Explain.
2. **EASY** Look at the polyp diagram. Name the part that catches food and the part that holds the polyp safe.
(Use the map or drawing "Parts of a coral polyp." shown earlier in this lesson.)
3. **MEDIUM** Why do reef-building corals grow only in clear, shallow water where sunlight reaches them?

4. **MEDIUM** A diver found 4 sea anemones. Each one had 3 clownfish living in it. How many clownfish were there in all?
5. **HARD** In the Coral Fizz Test, the eggshell and seashell fizzed with many bubbles. The glass marble, plastic bead and gray pebble did not fizz at all. Which objects are made of limestone, like coral? What do they have in common?
6. **CHALLENGE** Ana tested a seashell in vinegar and an eggshell in plain water. The seashell fizzed and the eggshell did not. She wrote, "Seashells are limestone, but eggshells are not." What was wrong with her test, and how should she fix it?

COMMON MISTAKES

- Thinking coral is a plant or just a pretty rock. Coral is made by living animals, the polyps, which build a limestone skeleton.
- Thinking the algae inside coral are harmful. The tiny algae are partners: they make food from sunlight and share it with the coral.
- Thinking all sand comes from crushed rock. On many tropical beaches, much of the white sand comes from bits of coral and shells, much of it ground up by parrotfish.

Make it a game • Reef Hide and Seek. Scatter hula hoops, pillows or towels across the yard or a room. These are cracks and caves in the reef. Everyone is a small reef fish swimming around, and a parent is a hungry barracuda. When the barracuda shouts "Hungry!", every fish must hide in a cave before being tagged. Only one fish may hide in each cave, and after each round the barracuda takes one cave away, just as broken coral leaves fewer hiding places. Anyone tagged must name one reef creature to rejoin the game.

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

A coral reef is full of "things creeping innumerable": polyps too small to count, and fish, crabs, eels and turtles all crowded together in the habitat God made for them.

Practice answers

1. A coral is an animal, or really a colony of many tiny animals called polyps. The polyps build a hard limestone skeleton, which is why coral feels like rock.
2. The tentacles catch food. The hard limestone cup (the skeleton) holds and protects the polyp.
3. Tiny algae live inside the polyps and make food from sunlight, and they share that food with the coral. In deep or muddy water there is not enough light for the algae, so the coral cannot get enough food.
4. $4 \times 3 = 12$ clownfish ($3 + 3 + 3 + 3 = 12$).
5. The eggshell and the seashell. Both were built by living animals (a hen and a clam or snail), just as coral skeletons are built by polyps.

6. She changed two things at once: the object and the liquid. The eggshell may not have fizzed because it was in water, not vinegar. To make it fair, she should put both shells in the same amount of vinegar and watch them for the same time.

5.4 MY BACKYARD SURVEY

OBJECTIVES

- Tell how Frank Chapman began the Christmas Bird Count in 1900 and explain why scientists count living things the same way, in the same place, each time.
- Find at least three microhabitats in a backyard, park or schoolyard and tell what each one gives the creatures that live there.
- Survey two square plots, record the results with tally marks in a table and a bar graph, and compare them.

Warm-up. Look out a window for 5 minutes with a notebook. Make a tally mark every time you see a living thing move: a bird, a squirrel, an insect, a leaf-eating caterpillar, even a neighbor's cat. Then count your tallies by fives. How many living things did you see without even going outside?

Video. Coming soon. Backyard wildlife survey and citizen science for children: counting birds, finding creatures under logs, using a quadrat (search Cornell Lab of Ornithology, Audubon, National Wildlife Federation, SciShow Kids, Homeschool Pop (Alternate), and nature footage of backyard birds, pill bugs and earthworms).

KEY TERMS

survey

A careful count of the living things in a place, done the same way each time and written down.

microhabitat

A very small habitat inside a bigger one, such as the damp ground under a log or the bark of a tree.

quadrat

A square marked on the ground, such as 3 feet on each side, where a scientist counts every living thing.

tally marks

Quick counting marks in groups of five: four straight lines with a fifth line across them.

data

The facts and numbers a scientist collects and records, such as how many beetles were found.

CORE IDEAS

The story. In 1900 many hunters in America had a Christmas custom called the “side hunt.” They split into two teams and went out to shoot as many birds and animals as they could. Whichever team brought home the biggest pile won. Frank M. Chapman, a bird scientist at

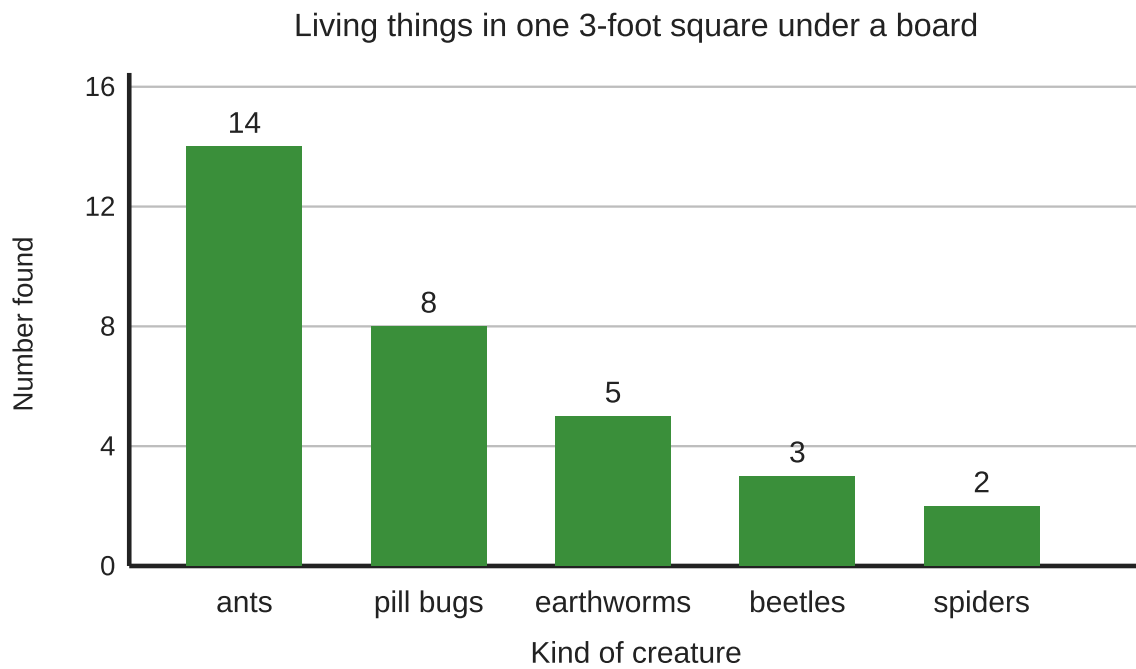
the American Museum of Natural History in New York, thought this was a sad waste. In his magazine, *Bird-Lore*, he invited people to try something new: go out on Christmas Day and *count* the birds instead of shooting them. On Christmas Day, 1900, twenty-seven bird watchers in 25 places, from Toronto in Canada to Pacific Grove in California, went out with notebooks. Together they counted about 90 kinds of birds.

How they figured it out. Chapman's idea grew into the Christmas Bird Count, and it has been held every winter since. Today tens of thousands of people take part. Each group counts inside the same circle, 15 miles across, during one day around Christmas, and writes down every bird it sees or hears. Because the count is done the same way in the same places year after year, scientists can compare the numbers. They can see which birds are growing more common, which are becoming rare, and which are spreading to new places. A careful count like this is called a **survey**, and the numbers it collects are called **data**.

The big idea. You do not need to travel to a prairie or a rainforest to study a habitat. Your own backyard, park or schoolyard is one, and it is really many small habitats packed together. Each small one is a **microhabitat**. Under a log or an old board it is dark, damp and cool, just right for pill bugs, earthworms, beetles and centipedes. The sunny lawn is warmer and drier, with ants, grasshoppers and robins hunting for worms. Tree bark hides spiders, beetles and gray-green lichens. A flower bed brings bees and butterflies. Each microhabitat gives its creatures the food, water, shelter and space they need.

Try it and see. Scientists often survey with a **quadrat**, a square marked on the ground. Make one with four sticks and string, 3 feet on each side, which is almost 1 meter. Kneel down and look closely for 15 minutes with a hand lens. Count every living thing you find and keep track with **tally marks**. If you do not know a creature's name, draw it and call it "small black beetle" or "Spider A." Real scientists do that too. Write the date, the time and the weather, because a cold morning and a warm afternoon may give very different counts. Then survey a second square in a different microhabitat and compare.

God's handiwork. The very first survey of animals was Adam's. God brought the beasts and the birds to Adam "to see what he would call them" (Genesis 2:19), and Adam gave each one a name. When you count and name the creatures in your yard, you are doing the same good work. "O LORD, how manifold are thy works! in wisdom hast thou made them all: the earth is full of thy riches" (Psalm 104:24).



Ella's survey of one quadrat under an old board. Each bar shows how many of one kind of creature she counted.

PICTURE STUDY



Insects and a Sprig of Rosemary, Jan van Kessel the Elder, 1653 · Oil on panel · National Gallery of Art, Washington, D.C.

Jan van Kessel was a painter in Antwerp, in what is now Belgium, in the 1600s. He painted insects so carefully that scientists today can tell which kinds he painted. This little painting is smaller than a postcard, only about 4½ by 5½ inches.

Van Kessel gathered about a dozen insects around one sprig of flowering rosemary: butterflies, a bumblebee, a moth, beetles and more. It is almost like a survey of one tiny

square of a garden. Some insects perch on the sprig, and some rest on the pale ground beside it, each with its own small shadow.

Look closely

- Count the insects. Make a tally mark for each one you find.
- Sort them by kind. How many butterflies, beetles and bees can you find?
- Find the bumblebee. How did van Kessel show that it is fuzzy?
- Find the little shadows under the insects. How do they help the insects look real?

Talk about it

1. If this sprig were a quadrat in your garden, what would your survey table look like?
2. Why might insects come to a flowering rosemary plant?
3. How is van Kessel's careful painting like the careful counting you do in a survey?

Safety first. Do your survey with an adult nearby. Learn to spot poison ivy ("leaves of three, let it be") before you kneel down. When you lift a log or board, roll it toward you so anything underneath, such as a snake or stinging insect, is on the far side, away from you. Do not touch wild animals, stinging insects, spiders or wild mushrooms. Put every log and board back the way you found it. Check for ticks afterward and wash your hands with soap.

EXPERIMENT: MY SQUARE-YARD SURVEY

Like the bird counters of 1900, you will do a real survey, the same way in two places, and compare the data. You will mark two square plots in different microhabitats and count every creature you find in each one.

You will need

- 8 sticks or pencils and about 25 feet of string (or 2 hula hoops)
- Yardstick or tape measure
- Hand lens (magnifying glass)
- Notebook, pencil and colored pencils
- Timer
- A thermometer (optional) and a simple field guide to insects or backyard animals (optional)

Steps

1. **Question:** Write it at the top of your page: "Does a shady, damp spot have more living things than a sunny lawn?"
2. **Prediction:** Write which square you think will have more creatures, and why.
3. Choose two spots: one in the sunny lawn and one in a shady, damp place, such as under a bush, beside a log or under an old board. Measure and mark a square 3 feet on each

side at each spot, using sticks and string.

4. **What we change:** only the microhabitat. **What we keep the same:** the size of the square, the time spent searching (15 minutes each), the same day and the same way of looking.
5. Write the date, time and weather at the top of your page. If you have a thermometer, lay it on the ground in each square for 3 minutes and record the temperature.
6. **What we measure:** Search each square for 15 minutes. Look on the plants, on the ground and under leaves. Gently roll any log or board toward you. Make a tally mark for every creature, in rows by kind: ants, beetles, spiders, worms, pill bugs, flying insects, birds, other.
7. **Record:** Count up your tally marks and make a table with three columns: Kind of creature, Sunny lawn, Shady spot. Then draw a bar graph for each square.
8. Write a conclusion: Which square had more living things? Which had more different kinds? Was your prediction right? What did the shady spot give its creatures that the lawn did not?

Tips

- Ants can be too many to count. Count the ants in a small part of the square and write “about.” Scientists estimate too.
- Sit still for the first two minutes. Creatures that hid when you came will start moving again.
- Do the same survey again in another season. A May count and an October count of the same square can be very different.

Check your work

- I wrote a question and a prediction before I started.
- I used squares of the same size and searched each for the same time.
- I recorded my counts with tally marks, a table and a bar graph.
- I put logs and boards back and left the creatures unharmed.

NATURE NOTEBOOK

1. Draw a map of your yard, park or schoolyard from above. Mark at least three microhabitats and draw one creature you found in each.
2. Draw the most interesting creature from your survey, large, with a hand lens view of one part such as its legs or antennae. If you do not know its name, give it a describing name.
3. Copy your survey table and bar graph neatly into your notebook, with the date, time and weather.

From history. In 1998 the Cornell Lab of Ornithology and the National Audubon Society started another count that families can join from home: the Great Backyard Bird Count. Every February, for four days, people all over the world count the birds they see for at

least 15 minutes and report them online. Children, parents and grandparents become real survey scientists, and their counts help show where birds are spending the winter.

WORKED EXAMPLES

Example 1. Your quadrat is a square that is 3 feet on each side. How many feet of string do you need to go all the way around it? How many square feet are inside? About how long is each side in meters?

1. A square has 4 sides, all the same length. Add them: $3 + 3 + 3 + 3 = \mathbf{12 \text{ feet}}$ of string (or $4 \times 3 = 12$).
2. To find the space inside, multiply the side by the side: $3 \times 3 = \mathbf{9 \text{ square feet}}$. You can picture 3 rows of 3 floor tiles that are each 1 foot square.
3. A meter is a little longer than 3 feet, so each side is **almost 1 meter**.
4. Leave a little extra string for tying knots at the corners.

Answer: 12 feet of string; 9 square feet inside; each side is almost 1 meter.

Example 2. Look at Ella's bar graph of the creatures she found under an old board. How many living things did she count in all? Which kind did she find most often? How many more pill bugs than spiders did she find?

(Use the map or drawing "Ella's survey of one quadrat under an old board." shown earlier in this lesson.)

1. Read each bar: ants 14, pill bugs 8, earthworms 5, beetles 3, spiders 2.
2. Add them: $14 + 8 = 22$; $22 + 5 = 27$; $27 + 3 = 30$; $30 + 2 = \mathbf{32 \text{ living things}}$.
3. The tallest bar is ants, so she found **ants** most often.
4. Pill bugs minus spiders: $8 - 2 = \mathbf{6 \text{ more pill bugs}}$.

Answer: 32 living things in all. Ants were most common. She found 6 more pill bugs than spiders.

PRACTICE

1. **EASY** What is a microhabitat? Name two microhabitats you could find in a backyard.
2. **EASY** Why should you roll a log toward you when you lift it?
3. **MEDIUM** Ben made these tally marks for beetles: two groups of five and three more single marks. How many beetles did he count?
4. **MEDIUM** Rosa surveyed two squares of the same size for 15 minutes each. She found 9 living things in the sunny lawn and 23 under an old log. How many more did she find under the log? Give one reason why.
5. **HARD** Why do Christmas Bird Count teams count in the same circle, on about the same day, in the same way, every year? Write two or three sentences.

6. **CHALLENGE** Theo counted the kinds of birds at his feeder for one hour. In January he saw 6 kinds. In May he saw 11 kinds. How many more kinds did he see in May? Give a reason why the count could change from winter to spring.

COMMON MISTAKES

- Thinking a backyard has no wildlife worth studying. Even a small yard has dozens of kinds of living things, many of them hidden under logs, leaves and bark.
- Thinking one count tells the whole story. Numbers change with the time of day, the weather and the season, so scientists repeat surveys and write down when and how they counted.
- Thinking you must know a creature's name before you can count it. Draw it, describe it and give it a label such as "Beetle A." You can look up its name later.

Make it a game · Tally Race. A parent cuts out 30 small paper creatures (for example 10 ants, 7 pill bugs, 6 worms, 4 beetles and 3 spiders) and hides them in a marked square of floor or yard while you wait in another room. Set a timer for 5 minutes. Find as many as you can and keep a tally for each kind. When time is up, compare your tallies with the parent's true numbers. Score a point for every kind you counted exactly right. Then trade places and hide them for the parent.

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)

God's creatures have much to teach anyone who will slow down and look. A backyard survey is one way to "ask the beasts" and learn from them.

Practice answers

1. A very small habitat inside a bigger one. Any two: under a log or board, the lawn, tree bark, a flower bed, a pile of leaves, a birdbath or puddle, a rock pile.
2. So the log is between you and anything underneath it. If a snake or stinging insect is there, it will be on the far side, away from you.
3. $5 + 5 + 3 = 13$ beetles.
4. $23 - 9 = 14$ more under the log. Reason: it is dark, damp and cool there, with shelter from birds and sun, and the rotting wood and leaves give food to pill bugs, worms and beetles.
5. If the count is done the same way each time, any change in the numbers comes from a real change in the birds, not from a change in how people counted. Then scientists can compare years and see which birds are becoming more or less common.
6. $11 - 6 = 5$ more kinds in May. Reason: in spring, birds that flew south for the winter (such as orioles, warblers or hummingbirds) come back, and there are more insects and flowers for food.

UNIT 5 REVIEW

A parent may read each question aloud. Answer in complete sentences, and show your work for number questions. The quiz is worth 40 points, 4 points for each question.

1. (4 pts) What is a habitat? Name the four things every habitat must give.
2. (4 pts) Why does a prairie have few trees? How do deep roots help prairie plants live through a dry summer or a fire?
3. (4 pts) How did Lewis and Clark catch a prairie dog in 1804? How does a prairie dog's burrow help it?
4. (4 pts) Name the four layers of a tropical rainforest from the top down, and name one animal that lives in any one of them.
5. (4 pts) A rainforest gets about 80 inches of rain in a year. Your town gets about 40 inches. How many more inches does the rainforest get? How many times as much is that?
6. (4 pts) What is a drip tip, and how does it help a rainforest leaf?
7. (4 pts) Is coral a plant, an animal or a rock? Explain what a polyp is and what it builds.
8. (4 pts) Why do reef-building corals need warm, clear, shallow water with lots of sunlight?
9. (4 pts) What is a survey? What did Frank Chapman ask people to do on Christmas Day, 1900, instead of the side hunt?
10. (4 pts) In two squares of the same size, searched for the same time, a student found 9 living things in the sunny lawn and 23 under an old board. How many more were under the board? Give one reason why.

UNIT PROJECT: MY HABITAT FIELD GUIDE

Make a small field guide with one page for each habitat in this unit: the prairie, the tropical rainforest, the coral reef and your own backyard. On each page, draw the habitat and at least three creatures that live there. Add a box that shows how the habitat gives food, water, shelter and space, and label two adaptations, such as deep roots, a drip-tip leaf or a prairie dog's digging claws.

At the back, add your experiment records: the Runoff Test table, the Drip Tip Test table, the Coral Fizz Test table, and your backyard survey table and bar graphs. Finish with a paragraph about which habitat you would most like to visit and what you would study there.

- **Accuracy:** Each habitat page names creatures that truly live there, shows food, water, shelter and space correctly, and labels real adaptations.
- **Records:** The experiment tables and survey graphs are complete, dated and correctly counted and added.
- **Explanation:** The writing explains how each creature fits its habitat and what each fair test showed.

- **Care:** The field guide is neat, colorful and easy to read, with careful drawings like a real naturalist's.

Answer key

1. A habitat is the place where a plant or animal lives and finds what it needs. It must give food, water, shelter and space.
2. In most places there is not enough rain for a forest, and fires and grazing bison keep young trees back. Deep roots reach water far down in the soil and stay safe underground when fire burns the grass, so the plant can grow back.
3. They dug and then poured barrel after barrel of river water down a hole until the prairie dog came out. The burrow is its shelter, safe from hawks, coyotes and cold, and its mound is a lookout that also keeps rainwater out.
4. Emergent layer, canopy, understory, forest floor. Examples: harpy eagle (emergent), sloth, toucan or howler monkey (canopy), tree frog or blue morpho butterfly (understory), leafcutter ants or jaguar (forest floor).
5. $80 - 40 = 40$ more inches. That is 2 times as much rain.
6. A drip tip is a long, pointed tip on a leaf. It lets rainwater run off quickly so the leaf dries and moss, mold and algae do not grow on it and block the sunlight.
7. Coral is an animal, a colony of many tiny animals called polyps. A polyp is a soft tube with a mouth ringed by stinging tentacles. It builds a hard limestone cup under itself, and many cups together build a reef.
8. Tiny algae live inside the polyps and make food from sunlight, which they share with the coral. Deep or muddy water does not let enough light reach them, so the coral would not get enough food.
9. A survey is a careful count of the living things in a place, done the same way each time and written down. Chapman asked people to go out and count the birds instead of shooting them. This became the Christmas Bird Count.
10. $23 - 9 = 14$ more under the board. Reason: under the board it is dark, damp and cool, it gives shelter from birds and sun, and rotting wood and leaves give food.

ANIMAL DEFENSES

In the food chains of Unit 4, every animal was either hunting or being hunted, and sometimes both. So how does a slow, small animal stay alive? God gave each kind of animal its own **defenses**: body parts and behaviors that protect it. In this unit you will study four animals with four very different defenses: sharp barbs, a terrible smell, bending armor and a boiling-hot chemical spray.

You will meet the scientists in Boston who looked at a porcupine quill under a microscope, the chemist in California who discovered what makes skunk spray smell, the Spanish writer who thought an armadillo looked like a horse dressed for battle, and the Cornell scientists who found that a tiny beetle fires a hot spray in 500 pops a second. Like them, you will ask a question, make a prediction, run a fair test, measure carefully and record what you see. In every lesson you will ask: **how does this defense work, and why is it so well made?**

BEFORE YOU BEGIN

- Knows the words predator and prey from Unit 4
- Can add and subtract numbers up to 1,000
- Can measure length in inches with a ruler
- Can read a simple table and bar graph

MASTERY CHECKLIST

- I can explain what a defense is and give an example of a body part defense and a behavior defense.
- I can explain how a porcupine's barbed quills work and why a porcupine cannot shoot them.
- I can name a skunk's warnings and explain why its black-and-white coat is a set of warning colors.
- I can label the parts of an armadillo's armor and tell how the nine-banded armadillo escapes danger.
- I can explain how the bombardier beetle keeps its chemicals apart and then mixes them to make a hot spray.
- I can run a fair test by changing only one thing, and record my results in a table.

OPTIONAL BOOKS AND RESOURCES

- **Smithsonian's National Zoo and Conservation Biology Institute: Animals** (<https://nationalzoo.si.edu/animals>): Free. Fact pages, photos and live animal cams. Look up the porcupine, skunk and armadillo pages to compare their defenses.
- **Biodiversity Heritage Library** (<https://www.biodiversitylibrary.org/>): Free. Search "Viviparous Quadrupeds of North America" to page through Audubon's mammal plates, including the porcupine, skunk and armadillo, as a parent-guided picture study.

6.1 PORCUPINE QUILLS ★

OBJECTIVES

- Describe how a porcupine's quills protect it, and explain why a porcupine cannot shoot its quills.
- Tell how scientists in Boston in 2012 looked at a quill under a microscope and found out why quills go in easily and come out hard.
- Run a fair test of a smooth "quill" and a barbed "quill," measure the pull with pennies, and record the results in a table.

Warm-up. Pretend you are a small, round, slow animal. You cannot run fast, and you cannot fly. A hungry fox is coming! Draw three ideas for staying safe. Then gently press your palm on the bristles of a hairbrush. What would a fox think if its nose touched a coat made of bristles?

Video. Coming soon. North American porcupine quills and defense for children (search Smithsonian's National Zoo, SciShow Kids, Homeschool Pop (Alternate), state wildlife agencies, and nature footage of porcupines raising their quills and climbing trees).

KEY TERMS

defense

A body part or a behavior that helps an animal keep from being hurt or eaten.

quill

A stiff, sharp hair on a porcupine, light and filled with a spongy core. A porcupine has about 30,000 of them.

barb

A tiny hook that points backward, like the hook on a fishhook. Barbs let a point slide in but catch when pulled out.

keratin

The tough material that makes hair, fingernails, hooves, horns and porcupine quills.

rodent

A mammal with long front teeth that keep growing all its life, such as a mouse, squirrel, beaver or porcupine.

CORE IDEAS

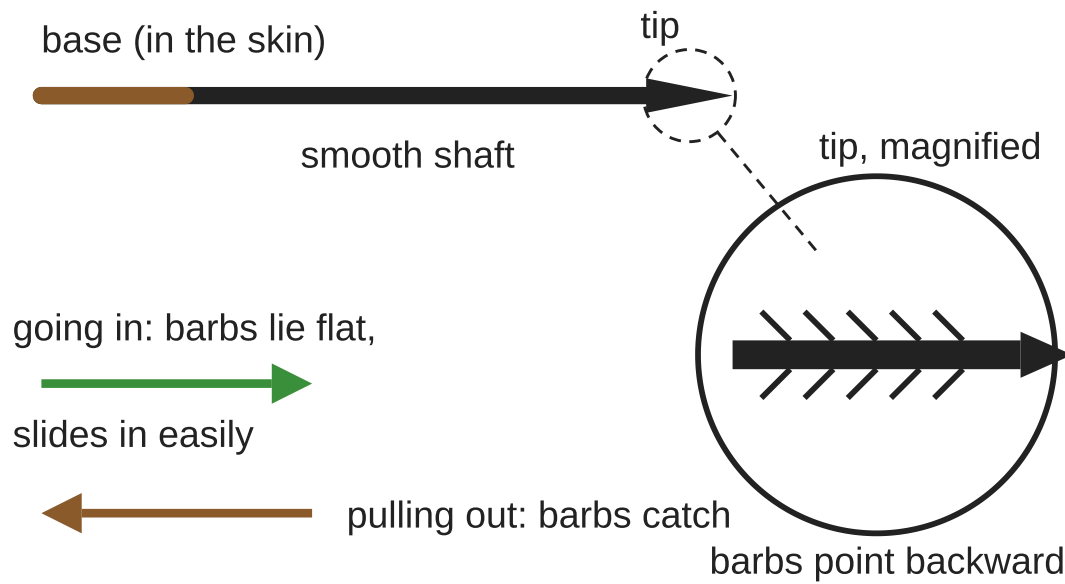
The story. In December 2012, a team of doctors and scientists in Boston, Massachusetts, led by Jeffrey Karp, reported the answer to a question that every dog owner in porcupine country already wonders about. Why do porcupine quills slide into skin so easily, and why are they so hard to pull back out? A quill looks like a plain, smooth needle. The team suspected the answer was hiding at the very tip, too small to see with your eyes alone.

How they figured it out. The scientists looked at the tip of a quill under a powerful microscope. It was covered with hundreds of tiny **barbs**, overlapping like shingles on a roof, and every one pointed backward. Then they ran a test. They pushed quills into pieces of meat and measured how hard they had to push and pull. They also tested quills from an African porcupine, which have no barbs. The barbed quills went in with *less* push and needed *much more* pull to come out. Going in, the barbs lie flat. Coming out, they catch, like a fishhook.

The big idea. A **defense** is any body part or behavior that protects an animal. The North American porcupine is a slow, chubby **rodent** that eats bark, twigs and leaves. It is covered with about 30,000 **quills**. Quills are stiff hairs made of **keratin**, the same stuff as your fingernails. Most are 1 to 3 inches long (about 2 to 8 centimeters). When a porcupine is calm, its quills lie flat. When a coyote or bobcat comes near, the porcupine warns first. It chatters its teeth and gives off a strong smell. Then it raises its quills, turns its back and swings its spiky tail. A porcupine *cannot* shoot its quills. They are only loosely held, so they pull free and stick in whatever touches them. New quills grow back in their place.

In the world today. Most hunters leave porcupines alone after one painful lesson. One animal, the fisher, a large cousin of the weasel, has learned to attack the porcupine's face, where there are no quills. Curious dogs are not so wise, and veterinarians pull out many quills every year. Never try to pull them out yourself; take the pet to a vet. Doctors are now studying quill barbs to design better needles and staples that slide in gently and hold tight.

God's handiwork. Job says, "ask now the beasts, and they shall teach thee." The porcupine teaches us that a big defense can come from a tiny design. Thousands of barbs, each too small to see without a microscope, turn a slow, gentle plant eater into an animal almost nothing wants to bite.



A quill tip up close. The barbs point back toward the base, so the quill slides in easily but catches when pulled.

PICTURE STUDY



Canada Porcupine, from The Viviparous Quadrupeds of North America, John James Audubon, 1845–1848 · Hand-colored lithograph · Copies are held in many libraries and museums

After John James Audubon finished his great book of birds, he began a second giant project: a book of the four-footed mammals of North America. He worked with his sons and with his friend John Bachman, a pastor in Charleston, South Carolina, who wrote the descriptions.

Audubon tried to draw each animal at or near its real size and in a natural pose, so that a reader could study it almost as well as if it were sitting on the table.

Look closely

- Find the quills. Where on the body do they look longest and thickest?
- Look at the feet and claws. What do you think a porcupine does with claws like these?
- Find the tail. Why might a spiky tail be a good thing to swing at a hungry animal?
- Look at the face. Can you see any quills there? How does that fit what you learned about the fisher?

Talk about it

1. Does this porcupine look calm or frightened? What clues in the picture tell you?
2. Why do you think Audubon wanted to draw animals as real-looking as he could?
3. If you could ask Audubon one question about drawing a porcupine, what would it be?

Safety first. Scissors are used to snip the paper barbs; a parent should help. Never touch or chase a wild porcupine. If a pet gets quills in its face, keep it calm and take it to a veterinarian. Do not pull quills out yourself.

EXPERIMENT: THE BARB PULL TEST

Do backward barbs really make a quill harder to pull out? You will make two quills from drinking straws, one smooth and one with paper barbs, push each into play dough, and hang pennies on it until it pulls free. The pennies will measure the pull.

You will need

- 2 plastic drinking straws, each cut to 5 inches long, with one end snipped to a point
- Masking tape and scissors
- A large lump of play dough or modeling clay, about the size of an orange
- A heavy book
- A piece of string about 2 feet long and a small paper cup
- About 50 pennies
- A ruler, notebook and pencil

Steps

1. **Question:** Will a barbed quill hold more pennies than a smooth quill before it pulls out? Write your **prediction** in your notebook.
2. Make the barbed quill. Cut a strip of masking tape 3 inches long. Along one long edge, snip tiny cuts every quarter inch to make a fringe. Wrap the tape around one straw about 1 inch from the point, with the fringe flaps pointing back, away from the point. Bend each flap up a little.
3. Leave the other straw smooth. This is the smooth quill.

4. Press the dough into a block at the edge of a table and set the heavy book behind it so it cannot slide.
5. Push the smooth quill straight into the side of the dough, sideways, exactly 1½ inches deep. Use your ruler.
6. Tape one end of the string to the back end of the straw. Let the string hang over the table edge and tape the paper cup to it.
7. Drop pennies into the cup one at a time until the quill pulls out. Count the pennies and write the number.
8. Smooth the hole closed and do it again, for 3 tries in all. Then do 3 tries with the barbed quill.
9. Make a table with two columns, Smooth quill and Barbed quill, and three rows, Try 1, Try 2, Try 3. Add up each column.
10. Write one sentence: Was your prediction right? What did the barbs do?

Tips

- **What we change:** smooth or barbed. **What we keep the same:** the same dough, the same depth, the same straw size, the same cup. **What we measure:** the number of pennies.
- Doing 3 tries for each quill makes the test fairer, because one try can be a fluke.
- Look at the hole the barbed quill leaves. Is it neat or torn?

Check your work

- I made a prediction before testing.
- I kept everything the same except the barbs.
- I recorded 3 tries for each quill in a table and added them up.
- I can explain why barbs make a quill hard to pull out.

NATURE NOTEBOOK

1. Draw a porcupine in two poses: calm, with quills lying flat, and on guard, with quills raised and back turned. Label the quills, tail and face.
2. Draw a quill as long as it really is (about 3 inches) and draw a magnifying circle on its tip showing the barbs pointing backward.
3. Copy your penny table into your notebook and draw a small bar graph of the total pennies for each quill.

From history. Long before glass trade beads came from Europe, many American Indian peoples of the northern woodlands and the Great Plains decorated moccasins, bags and clothing with porcupine quills. Women gathered the quills, softened them, flattened them and dyed them bright colors with plants. Then they wrapped, folded or stitched them into beautiful patterns. This art, called **quillwork**, is still practiced today, and fine old pieces are kept in museums such as the Smithsonian.

WORKED EXAMPLES

Example 1. A long porcupine quill is 3 inches long. One inch is about $2\frac{1}{2}$ centimeters. About how many centimeters long is the quill?

(Use the map or drawing “Use the quill drawing to picture how long 3 inches is.” shown earlier in this lesson.)

1. Each inch is about $2\frac{1}{2}$ centimeters.
2. Add $2\frac{1}{2}$ three times: $2\frac{1}{2} + 2\frac{1}{2} + 2\frac{1}{2}$.
3. $2 + 2 + 2 = 6$, and $\frac{1}{2} + \frac{1}{2} + \frac{1}{2} = 1\frac{1}{2}$.
4. $6 + 1\frac{1}{2} = 7\frac{1}{2}$.

Answer: About $7\frac{1}{2}$ centimeters.

Example 2. Sam did the Barb Pull Test. The smooth quill held 4, 5 and 3 pennies. The barbed quill held 12, 13 and 11 pennies. Add up each quill’s pennies. Which quill held more, and how many times as many?

1. Smooth quill: $4 + 5 + 3 = 12$ pennies.
2. Barbed quill: $12 + 13 + 11 = 36$ pennies.
3. 36 is more than 12, so the barbed quill held more.
4. Count by 12s: 12, 24, 36. That is 3 twelves, so 36 is 3 times as many as 12.

Answer: The barbed quill held 36 pennies and the smooth quill held 12. The barbed quill held 3 times as many.

PRACTICE

1. **EASY** Can a porcupine shoot its quills at an enemy? Explain.
2. **EASY** What material are quills made of? Name one other thing made of the same material.
3. **MEDIUM** A porcupine loses 20 quills on Monday and 15 quills on Tuesday. How many quills did it lose in all? Should it worry about running out?
4. **MEDIUM** A quill is 4 inches long. One inch is about $2\frac{1}{2}$ centimeters. About how many centimeters long is it?
5. **HARD** Read the table. Smooth quill: 3, 4, 5 pennies. Barbed quill: 9, 10, 11 pennies. Find the total for each quill. How many more pennies did the barbed quill hold in all?
6. **CHALLENGE** Mia pushed the smooth quill 1 inch deep into soft play dough, and the barbed quill 2 inches deep into stiff clay. The barbed quill held more pennies. Was this a fair test? Explain what she should change.

COMMON MISTAKES

- Thinking porcupines shoot or throw their quills. They cannot. Quills come loose when something touches them.
- Thinking porcupines are mean animals that attack. They are gentle plant eaters that warn first and use their quills only to defend themselves.
- Thinking porcupines and hedgehogs are close cousins because both are prickly. A porcupine is a rodent, related to beavers and squirrels; a hedgehog is not a rodent at all.

Make it a game · Porcupine on Guard. One player is the porcupine and stands with arms down (quills flat). The parent walks toward the porcupine slowly as a coyote. The porcupine must do the defenses in the right order: chatter teeth (click your tongue), raise quills (spread arms and fingers), turn your back, and swing your tail (wiggle!). Do all four in the right order before the coyote reaches you to score a point. Then switch, and the coyote must say one true fact about quills before each step forward.

Scripture. “But ask now the beasts, and they shall teach thee; and the fowls of the air, and they shall tell thee: Or speak to the earth, and it shall teach thee: and the fishes of the sea shall declare unto thee. Who knoweth not in all these that the hand of the LORD hath wrought this?” (Job 12:7-9, KJV)

The scientists in Boston “asked” the porcupine by looking closely and testing carefully, and it taught them something new. When we study an animal well, we are learning from the work of God’s hand.

Practice answers

1. No. The quills are loosely attached, so they pull free and stick into an animal that touches the porcupine. The porcupine cannot throw or shoot them.
2. Keratin. Fingernails, hair, hooves and horns are also made of keratin.
3. $20 + 15 = 35$ quills. No. It has about 30,000 quills, and lost quills grow back.
4. $2\frac{1}{2} + 2\frac{1}{2} + 2\frac{1}{2} + 2\frac{1}{2} = 10$. About 10 centimeters.
5. Smooth: $3 + 4 + 5 = 12$. Barbed: $9 + 10 + 11 = 30$. The barbed quill held $30 - 12 = 18$ more pennies.
6. No, it was not fair. She changed three things at once: barbs, depth and dough. She should use the same dough and the same depth for both quills and change only the barbs. Then she would know the barbs made the difference.

6.2 SKUNK SPRAY

OBJECTIVES

- Name the warnings a striped skunk gives before it sprays, and explain why its black-and-white coat is a warning sign.
- Tell how chemist William Wood in California discovered in 1990 which chemicals give skunk spray its smell, and why a sprayed dog can smell again after a bath.
- Test how fast a smell travels across a room at different distances, record the times, and read the results on a bar graph.

Warm-up. Close your eyes. A parent holds three small cups under your nose, one at a time: a slice of onion, a spoonful of vinegar and a drop of vanilla. Name each smell. Which one made you want to pull your head away? A smell can say “stay back!” without making a sound.

Video. Coming soon. Striped skunk defense and warning signals, spotted skunk handstand, for children (search Smithsonian’s National Zoo, SciShow Kids, Homeschool Pop (Alternate), state wildlife agencies, and nature footage of skunks stamping and raising their tails).

KEY TERMS

warning colors

Bold, easy-to-see colors or patterns that tell other animals, “Leave me alone, I can hurt you.” A skunk’s black and white stripes are warning colors.

scent glands

Two small pouches under a skunk’s tail that make and store its smelly, oily spray.

sulfur

A natural yellow element. Chemicals with sulfur in them cause strong smells, like rotten eggs, onions and skunk spray.

nocturnal

Active mostly at night and resting during the day. Skunks are nocturnal.

CORE IDEAS

The story. Everyone knows the smell of a skunk, but for a long time nobody knew exactly what made it. In 1990, a chemistry professor named William Wood at Humboldt State University in Arcata, California, published the answer. He had collected spray from striped skunks and studied it in his laboratory, one chemical at a time. It was a smelly job, but he wanted a true answer.

How they figured it out. Wood used laboratory machines that separate a mixture into its parts, the way a sieve separates sand from pebbles. He found that most of the awful smell

comes from a few chemicals that contain **sulfur**, the same element that gives rotten eggs and onions their strong smell. He found something else too. Some chemicals in the spray do not smell much at first, but they slowly change into the smelly ones when they get wet. That is why a sprayed dog often smells bad all over again after a bath!

The big idea. The striped skunk is a **nocturnal** animal about the size of a house cat. It cannot run fast, so God gave it a powerful defense. Two **scent glands** under its tail store an oily spray. The skunk can aim the spray, and it can reach about 10 feet (about 3 meters). It stings the eyes and makes them water, and the smell can be noticed far downwind. But a skunk would much rather warn than spray. Its black-and-white coat is a set of **warning colors**. If an animal comes too close, the skunk stamps its front feet, hisses, raises its tail and may turn its body into a U shape so both ends face the enemy. The little spotted skunk even does a handstand! Only then does it spray.

In the world today. Why does a skunk warn first? Because it has only enough spray for about five or six squirts. Then it needs about ten days to make more. A skunk that sprays too often would be left with no defense. Most hunters learn the lesson after one spray and remember those stripes. One hunter does not mind: the great horned owl, which has a poor sense of smell and swoops down silently at night.

God's handiwork. The skunk's defense is fair and wise. It gives plenty of warning, it seldom causes lasting harm, and it saves its spray for real danger. When you see a skunk, do what wise animals do: heed the warning, back away slowly and let it go on its way.

PICTURE STUDY



Common American Skunk, from The Viviparous Quadrupeds of North America, John James Audubon, 1845–1848 · Hand-colored lithograph · Copies are held in many libraries and museums

This print comes from the same great book of North American mammals as Audubon's porcupine. Audubon and his helpers worked from real animals, and his friend John Bachman wrote down what was known about each one's habits. Look closely: the skunk is one of the easiest animals in the book to recognize, and that is exactly the point of its coat.

Look closely

- Follow the white stripes with your finger. Where do they start, and where do they go?
- Look at the tail. How big is it compared to the body? Why would a skunk want a big tail to raise high?
- Look at the feet. Can you see claws for digging up insects and grubs?
- Look at the colors. Would this animal be easy or hard to see at night? Why does that matter?

Talk about it

1. Why would a skunk want to be easy to see, when most small animals try to hide?
2. What clues in this picture would warn a fox to stay away?
3. If you drew a skunk giving its warning, what would you change in this picture?

Safety first. Never go near a wild skunk, even a friendly-looking one, and never touch one that is out in the daytime acting strangely; tell an adult. Wild animals can carry diseases such as rabies. In the smell test, use only food smells such as vanilla or orange peel, and ask first if anyone in the family has allergies.

EXPERIMENT: HOW FAST DOES A SMELL TRAVEL?

A skunk's spray works partly because its smell spreads through the air. Smells are made of tiny bits that drift and spread out. In this test you will find out how long it takes a smell to reach people standing at different distances.

You will need

- A cotton ball and a small dish
- Vanilla extract or peppermint extract
- A tape measure or yardstick
- Masking tape for marking spots on the floor
- A stopwatch or a clock with a second hand
- Two or three helpers
- Notebook and pencil

Steps

1. **Question:** Does a smell take longer to reach someone who is farther away? Write your **prediction**.

2. Choose a room with the doors and windows closed and no fan running. Put the dish on the floor at one end.
3. Measure from the dish and mark spots on the floor with tape at 5 feet, 10 feet and 15 feet.
4. Each helper stands on one tape mark with eyes closed.
5. A parent puts 10 drops of extract on the cotton ball, sets it in the dish and starts the stopwatch.
6. Each helper raises a hand the moment he or she smells the extract. Write down the time in seconds for each spot.
7. Air out the room for 15 minutes. Then do the test again with helpers trading spots, so each spot is tested by a different nose.
8. Make a table: Distance, Try 1 seconds, Try 2 seconds. Then draw a bar graph with one bar for each distance.

Tips

- **What we change:** the distance. **What we keep the same:** the same extract, the same 10 drops, the same closed room. **What we measure:** the seconds until the smell is noticed.
- Trading spots matters, because some noses are sharper than others.
- Skunks spray outdoors where the wind carries the smell much farther and faster than in a still room.

Check your work

- I made a prediction before testing.
- I measured the distances in feet with a tape measure.
- I recorded the seconds for each distance in a table.
- I drew a bar graph and wrote what it shows.

NATURE NOTEBOOK

1. Draw a striped skunk giving its warnings in order: stamping its feet, raising its tail and turning into a U shape. Number each picture 1, 2, 3.
2. Draw a spotted skunk doing its handstand warning. Label its tail and front feet.
3. Make a “Smell Map” of your test room. Mark the dish and the 5-foot, 10-foot and 15-foot spots, and write the seconds next to each.

From history. In 1993, a chemist in Illinois named Paul Krebaum was working on a different problem: removing the smell of sulfur chemicals in his laboratory. When a friend’s cat was sprayed by a skunk, he tried his mixture of hydrogen peroxide, baking soda and dish soap, and it worked. The sulfur chemicals were changed into new chemicals with almost no smell. He shared the recipe in a chemistry magazine, and veterinarians have recommended it ever since. It must be mixed fresh and used by a grown-up, never stored in a closed bottle.

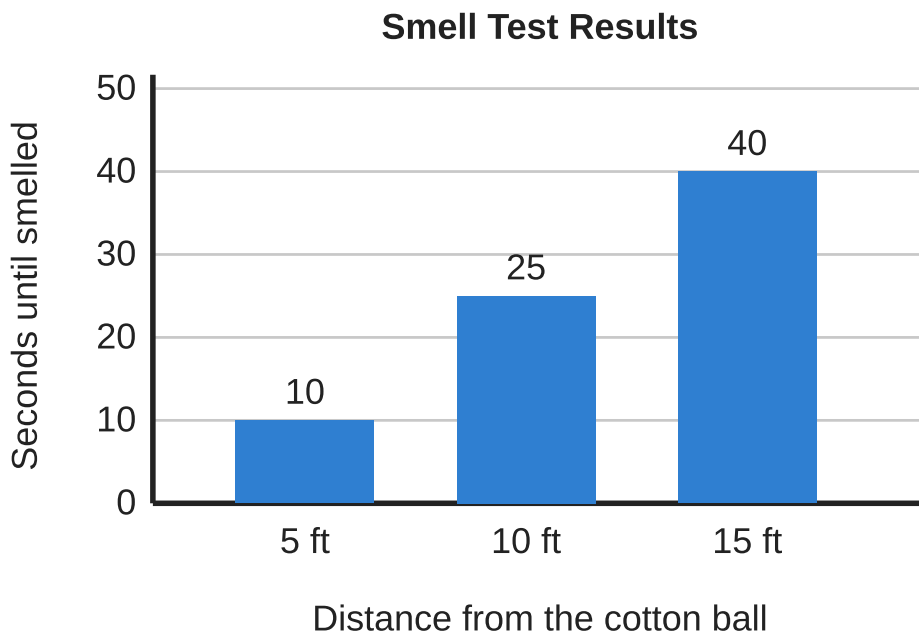
WORKED EXAMPLES

Example 1. A skunk's spray can reach about 10 feet. A hiker stands 4 yards away from a skunk. One yard is 3 feet. Is the hiker inside or outside the spray zone?

1. Change yards to feet. Each yard is 3 feet.
2. $4 \text{ yards} = 3 + 3 + 3 + 3 = 12 \text{ feet}$.
3. Compare: 12 feet is more than 10 feet.
4. The hiker is just outside the spray zone, but only by 2 feet. Wise hikers back away slowly.

Answer: 12 feet away, which is 2 feet outside the 10-foot spray zone.

Example 2. Read the bar graph from a smell test. How many seconds did the smell take to reach the 10-foot spot? How much longer did it take to reach 15 feet than 5 feet?



Smell test results: the farther away, the longer the smell took to arrive.

1. Find the bar labeled 10 ft. Its top lines up with 25 on the side scale. The smell took 25 seconds.
2. Find the 15 ft bar: 40 seconds. Find the 5 ft bar: 10 seconds.
3. Subtract: $40 - 10 = 30 \text{ seconds}$.

Answer: 25 seconds to reach 10 feet. It took 30 seconds longer to reach 15 feet than 5 feet.

PRACTICE

1. **EASY** Name two warnings a striped skunk gives before it sprays.
2. **EASY** Why is it helpful for a skunk to have bold black-and-white fur instead of fur that blends in?
3. **MEDIUM** A skunk has enough spray for 5 squirts. It sprays 1 time at a dog and 2 times at a fox. How many squirts are left?
4. **MEDIUM** Skunk spray reaches about 10 feet. A cat is 3 yards from a skunk. One yard is 3 feet. Is the cat in range?
5. **HARD** A skunk uses up all its spray on May 4. It takes about 10 days to make more. About what date will its spray be refilled?
6. **CHALLENGE** The great horned owl is one of the few animals that hunts skunks. Write two or three sentences explaining why the skunk's defense does not stop the owl very well.

COMMON MISTAKES

- Thinking skunk spray is urine or comes from the mouth. It is an oily liquid made in two scent glands under the tail.
- Thinking a skunk sprays the moment it sees you. A skunk warns first and saves its spray, because it has only a few squirts and needs about ten days to make more.
- Thinking tomato juice washes away skunk smell. It mostly covers the smell for a while. The smelly sulfur chemicals need to be changed by a stronger cleaner to really go away.

Make it a game • Warning or Spray?. One player is the skunk. The other is a curious dog who takes one step closer at a time. At each step the skunk must give the next warning, in order: stamp feet, hiss, raise tail, turn into a U. If the dog takes one more step after the U, the skunk may “spray” by tossing a soft scarf or sock. If the dog backs away after any warning, the dog scores a point for being wise. Switch places and play again.

Scripture. “A prudent man foreseeth the evil, and hideth himself; but the simple pass on, and are punished.” (Proverbs 22:3, KJV)

A wise fox sees the stamping feet and raised tail and backs away. A foolish one keeps coming and gets sprayed. God gives warnings in nature and in His Word, and wise people pay attention to them.

Practice answers

1. Any two: it stamps its front feet, hisses, raises its tail, or turns its body into a U shape so both ends face the enemy.
2. The bold colors are warning colors. Animals that have been sprayed remember the stripes and stay away, so the skunk often does not need to spray at all.
3. $1 + 2 = 3$ used. $5 - 3 = 2$ squirts left.

4. $3 \text{ yards} = 3 + 3 + 3 = 9 \text{ feet}$. 9 feet is less than 10 feet, so yes, the cat is in range. It should back away.
5. $\text{May } 4 + 10 \text{ days} = \text{about May } 14$.
6. The great horned owl has a poor sense of smell, so the spray does not bother it as much. It hunts at night and swoops down silently from above, so it can grab the skunk before the skunk can stamp, turn and aim.

6.3 ARMADILLO ARMOR

OBJECTIVES

- Name the parts of a nine-banded armadillo's armor (head shield, shoulder shield, bands, hip shield and tail rings) and tell what each band of soft skin lets it do.
- Explain how the nine-banded armadillo really escapes danger, and how it is different from the three-banded armadillo that rolls into a ball.
- Build a solid "shell" and a banded "shell" from craft sticks, test which one bends around a can, and record the results.

Warm-up. Hold a book with a stiff cover. Try to bend it around your arm. Now hold a slinky, a watchband with links, or a row of dominoes taped to a strip of cloth. Which one could bend around your arm and still cover it? Think: what would a knight need to be able to do in his armor?

Video. Coming soon. Nine-banded armadillo and three-banded armadillo rolling into a ball, armadillo armor for children (search Smithsonian's National Zoo, San Diego Zoo, SciShow Kids, Homeschool Pop (Alternate), and nature footage of armadillos digging and jumping).

KEY TERMS

armor

A hard covering that protects a body. An armadillo's armor is made of small bony plates that grow in its skin.

shield

A large, stiff piece of armor. An armadillo has a shield over its shoulders and another over its hips.

band

A narrow strip of armor across the middle of an armadillo's back. Soft skin between the bands lets the armadillo bend.

burrow

A hole or tunnel an animal digs in the ground to live in or hide in.

mammal

A warm-blooded animal with hair that feeds its babies milk. Armadillos are mammals, even though they wear armor.

CORE IDEAS

The story. In 1526, a Spanish writer named Gonzalo Fernández de Oviedo published a book about the plants and animals he had seen in the lands across the Atlantic Ocean. He described many creatures no one in Europe had ever seen. One was a small animal covered

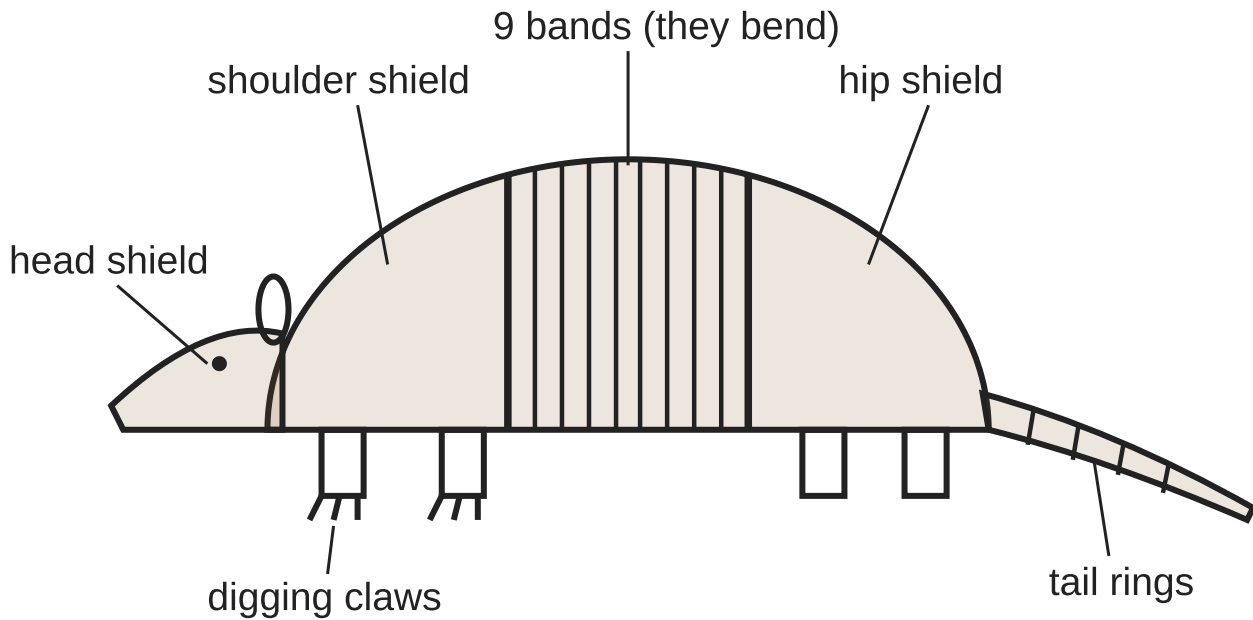
from head to tail with hard plates. He wrote that it looked something like a horse dressed in armor for battle. Spanish speakers came to call it the *armadillo*, which means “little armored one.”

How they figured it out. Later naturalists looked closely at the armor. It is not one solid shell like a turtle’s. It is made of hundreds of small bony plates that grow inside the skin, each covered with a thin scale of keratin. Over the shoulders, the plates fit tightly into a stiff **shield**. Over the hips is another shield. In between are narrow **bands** joined by soft, folding skin. The nine-banded armadillo usually has nine of them. There is a little shield on the head and rings of armor around the tail. The belly has no armor at all, only soft skin and a little hair.

The big idea. Armor that cannot bend would make an animal stiff and slow. The bands let the armadillo bend, run, twist into tight places and dig. Many people think every armadillo rolls into a ball, but the nine-banded armadillo cannot. Only the three-banded armadillos of South America can roll into a tight ball, with the head and tail shields fitting together like puzzle pieces. The nine-banded armadillo escapes in other ways. It runs into thorny bushes, where its armor protects it and its enemy gets scratched. It digs into the ground very fast with strong claws. When startled, it can jump straight up 3 to 4 feet (about 1 meter)! It can even hold its breath for about six minutes and walk across the bottom of a small stream.

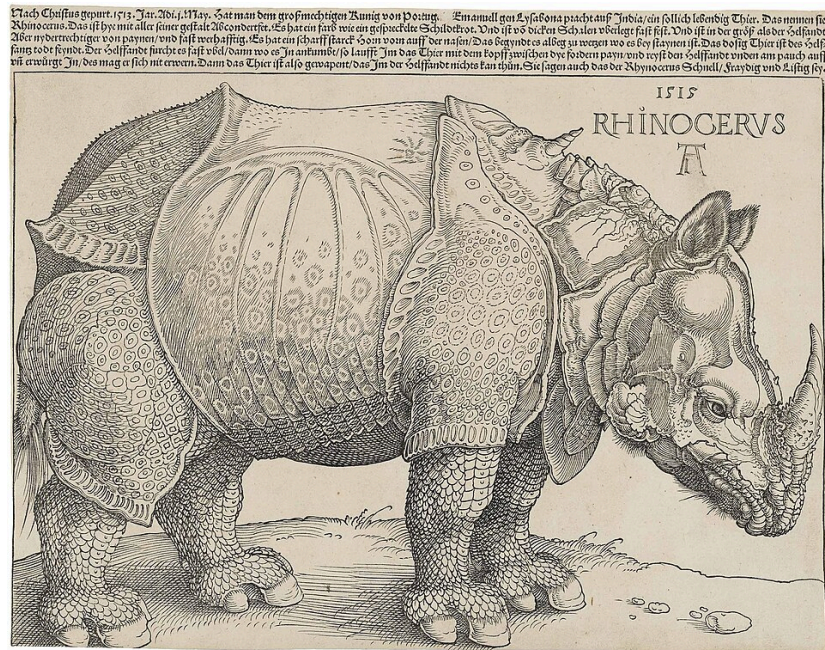
In the world today. The nine-banded armadillo is the only armadillo that lives in the United States. It is found in Texas, Florida and many other southern states. It is a **mammal** about the size of a house cat. It comes out mostly at night, sniffing the ground with its long nose for beetles, grubs and ants, then digging them up. It sleeps in a **burrow** it digs itself.

God’s handiwork. Engineers who design armor for people face a hard problem: hard things protect, but they do not bend. The armadillo shows one answer. Stiff shields cover the parts that do not need to move, and overlapping bands cover the part that must bend. Strong and flexible together: that is wise design.



The parts of a nine-banded armadillo's armor. The soft skin between the bands lets it bend.

PICTURE STUDY



The Rhinoceros, Albrecht Dürer, 1515 · Woodcut print · Prints are held in many 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 one in Europe had seen a living rhinoceros since the days of ancient Rome. In Nuremberg, Germany, the artist Albrecht Dürer read a letter describing it and saw a quick sketch, but he never saw the animal itself. From those clues he carved this famous woodcut.

Dürer drew the rhino's thick folds of skin as if they were plates of a knight's armor, with rivets and seams. He also added a small extra horn on its shoulders that a real rhinoceros does not have. For a long time, this picture was copied in books as the way a rhinoceros looked.

Look closely

- Find the places where the rhino looks like it is wearing armor. Point to the "seams" between the plates.
- Find the small twisted horn on the shoulders. A real Indian rhinoceros does not have this horn.
- Look at the legs. What did Dürer draw on them?
- Compare this rhino's armor with the armadillo diagram. Which one has plates that can bend?

Talk about it

1. Why do you think Dürer drew the rhino's skin like armor?
2. Dürer never saw the real animal. What mistakes can happen when you draw from someone else's description?
3. Why is it better for a scientist to observe a real animal, if possible, before drawing it?

Safety first. Never pick up or handle a wild armadillo. Wild armadillos can carry germs that make people sick. A parent should help with scissors and glue.

EXPERIMENT: THE ARMOR BEND TEST

Why does an armadillo have bands in the middle instead of one solid shell? You will build two shells from craft sticks, one solid and one banded, and test which one can bend around a can while still covering it.

You will need

- 18 craft sticks (9 for each shell)
- A strip of cardboard about 6 inches by 4 inches
- Glue or strong tape
- A strip of cloth or wide ribbon about 6 inches long
- A soup can
- Notebook and pencil

Steps

1. **Question:** Can a shell made of bands wrap around a round body better than a solid shell? Write your **prediction**.
2. Make the solid shell. Glue or tape 9 craft sticks side by side, touching, onto the stiff cardboard strip. Let it dry.

3. Make the banded shell. Tape 9 craft sticks side by side onto the cloth strip, leaving a tiny gap between each stick, like the soft skin between an armadillo's bands.
4. Lay the soup can on its side. Press the solid shell around the can as far as it will go without breaking anything. Count how many sticks touch the can.
5. Do the same with the banded shell. Count how many sticks touch the can.
6. Do each test 2 more times, for 3 tries each. Record the numbers in a table.
7. Now press your finger on each shell. Do both still protect what is underneath?
8. Write one sentence telling which shell is more like an armadillo and why.

Tips

- **What we change:** solid or banded. **What we keep the same:** 9 sticks, the same can, the same gentle push. **What we measure:** how many sticks touch the can.
- If you have time, make a third shell with only 3 bands in the middle and stiff "shields" on the ends, like a real armadillo. How does it do?

Check your work

- I made a prediction before testing.
- I changed only one thing: solid or banded.
- I counted and recorded the sticks touching the can for 3 tries each.
- I can explain why bands help an armadillo move and dig.

NATURE NOTEBOOK

1. Copy the armadillo diagram. Color the shoulder shield one color, the bands another and the hip shield a third. Count and number the bands.
2. Draw a three-banded armadillo rolled into a ball and a nine-banded armadillo running into a thorny bush. Write one sentence under each.
3. Draw your two craft-stick shells wrapped around the can and write how many sticks touched in each.

From history. Nine-banded armadillos once lived only south of the Rio Grande, in Mexico and lands farther south. In the 1800s they crossed the river into Texas, and since then they have spread across much of the southern United States. In 1995 Texas named the nine-banded armadillo its official state small mammal.

WORKED EXAMPLES

Example 1. Look at the armadillo diagram. Count the bands between the shoulder shield and the hip shield. Then use this table: three-banded armadillo, 3 bands; six-banded armadillo, 6 bands; nine-banded armadillo, 9 bands. How many more bands does the nine-banded armadillo have than the three-banded armadillo?

(Use the map or drawing “Count the bands between the shoulder shield and the hip shield.” shown earlier in this lesson.)

1. Count the strips between the two shields in the diagram: 1, 2, 3, 4, 5, 6, 7, 8, 9.
There are 9 bands, which matches the name.
2. Find the three-banded armadillo in the table: 3 bands.
3. Subtract: $9 - 3 = 6$.

Answer: The diagram shows 9 bands. The nine-banded armadillo has 6 more bands than the three-banded armadillo.

Example 2. A nine-banded armadillo can hold its breath for about 6 minutes. There are 60 seconds in 1 minute. How many seconds is that? Ben can hold his breath for 30 seconds. How many seconds longer can the armadillo hold its breath?

1. Count by 60s six times: 60, 120, 180, 240, 300, 360.
2. 6 minutes = 360 seconds.
3. Subtract Ben’s time: $360 - 30 = 330$.

Answer: 6 minutes is 360 seconds. The armadillo can hold its breath 330 seconds longer than Ben.

PRACTICE

1. **EASY** Can a nine-banded armadillo roll up into a tight ball? Which armadillo can?
2. **EASY** Name two ways a nine-banded armadillo escapes from danger.
3. **MEDIUM** A startled armadillo jumps 3 feet straight up. There are 12 inches in 1 foot. How many inches is that?
4. **MEDIUM** Use the table: three-banded armadillo, 3 bands; six-banded armadillo, 6 bands; nine-banded armadillo, 9 bands. How many bands do the three armadillos have all together? Which armadillo has twice as many bands as the three-banded one?
5. **HARD** In the Armor Bend Test, Lily’s solid shell touched the can with 2 sticks, 2 sticks and 3 sticks. Her banded shell touched with 7, 8 and 8 sticks. Find each total. How many more did the banded shell touch? What does this show?
6. **CHALLENGE** Write two or three sentences: Why is armor with bands in the middle better for an armadillo than one solid shell?

COMMON MISTAKES

- Thinking all armadillos roll into a ball. Only the three-banded armadillos can. The nine-banded armadillo runs, digs or jumps instead.
- Thinking an armadillo's armor is one solid shell like a turtle's. It is made of many small bony plates in the skin, with stiff shields and bendable bands.
- Thinking armadillos are reptiles because they have scales. They are mammals: they have hair on their bellies, are warm-blooded and feed their babies milk.

Make it a game · Armadillo Escape. A parent calls out a danger, such as "A coyote is chasing you!", "You are crossing a stream!" or "A car light flashes!" The child must act out the right nine-banded armadillo escape: run into the "thorn bush" (behind the couch), dig (paw at the floor), walk the stream bottom (hold your breath and tiptoe), or jump straight up. If the parent says "Roll into a ball!", the child must freeze and say, "Not me! Only the three-banded armadillo can do that!" to score a bonus point.

Scripture. "Put on the whole armour of God, that ye may be able to stand against the wiles of the devil." (Ephesians 6:11, KJV)

The armadillo wears armor every day. Paul tells Christians that God gives them armor too: truth, righteousness, faith and the Word of God. Like the armadillo's armor, it protects us while we keep moving and working.

Practice answers

1. No. The nine-banded armadillo cannot. The three-banded armadillos of South America can roll into a tight ball.
2. Any two: it runs into thorny bushes, it digs into the ground very fast, it jumps straight up when startled, or it crosses a stream underwater.
3. $12 + 12 + 12 = 36$ inches.
4. $3 + 6 + 9 = 18$ bands all together. The six-banded armadillo has twice as many ($3 + 3 = 6$).
5. Solid: $2 + 2 + 3 = 7$. Banded: $7 + 8 + 8 = 23$. The banded shell touched $23 - 7 = 16$ more. It shows that bands let armor bend around a round body, like an armadillo's.
6. Example: The bands let the armadillo bend its body so it can run, twist through bushes and dig fast. One solid shell would protect it but make it stiff and slow. With shields on the ends and bands in the middle, it is protected and can still move.

6.4 THE BOMBARDIER BEETLE

OBJECTIVES

- Tell how Thomas Eisner and his team at Cornell University discovered that the bombardier beetle sprays a boiling-hot chemical spray.
- Explain in simple words how the beetle's two chambers keep its chemicals apart until they are needed and then mix them in a chemical reaction.
- Model a two-part chemical reaction with baking soda and vinegar, change one thing, measure the result in inches and read a data table.

Warm-up. Put a spoonful of baking soda in one small cup and a spoonful of vinegar in another. Look at each one. Nothing happens! Now, over a tray, pour the vinegar into the baking soda. What happens? Why do you think nothing happened while the two were in separate cups?

Video. Coming soon. Bombardier beetle hot chemical spray, slow motion, for children (search SciShow Kids, Smithsonian, Homeschool Pop (Alternate), Moody Science classics, university insect labs, and nature footage of bombardier beetles spraying).

KEY TERMS

beetle

An insect with six legs and a pair of hard front wings, called wing covers, that protect the thin flying wings underneath.

chamber

A small, closed space, like a room inside a body or a machine.

chemical reaction

A change in which substances mix and turn into new substances, often giving off gas or heat.

enzyme

A helper made by a living thing that makes a chemical reaction happen very fast.

pulse

One short burst. A bombardier beetle's spray comes out in many quick pulses, pop, pop, pop.

CORE IDEAS

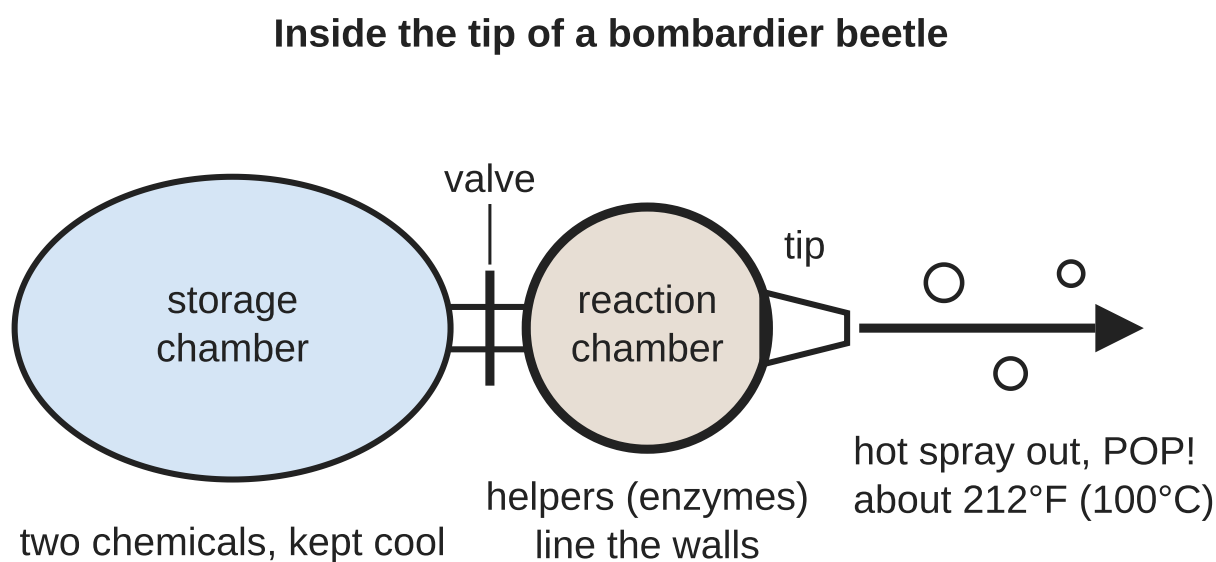
The story. In 1969, at Cornell University in Ithaca, New York, an insect scientist named Thomas Eisner and an engineer named Daniel Aneshansley reported something amazing about a beetle about half an inch long (about 1 centimeter). When the bombardier beetle is grabbed by an ant or a frog, it fires a spray from the tip of its body with a little *pop* you can hear. And the spray is **boiling hot**.

How they figured it out. Eisner's team glued a thin wire to a beetle's back so it could stand but not run away. Then they gently pinched one of its legs with tweezers. Every time, the beetle swung the tip of its body around and sprayed exactly at the pinched leg, even over its own back! The team measured the heat of the spray and found it was about 212°F (100°C), the temperature of boiling water. Later they worked with Harold Edgerton of MIT, a famous inventor of super-fast flash photography. Their photos, reported in 1990, showed that the spray does not come out in one stream. It comes out in quick **pulses**, about 500 tiny bursts every second.

The big idea. Inside the beetle are two **chambers**. The first is a storage chamber that holds two chemicals. Kept there, they are safe and stay cool. When the beetle is attacked, muscles squeeze a little of the mixture through a valve into the second chamber, the reaction chamber. Its walls are lined with **enzymes**, helpers that make a **chemical reaction** happen in a flash. The mixture turns into new chemicals that sting, gets boiling hot and makes gas. The gas pushes the hot spray out of the tip with a pop.

In the world today. Ants, spiders and many birds quickly learn to leave bombardier beetles alone. In 2018, scientists in Japan watched toads that had swallowed bombardier beetles. Some of the toads threw the beetles back up, and the beetles walked away alive! Engineers in England have studied the beetle's pulsing spray chamber to design better sprayers for things like fire extinguishers.

God's handiwork. Think of all the parts that must work together: a storage chamber, a valve, a muscle to squeeze it, helpers in the reaction chamber, tough walls that are not hurt by the heat, and a tip that can aim. If the chemicals mixed too soon, the beetle would burn itself. People who study this tiny insect are filled with wonder at how well it is made.



How a bombardier beetle sprays: chemicals wait in the storage chamber, pass through a valve, and react in the reaction chamber.

PICTURE STUDY



Stag Beetle, Albrecht Dürer, 1505 · Watercolor and gouache on paper · J. Paul Getty Museum, Los Angeles

Albrecht Dürer, the German artist who painted the *Columbine* and the *Large Piece of Turf*, also loved to paint small creatures exactly as they were. In this painting he shows a male stag beetle so carefully that it almost seems ready to walk off the page. He even painted its shadow on the paper.

The stag beetle is a different kind of beetle from the bombardier beetle, but they share the beetle plan: six legs, a head, a hard body and wing covers. The male stag beetle's huge jaws look like a deer's antlers. He uses them mostly to wrestle other male stag beetles.

Look closely

- Count the legs. Does the number match what you know about insects?
- Find the wing covers on the back. How do they help protect the beetle?
- Find the shadow. Why do you think Dürer painted it?
- Look at the jaws. What do they remind you of?

Talk about it

1. Dürer could have painted the beetle bigger or brighter, but he painted it just as it looked. Why is that a good habit for a scientist too?
2. Which defenses can you see in this picture? Which defense of the bombardier beetle could a painting not show?
3. If you painted a bombardier beetle spraying, how would you show the heat and the pop?

Safety first. Wear safety glasses and work on a tray when mixing baking soda and vinegar; vinegar stings if it gets in your eyes. Never point the bottle at anyone's face. Do not try to catch bombardier beetles or other ground beetles with bare hands. The optional yeast and hydrogen peroxide demonstration is done only by a parent, with safety glasses, using regular 3% drugstore hydrogen peroxide.

EXPERIMENT: TWO CHAMBERS IN A BOTTLE

The bombardier beetle keeps its chemicals apart until it needs them. You will do the same with baking soda in a balloon and vinegar in a bottle. When you mix them, the reaction makes a gas that blows up the balloon. You will test whether using more baking soda makes more gas.

You will need

- 3 small empty plastic water bottles, the same size
- 3 balloons, the same kind
- White vinegar and a measuring cup
- Baking soda and a teaspoon
- A funnel (or a paper rolled into a cone)
- A piece of string and a ruler (or a soft tape measure)
- Safety glasses, a tray, notebook and pencil

Steps

1. **Question:** Does more baking soda make more gas? Write your **prediction**.
2. Pour $\frac{1}{2}$ cup of vinegar into each bottle. This is the storage chamber.
3. Using the funnel, put 1 teaspoon of baking soda into the first balloon, 2 teaspoons into the second and 3 teaspoons into the third. Label them 1, 2 and 3.
4. Stretch the neck of each balloon over the mouth of a bottle, letting the balloon hang to the side so no soda falls in yet. The two chemicals are kept apart, like in the beetle.
5. Lift the first balloon so the baking soda falls into the vinegar. Watch and listen. Do the same with the other two.
6. When the bubbling stops, wrap the string around the fattest part of each balloon. Mark the string, then measure it with the ruler in inches.
7. Record the results in a table: Teaspoons of baking soda, Inches around the balloon.
8. Write one sentence: Was your prediction right?

Tips

- **What we change:** the teaspoons of baking soda. **What we keep the same:** the vinegar, the bottles and the balloons. **What we measure:** the inches around each balloon.
- The beetle's reaction is much faster and gets boiling hot. Ours is slow and cool, so it is safe for the kitchen.

- Optional parent demonstration: in a clean bottle, a parent pours $\frac{1}{2}$ cup of 3% hydrogen peroxide, adds a squirt of dish soap, then adds a packet of yeast stirred into a little warm water. The yeast contains a helper (an enzyme) that breaks the hydrogen peroxide apart very fast. Foam pours out and the bottle feels warm, a little like the beetle's reaction chamber.

Check your work

- I kept the two chemicals apart until I chose to mix them.
- I changed only the amount of baking soda.
- I measured each balloon in inches and recorded the numbers in a table.
- I can explain why the bombardier beetle keeps its chemicals in a separate chamber.

NATURE NOTEBOOK

1. Draw a bombardier beetle spraying at an ant. Show its six legs, wing covers and the tip of its body aiming the spray. Add "POP!" in big letters.
2. Copy the two-chamber diagram and label the storage chamber, valve, reaction chamber and hot spray.
3. Draw your three balloons on their bottles and write the inches around each one underneath.

From history. As a young student at Cambridge University in England, Charles Darwin loved collecting beetles. In his autobiography he told how he once caught a rare beetle in each hand and then spotted a third. To free a hand, he popped one beetle into his mouth. It squirted a burning, bitter liquid that made him spit it out, and he lost both that beetle and the third one. Many people think it was a bombardier beetle or a close cousin. Real scientists sometimes learn things the hard way!

WORKED EXAMPLES

Example 1. The bombardier beetle's spray is about 212°F , the temperature of boiling water. A warm bath is about 100°F . How many degrees hotter is the beetle's spray than a warm bath?

(Use the map or drawing "The reaction chamber is where the spray gets boiling hot." shown earlier in this lesson.)

1. Subtract the bath temperature from the spray temperature: $212 - 100$.
2. $212 - 100 = 112$.
3. On the Celsius scale, the spray is about 100°C , because water boils at 100°C .

Answer: The spray is about 112 degrees Fahrenheit hotter than a warm bath.

Example 2. Read this table from the Two Chambers in a Bottle test. 1 teaspoon of baking soda: balloon 10 inches around. 2 teaspoons: 14 inches. 3 teaspoons: 17 inches. How many inches bigger around was the 3-teaspoon balloon than the 1-teaspoon balloon? What pattern do you see?

1. Find the 3-teaspoon balloon: 17 inches.
2. Find the 1-teaspoon balloon: 10 inches.
3. Subtract: $17 - 10 = 7$ inches.
4. Look down the table: as the baking soda goes up (1, 2, 3), the balloon size goes up (10, 14, 17).

Answer: 7 inches bigger. The pattern: more baking soda made more gas, so the balloon got bigger.

PRACTICE

1. **EASY** Where does the bombardier beetle store its chemicals before it sprays? Where do they react?
2. **EASY** Is the bombardier beetle's spray fire? Explain.
3. **MEDIUM** The beetle's spray comes out in about 500 pulses every second. About how many pulses come out in 2 seconds?
4. **MEDIUM** A cup of hot cocoa is about 160°F. The beetle's spray is about 212°F. How many degrees hotter is the spray?
5. **HARD** Jake did the balloon test but used $\frac{1}{2}$ cup of vinegar in bottle 1, 1 cup in bottle 2 and 2 cups in bottle 3, along with 1, 2 and 3 teaspoons of baking soda. Can he tell whether the baking soda made the difference? Why or why not?
6. **CHALLENGE** Write two or three sentences: Why does the bombardier beetle need two separate chambers instead of keeping everything mixed together in one?

COMMON MISTAKES

- Thinking the bombardier beetle shoots fire. It sprays a hot liquid pushed out by gas, not flames.
- Thinking the spray is hot all the time inside the beetle. The chemicals stay cool in the storage chamber and only get hot when they mix in the reaction chamber.
- Thinking a chemical reaction needs a laboratory. Living things carry out chemical reactions all the time, in beetles, in plants and in your own body.

Make it a game · Beetle Bombardier. The child is the beetle and kneels on the floor. A parent, the hungry ant, sneaks up and gently taps one of the beetle's "legs" (an arm, a knee or a foot). The beetle must turn and aim a pretend spray at exactly that spot, saying "Pop, pop, pop!" If the beetle aims at the right spot, it scores a point. For a bonus point,

the beetle must name the next step in order: storage chamber, valve, reaction chamber, hot spray.

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. The porcupine has barbs, the skunk has a smell, the armadillo has armor, and a beetle smaller than your fingertip has its own chemistry set. God’s wisdom shows in the smallest creatures.

Practice answers

1. They are stored in the storage chamber. They react in the reaction chamber, where helpers called enzymes make the reaction happen fast.
2. No. It is a boiling-hot liquid spray with gas pushing it out. There are no flames.
3. $500 + 500 = 1,000$ pulses.
4. $212 - 160 = 52$ degrees hotter.
5. No. He changed two things at once, the vinegar and the baking soda, so he cannot tell which one made the balloons bigger. He should keep the vinegar the same in every bottle and change only the baking soda.
6. Example: If the chemicals and the helpers were mixed all the time, the reaction would happen inside the beetle and the boiling heat would hurt it. Keeping the chemicals in a storage chamber keeps them safe and cool. The beetle mixes them in the reaction chamber only when it needs to spray.

UNIT 6 REVIEW

Answer each question. A parent may read the questions aloud. Use complete sentences for explanations and show your work for numbers. The quiz is worth 40 points.

1. (4 pts) What is a defense? Give one example from this unit.
2. (4 pts) Why are porcupine quills easy to push in but hard to pull out?
3. (4 pts) True or false: A porcupine can shoot its quills at an enemy. Explain.
4. (4 pts) Name three warnings a striped skunk gives before it sprays.
5. (4 pts) A skunk has enough spray for 6 squirts. It uses 2 on a dog and 1 on a fox. How many are left? Why is it wise for a skunk to warn before spraying?
6. (4 pts) Skunk spray can reach about 10 feet. A girl stands 3 yards from a skunk. One yard is 3 feet. Is she in range?
7. (4 pts) Name the parts of a nine-banded armadillo's armor from front to back. What does the soft skin between the bands let it do?
8. (4 pts) Which armadillo can roll into a tight ball? Name two ways the nine-banded armadillo escapes instead.
9. (4 pts) Put these in order to tell how a bombardier beetle sprays: reaction chamber, hot spray comes out, storage chamber, valve.
10. (4 pts) In a balloon test, Ava put 1, 2 and 3 teaspoons of baking soda into balloons over bottles of vinegar. Name the one thing she changed and two things she should keep the same.

UNIT PROJECT: MY FIELD GUIDE TO ANIMAL DEFENSES

Make a small field guide booklet with one page for each animal in this unit: the porcupine, the striped skunk, the nine-banded armadillo and the bombardier beetle. On each page, draw the animal carefully from a photo or picture study, label its defense, write two or three sentences telling how the defense works, and add one number fact (such as 30,000 quills or a 10-foot spray). Add a fifth page about an animal near your home and its defense. At the back, include the data table from one of your experiments and a sentence telling what you found.

- **Accuracy:** Each defense is named and explained correctly, and the number facts are right.
- **Observation:** Drawings are careful, show real body parts and are clearly labeled.
- **Experiment record:** The data table is complete and neat, and the sentence tells what changed, what stayed the same and what was found.
- **Care:** The booklet is neat, colorful, in order and easy to read.

Answer key

1. A defense is a body part or behavior that helps an animal keep from being hurt or eaten.
Examples: porcupine quills, skunk spray, armadillo armor, the bombardier beetle's hot spray.

2. The tip of each quill is covered with tiny barbs that point backward. Going in, the barbs lie flat. Pulling out, they catch, like a fishhook.
3. False. The quills are loosely attached and come loose when an animal touches them, but the porcupine cannot shoot them.
4. Any three: it stamps its front feet, hisses, raises its tail, turns its body into a U shape. (The spotted skunk may do a handstand.)
5. $6 - 3 = 3$ squirts left. A skunk has only a few squirts and needs about ten days to make more, so it saves its spray for real danger.
6. 3 yards = 9 feet. 9 feet is less than 10 feet, so yes, she is in range and should back away slowly.
7. Head shield, shoulder shield, bands, hip shield, tail rings. The soft skin between the bands lets it bend, so it can run, twist and dig.
8. The three-banded armadillo. The nine-banded armadillo runs into thorny bushes, digs fast, jumps straight up, or crosses streams underwater (any two).
9. Storage chamber, valve, reaction chamber, hot spray comes out.
10. She changed the amount of baking soda. She should keep the same amount of vinegar, the same size bottles and the same kind of balloons (any two).

SEA MONSTERS AND FLYING REPTILES

Long ago the seas were full of creatures stranger than any dragon in a storybook: reptiles with necks longer than their bodies, giant sea lizards with hinged jaws, and above the waves, reptiles that flew on wings of skin. In this unit you will meet them the way scientists first did, as bones in rock. You will learn to look closely, count, measure, compare and draw, and to ask the scientist's question: **what do these bones tell us about how the animal lived?**

You will walk the stormy beach at Lyme Regis, England, where Mary Anning found the first nearly complete plesiosaur in 1823. You will go down into the chalk tunnels of Maastricht where quarry men found a giant jaw, and follow Georges Cuvier as he shows it belonged to a sea lizard. You will see how Cosimo Collini's puzzling fossil turned out to be a flying reptile. Last, you will read Job 41, where God Himself describes the mighty leviathan, and compare its clues with the animals you know.

Every lesson has a small experiment: bending straw necks, racing clay shapes through water, dropping paper wings and testing overlapping scales. Museum words like "Jurassic" and "Cretaceous" are explained in the Thinking About Time boxes, so you can read a museum sign accurately and also know how Christians who read Genesis as history understand these fossils.

BEFORE YOU BEGIN

- Can add and subtract numbers up to 100 and count by 2s, 3s, 4s and 5s
- Can measure with a ruler in inches
- Knows that reptiles have scales and breathe air (from earlier animal units)
- Can read a simple bar graph

MASTERY CHECKLIST

- I can tell how Mary Anning found the first nearly complete plesiosaur and why her careful work mattered.
- I can name the parts of a plesiosaur and a mosasaur and tell how each one swam.
- I can explain how a pterosaur's wing was different from a bird's wing and a bat's wing.
- I can explain that plesiosaurs, mosasaurs and pterosaurs were reptiles but not dinosaurs.
- I can read a bar graph of animal lengths and make a scale drawing.
- I can tell what Job 41 says about leviathan and explain its main point: God made all creatures and rules over them.

OPTIONAL BOOKS AND RESOURCES

- **Smithsonian National Museum of Natural History** (<https://naturalhistory.si.edu/>): Free. The museum website has pictures of fossil marine reptiles and pterosaurs from

its collections. A visit to the fossil hall in Washington, D.C., is a good Nature Lab trip.

- **Lyme Regis Museum** (<https://www.lymeregismuseum.co.uk/>): The museum stands on the site of Mary Anning's family home in Lyme Regis. Its website has pages about Mary Anning and the fossils of the Lyme Regis coast.
- **Friends of Crystal Palace Dinosaurs** (<https://www.cpdinosaurs.org/>): Free. Photographs and history of Benjamin Waterhouse Hawkins's life-size models from 1854, including the plesiosaurs in Lesson 7.1.

7.1 PLESIOSAURS: MARY ANNING'S GREAT FIND (1823) ★

OBJECTIVES

- Tell how Mary Anning found the first nearly complete plesiosaur skeleton at Lyme Regis, England, in 1823, and why scientists came to trust her careful work.
- Name the main parts of a plesiosaur's body and explain how its flippers and lungs fit a life in the sea.
- Compare neck bones and body lengths using simple numbers in feet and meters.

Warm-up. Put your fingers on the back of your neck and slowly nod your head up and down. Can you feel the bumps? Those are your neck bones. You have seven of them, and so does a giraffe, even though its neck is much longer. Now guess: how many neck bones do you think a long-necked sea reptile might have had? Write your guess on a slip of paper and save it for the end of the lesson.

Video. Coming soon. Mary Anning and the plesiosaur of Lyme Regis; plesiosaur skeletons and how plesiosaurs swam with four flippers; search the Natural History Museum (London), Smithsonian, Lyme Regis Museum, SciShow Kids and Homeschool Pop (Alternate), and footage of sea turtles swimming for comparison.

KEY TERMS

fossil

The remains or trace of a living thing that has been kept in rock, such as a bone, shell, tooth or footprint.

marine reptile

A reptile that lived in the sea. Marine reptiles breathed air with lungs, like sea turtles do today.

plesiosaur

A sea reptile with a wide body, four long flippers and a short tail. Many kinds had a very long neck and a small head.

flipper

A flat, paddle-shaped limb for swimming. Inside a plesiosaur's flipper were long finger bones.

vertebra

One of the small bones that make up the backbone and neck. More than one are called vertebrae.

CORE IDEAS

The story. Lyme Regis is a little seaside town on the south coast of England. Its gray cliffs crumble in winter storms, and stony bones and curly shells tumble out onto the beach. Mary

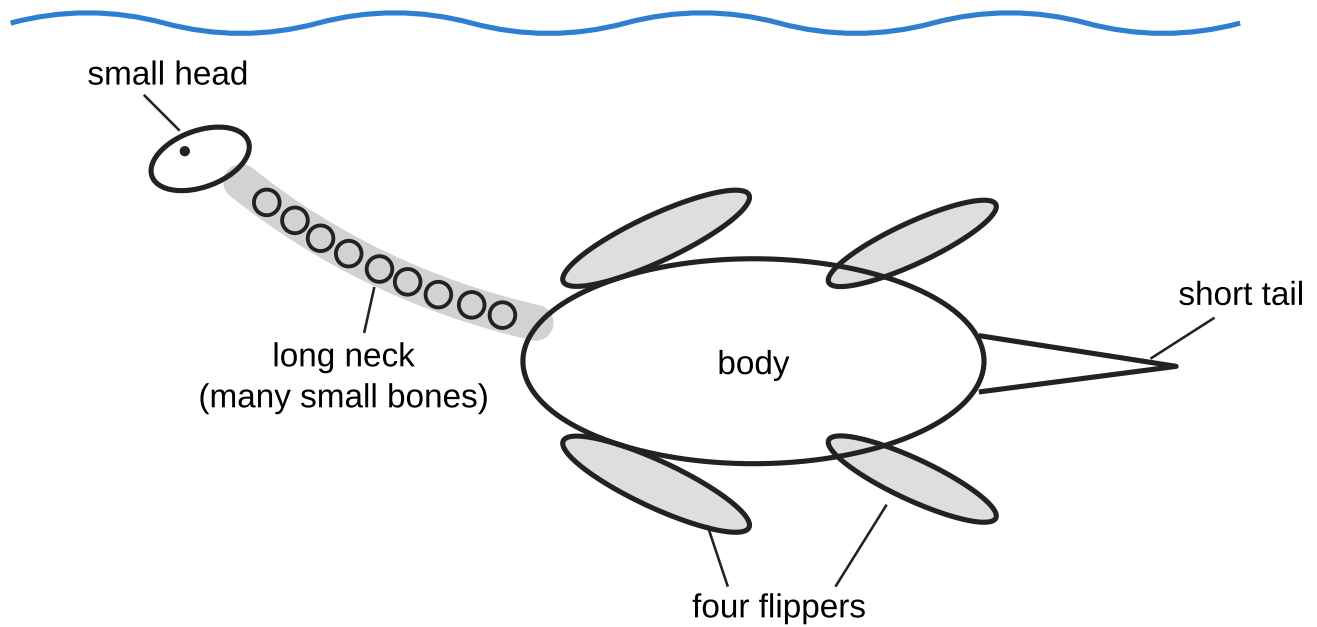
Anning grew up there in a poor family. Her father, a cabinetmaker, taught her to hunt the beach for fossils, which visitors called “curiosities” and liked to buy. After he died, Mary, her mother and her brother Joseph kept collecting to pay the bills. While she was still a girl, Mary helped dig out the skeleton of an ichthyosaur, a sea reptile shaped like a dolphin. Then, in December 1823, she uncovered something even stranger: a small head, a very long neck, a wide body, four great paddles and a short tail. It was the first nearly complete plesiosaur skeleton anyone had ever found.

How they figured it out. Mary worked the bones out of the rock with great care, made a careful drawing of the skeleton and wrote a letter describing it. Two English scientists, William Conybeare and Henry De la Beche, had already guessed from a few loose bones that such an animal existed. They named it *Plesiosaurus*, which means “near to a lizard.” But the famous French scientist Georges Cuvier doubted the new skeleton. No animal he knew had so many neck bones, and he wondered whether someone had joined the bones of two animals together. In early 1824 the skeleton was studied and shown to the Geological Society in London, and it was real. Cuvier agreed he had been wrong. Mary had never gone to college, but she knew bones as well as the professors did.

The big idea. A plesiosaur was a **marine reptile**. It was not a dinosaur, and it was not a fish. It breathed air with lungs, so it had to come up to the surface to breathe, as a sea turtle does. It swam with four long **flippers**, “flying” through the water with strong strokes. Inside each flipper were long finger bones packed close together. Some plesiosaurs had amazing necks. One kind, *Elasmosaurus*, had about 72 neck **vertebrae**, while you and a giraffe have only 7. A fossil found in Kansas shows a mother plesiosaur with a baby inside her body, so we know plesiosaurs gave birth to live babies in the water instead of laying eggs on a beach.

In the world today. Mary’s plesiosaur is kept at the Natural History Museum in London. In 1854 an artist named Benjamin Waterhouse Hawkins built life-size models of plesiosaurs for Crystal Palace Park in London, and families still visit them today. On museum signs you will often see the words “Jurassic” and “Cretaceous” next to plesiosaurs. Those are museum words; read the Thinking About Time box to see what they mean.

God’s handiwork. On the fifth day of creation, God filled the seas with living creatures “after their kind” (Genesis 1:21). A plesiosaur’s body shows wise design for the water: paddles to push, lungs to breathe, and a neck that could reach quickly after fish. When we study it, we are learning about the work of the Creator.



The parts of a plesiosaur. Count the small circles in the neck: each one stands for a neck bone (the real animal had even more).

Thinking About Time

What the sign says. Museum signs say plesiosaurs lived during the “Jurassic” and “Cretaceous” periods, a very, very long time ago, and that they died out long before the first people lived.

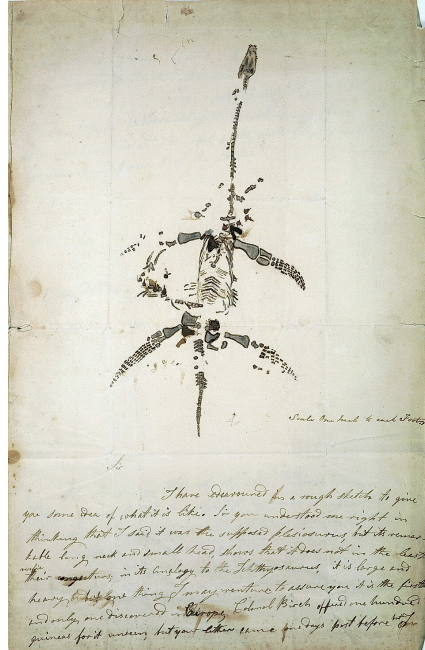
What we observe. We find plesiosaur bones in layers of rock, often together with ammonite shells and other sea creatures. Some are in sea cliffs like those at Lyme Regis, and some are in places far from any sea, like Kansas. We can dig, measure and count the bones, but no one today watched these animals live or die.

How Christians read it. Many Christians read these fossils as the remains of sea creatures God made on the fifth day of creation, many of them buried quickly in mud during the Flood of Noah’s day. Quick burial helps explain how whole skeletons stayed together in one piece instead of being scattered.

Try it. Find Kansas on a map of the United States. It is far from any ocean. Talk about how sea reptile bones could have ended up there.

Genesis 7:19

PICTURE STUDY



Letter and Sketch of the Plesiosaurus, Mary Anning, December 26, 1823 · Ink on paper (a handwritten letter with a pen drawing) · Wellcome Collection, London, England

Just a few weeks after she uncovered the skeleton, Mary Anning wrote this letter to describe her great find, and she drew the whole skeleton beside her words. Scientists far away could not come to the beach to see the bones, so her careful drawing let them see it for themselves.

This is the same work you do in your science notebook: look closely, draw what is really there and write it down with the date. Mary had never gone to college, but her drawing shows how well she knew bones.

Look closely

- Count the paddles. Do you see all four?
- Compare the neck with the body. Which is longer?
- Find the ribs. How did Mary show them with only a pen?
- Look at the handwriting around the drawing. Why do you think she wrote a letter and drew a picture together?

Talk about it

1. How is Mary's drawing like the plesiosaur figure in this lesson? How is it different?
2. Why would a drawing help Cuvier and the other scientists believe the skeleton was real?
3. If you found a fossil, what would you write beside your drawing?

Safety first. An adult should cut the straws or watch closely while you use scissors.

EXPERIMENT: THE NECK BONE BEND TEST

Why would a long neck be made of many small bones instead of a few long ones? You will build two pretend necks of the same length and test which one bends more. **Question:** Does a neck made of many short pieces bend more than a neck made of a few long pieces?

You will need

- 2 drinking straws (paper or plastic)
- 2 pipe cleaners, each about 12 inches long
- Scissors
- Ruler with inches and centimeters
- Tape and a sheet of paper
- Science notebook and pencil

Steps

1. **Predict.** Write which neck you think will bend more: the one with 3 pieces or the one with 12 pieces.
2. Measure and cut 6 inches from each straw. Cut the first 6-inch straw into 3 pieces, each 2 inches long. Cut the second into 12 pieces, each half an inch long.
3. Thread the 3 long pieces onto one pipe cleaner and the 12 short pieces onto the other. Push the pieces close together. These are your two necks. Each is 6 inches long.
4. Tape the bottom end of each neck to the paper. This is where the neck joins the body.
5. Gently curl each neck as far as it will go without bending a straw piece. Measure the distance in inches from the tip of the neck back to the taped end. A smaller number means the neck curled more.
6. Do the test 3 times for each neck and write the results in a table with columns: Number of pieces, Try 1, Try 2, Try 3.
7. **What we changed:** the number of pieces. **What we kept the same:** the total length, the kind of straw and the pipe cleaner. **What we measured:** the distance from the tip to the base.
8. Write one sentence: Was your prediction right? What does this tell you about a plesiosaur's many neck bones?

Tips

- Straw pieces bend at the gaps between them, just as a real neck bends at the joints between its bones.
- If you have a centimeter ruler, write each measurement in centimeters too. One inch is about 2 and a half centimeters.

Check your work

- I made a prediction before I tested.
- I kept the length of both necks the same.

- I measured and recorded three tries for each neck.
- I can explain why many small bones let a long neck bend.

NATURE NOTEBOOK

1. Copy the plesiosaur figure into your notebook. Label the head, neck, body, four flippers and tail.
2. Draw a cliff at Lyme Regis with layers of rock and a skeleton peeking out. Add Mary Anning with her basket and hammer, and write the date: December 1823.
3. Draw two necks side by side: a giraffe neck with 7 bones and a plesiosaur neck with many more. Write the numbers under each.

From history. In 1824 a visitor to Lyme Regis, Lady Harriet Silvester, wrote in her diary about meeting Mary Anning. She said that by reading and hard work Mary had learned so much that she wrote and talked with professors about fossils, and that they all agreed she understood the science better than anyone else in the kingdom. Mary was a churchgoing Christian, and she kept collecting on the stormy beaches of Lyme Regis for the rest of her life.

WORKED EXAMPLES

Example 1. The plesiosaur *Elasmosaurus* had about 72 neck bones. A giraffe has 7. How many more neck bones did *Elasmosaurus* have? About how many times as many is that?

1. To find how many more, subtract: $72 - 7 = 65$.
2. To find about how many times as many, think of tens of 7: $7 \times 10 = 70$, which is very close to 72.
3. So *Elasmosaurus* had about 10 times as many neck bones as a giraffe.

Answer: 65 more neck bones, about 10 times as many as a giraffe.

Example 2. *Plesiosaurus*, Mary Anning's plesiosaur, was about 10 feet long. *Elasmosaurus* was about 34 feet long. How much longer was *Elasmosaurus*? Scientists measure in meters. One meter is a little more than 3 feet. About how many meters long was *Plesiosaurus*?

1. Subtract the lengths: $34 \text{ feet} - 10 \text{ feet} = 24 \text{ feet}$.
2. A meter is a little more than 3 feet. Count by 3s toward 10: 3, 6, 9. That is 3 meters, with a little left over.
3. Because each meter is a little *more* than 3 feet, 3 meters is very close to 10 feet.

Answer: *Elasmosaurus* was about 24 feet longer. *Plesiosaurus* was about 3 meters long.

PRACTICE

1. **EASY** Who found the first nearly complete plesiosaur skeleton? Where and in what year?
2. **EASY** Was a plesiosaur a dinosaur, a fish or a marine reptile? Give one clue.
3. **MEDIUM** A museum hall shows 3 plesiosaur skeletons. Each plesiosaur has 4 flippers. How many flippers are in the hall?
4. **MEDIUM** A long school bus is about 40 feet long. *Elasmosaurus* was about 34 feet long. How much shorter than the bus was *Elasmosaurus*?
5. **HARD** Sam did the Neck Bone Bend Test with three necks, each 6 inches long. Here is Sam's sample data for the distance from tip to base after curling: 3 pieces, 4 inches; 6 pieces, 2 inches; 12 pieces, 1 inch. Which neck curled the most? What pattern do you see?
6. **CHALLENGE** Georges Cuvier at first doubted Mary Anning's plesiosaur. Write two or three sentences: why did he doubt it, and what showed it was real?

COMMON MISTAKES

- Calling plesiosaurs "swimming dinosaurs." Plesiosaurs were marine reptiles, a different group from dinosaurs.
- Thinking plesiosaurs breathed water like fish. They had lungs and came up to the surface to breathe air.
- Thinking great fossils are found by luck alone. Mary Anning searched for years, studied animal bodies and kept careful records. Her skill is why she found what others missed.

Make it a game • Flipper, Fin or Foot?. A parent names an animal: plesiosaur, shark, sea turtle, goldfish, duck, dolphin, frog or crab. You call out "Flipper!", "Fin!" or "Foot!" for the way it moves, then say whether it breathes air or water. Score one point for each part you get right. Bonus point: name one way a plesiosaur's flippers were like a sea turtle's.

Scripture. "And God created great whales, and every living creature that moveth, which the waters brought forth abundantly, after their kind, and every winged fowl after his kind: and God saw that it was good." (Genesis 1:21, KJV)

The great creatures of the sea were made by God and called good. Mary Anning's careful work let people see some of those creatures for the first time.

Practice answers

1. Mary Anning, at Lyme Regis on the south coast of England, in 1823.
2. A marine reptile. Clues: it breathed air with lungs, it had four flippers instead of fins with gills, and it lived in the sea.
3. $3 \times 4 = 12$ flippers.
4. $40 - 34 = 6$ feet shorter.

5. The neck with 12 pieces curled the most, because its tip came closest to the base (1 inch).
Pattern: the more pieces the neck had, the more it could bend.
6. Cuvier doubted it because no animal he knew had so many neck bones, so he wondered whether two skeletons had been put together. When the skeleton was carefully studied and shown in London in 1824, it proved to be one real animal. Mary Anning's careful digging, drawing and description helped show the truth, and Cuvier admitted he had been wrong.

7.2 MOSASAURS: THE GREAT LIZARD OF THE MEUSE

OBJECTIVES

- Tell the story of the giant skull found in a chalk quarry near Maastricht and how Georges Cuvier showed it belonged to a sea-going lizard.
- Describe a mosasaur's body (hinged jaws, extra teeth, flippers and tail fin) and compare it with a plesiosaur.
- Read a bar graph of sea-creature lengths and make a simple scale drawing.

Warm-up. Find a picture of a lizard and a picture of a fish in a book or online with a parent. Make two quick lists: three ways they are different and one way they are alike. Now imagine a lizard as long as a school bus that lives its whole life in the sea. Which of its body parts would need to change? Draw your idea in one minute.

Video. Coming soon. Mosasaurs and the Maastricht skull; mosasaur fossils from the Kansas chalk; monitor lizards swimming for comparison; search the Smithsonian, the Natural History Museum (London), the Sternberg Museum of Natural History, SciShow Kids, Homeschool Pop (Alternate) and nature footage of Komodo dragons and monitor lizards.

KEY TERMS

mosasaur

A large sea lizard with a long body, four flippers, a strong tail with a fin and jaws full of sharp teeth.

chalk

A soft, white rock made mostly of the tiny shells of very small sea creatures. Many mosasaur bones are found in chalk.

quarry

A place where people dig or cut rock out of the ground.

jaw hinge

A joint where a jaw can bend. A mosasaur's lower jaw had an extra hinge partway along each side.

tail fluke

A flat fin at the end of a tail that pushes against the water, like the tail fin of a shark.

CORE IDEAS

The story. Near the city of Maastricht, in the Netherlands, there is a hill called Saint Peter's Mountain. For hundreds of years, workers dug soft chalk rock out of long tunnels under it. Sometime in the 1770s (old accounts give different years), by the light of their lamps, the quarry men found a giant jaw full of sharp, curved teeth sticking out of the tunnel wall. The

skull was about as long as you are tall. The story goes that a local fossil collector and a church leader who owned the land both claimed it. Then, in 1795, a French army captured Maastricht, and the story goes that the soldiers were promised a reward of wine for finding the famous skull. It was carried off to Paris, and it is still there today.

How they figured it out. What was it? Some people said it was a crocodile. Others said a whale. The Dutch scientist Adriaan Camper and then the French scientist Georges Cuvier compared it bone by bone with living animals. They saw that the teeth were fastened to the jawbone the way a lizard's are, and that there were extra teeth on the roof of the mouth, as some lizards and snakes have. It was a lizard, a giant sea lizard related to today's monitor lizards! In 1822 the English scientist William Conybeare named it *Mosasaurus*, which means "lizard of the Meuse," after the river that flows past Maastricht.

The big idea. A **mosasaur** had a long body, four flippers and a long, strong tail. Newer fossils show that the end of its tail bent down and held a fin, a **tail fluke**, a little like a shark's. A mosasaur swam by sweeping that tail from side to side and steered with its flippers. Its lower jaw had an extra **jaw hinge** partway along each side, so the jaw could flex around big prey, and the extra teeth on the roof of its mouth kept slippery food from escaping. Mosasaurs ate fish, turtles, shelled ammonites and even other mosasaurs. Like plesiosaurs, they breathed air and gave birth to live babies. The biggest, *Mosasaurus*, grew to about 40 feet (about 12 meters) long or more.

In the world today. Some of the best mosasaur fossils in the world come from the chalk of western Kansas, hundreds of miles from any ocean. Fossil hunters there have found mosasaurs with small, diamond-shaped scales pressed into the rock and with the bones of their last meals inside their ribs. You can see Kansas mosasaurs at the Sternberg Museum of Natural History in Hays, Kansas, and at the Smithsonian in Washington, D.C. Museum signs call the time of mosasaurs the "Cretaceous," a museum word that comes from the Latin word for chalk.

God's handiwork. The psalm writer looked at the sea and praised God for "things creeping innumerable, both small and great beasts" (Psalm 104:25). The mosasaur was one of the greatest. Its hinged jaw and gripping teeth show a body fitted for its life in the sea.



Thinking About Time

What the sign says. Museum signs say mosasaurs lived in the "Late Cretaceous," the last part of what they call "the age of dinosaurs," and that they died out at the same time as the dinosaurs, a very, very long time before people.

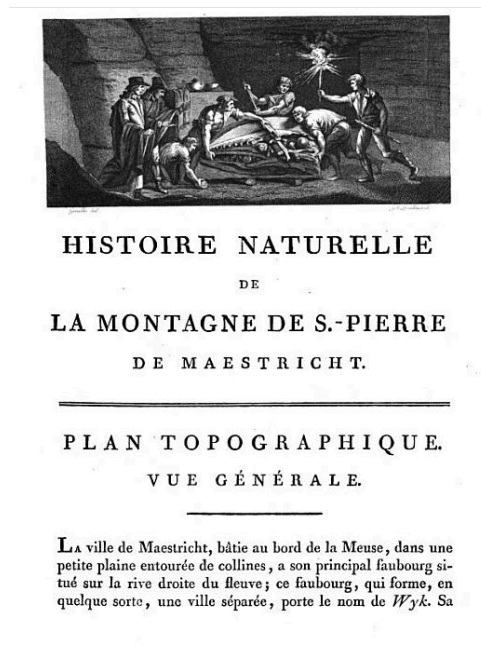
What we observe. We find mosasaur bones in thick layers of chalk in the Netherlands, in Kansas and in other places, together with sharks' teeth, fish, clams and ammonites. Chalk is made of the tiny shells of very small sea creatures. Sea fossils are found high and dry on land, far from today's oceans.

How Christians read it. Many Christians read these chalk beds and sea fossils on dry land as a record of the Flood, when the waters covered the earth and sea creatures were buried in great layers of mud and chalk. They believe mosasaurs were among the sea creatures God made on the fifth day.

Try it. If you can, look at a piece of natural chalk rock with a magnifying glass. (Much classroom chalk today is made of a different mineral, gypsum.)

Genesis 7:20

PICTURE STUDY



The finding of the great skull in the quarry of Saint Peter's Mountain, Plate from the book of Barthélemy Faujas de Saint-Fond, 1799 · Engraving (a printed picture) · Published in Paris in Faujas de Saint-Fond's Natural History of Saint Peter's Mountain of Maastricht; copies are kept in many libraries

Barthélemy Faujas de Saint-Fond was a French scientist who wrote a big book about the hill at Maastricht and the fossils found in its chalk tunnels. One of its pictures shows the moment the great jaw was found in the rock, deep inside the quarry.

Before photographs, books used engravings like this one. An artist drew the picture, and then lines were cut into a metal plate so that many copies could be printed in ink.

Look closely

- Find the giant jaw. Where is it: on the floor, in the wall or in someone's hands?
- Look for the lights. How did the workers see underground?
- Count the people. Which ones look like workers and which look like visitors?
- Look at the size of the jaw next to the men. About how many men lying down would it take to match it?

Talk about it

1. Why do you think so many people wanted to own this skull?
2. How do you think the workers felt when they first saw the teeth in the wall?
3. What would you do first if you found a giant bone while digging?

Safety first. Use a plastic container if you can. Wipe up spilled water right away so no one slips, and work with an adult nearby.

EXPERIMENT: THE SEA LIZARD SHAPE RACE

A mosasaur had a long, smooth, pointed body. Does a smooth, pointed shape really move through water more easily than a flat or round one? **Question:** Which clay shape sinks fastest through water: a ball, a flat pancake or a long, pointed “mosasaur” shape?

You will need

- Modeling clay
- A tall, clear container of water (a large plastic bottle with the top cut off by an adult, or a tall plastic vase)
- A kitchen scale (if you have one) or a measuring spoon
- Towel
- Science notebook and pencil

Steps

1. **Predict.** Write which shape you think will reach the bottom first.
2. Make three lumps of clay that are the same size. If you have a kitchen scale, check that they weigh the same. If not, press each lump into the same measuring spoon.
3. Shape one lump into a ball, one into a flat pancake and one into a long, smooth body pointed at both ends, like a mosasaur.
4. Hold two shapes just at the top of the water. Let go of both at the same moment. Watch which one reaches the bottom first.
5. Race every pair: pointed against ball, pointed against pancake, ball against pancake. Do each race 3 times and record the winner each time in a table.
6. **What we changed:** the shape. **What we kept the same:** the amount of clay, the water, the container and the starting height. **What we observed:** which shape reached the bottom first.
7. Write a sentence: Which shape won the most races? How does this help explain the shape of a mosasaur?

Tips

- Use a spoon or tongs to fish the clay out of the water between races.
- Ask a helper to watch the bottom of the container while you drop, so you have two pairs of eyes.

Check your work

- I made my three clay shapes from the same amount of clay.
- I raced each pair 3 times and recorded the winners.
- I can explain why a smooth, pointed body helps a sea animal move through water.

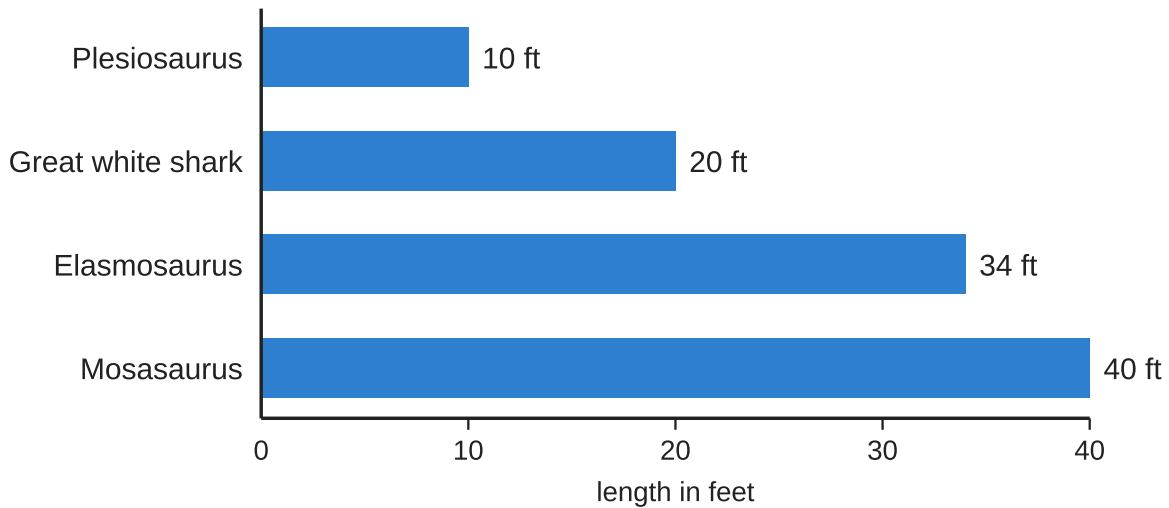
NATURE NOTEBOOK

1. Draw a mosasaur skull from the side. Show the extra hinge in the lower jaw and the extra row of teeth on the roof of the mouth.
2. Draw a plesiosaur and a mosasaur one above the other. Circle the part each one mainly used to push through the water.
3. Make a scale drawing of a 40-foot mosasaur using 1 inch for every 4 feet. Write the scale under your drawing.

From history. Georges Cuvier's study of the Maastricht skull helped him prove something new: some kinds of animals that once lived are now completely gone, or **extinct**. No living lizard anywhere in the world was so big or so fitted to the sea, so Cuvier argued that this creature no longer lived anywhere on earth. The skull he studied is still kept at the National Museum of Natural History in Paris.

WORKED EXAMPLES

Example 1. Use the bar graph of sea-creature lengths. How much longer was *Mosasaurus* than a large great white shark? Which animal on the graph was about twice as long as *Plesiosaurus*?



How long were they? Each bar shows a length in feet.

1. Read the end of each bar: *Mosasaurus* is about 40 feet. The great white shark is about 20 feet.
2. Subtract: $40 - 20 = 20$ feet.
3. *Plesiosaurus* is about 10 feet. Twice 10 is $10 + 10 = 20$. The bar that ends at 20 feet is the great white shark.

Answer: *Mosasaurus* was about 20 feet longer than a large great white shark. The shark was about twice as long as *Plesiosaurus*.

Example 2. You want to draw a 40-foot *Mosasaurus* on paper. You decide that 1 inch on paper will stand for 4 feet. How long should your drawing be? How long would a 10-foot *Plesiosaurus* be at the same scale?

1. Ask: how many 4-foot pieces fit into 40 feet? $40 \div 4 = 10$.
2. Each 4-foot piece is 1 inch, so the mosasaur drawing is 10 inches long.
3. For the plesiosaur: $10 \div 4 = 2$ with 2 feet left over. Two feet is half of 4 feet, so that is 2 and a half inches.

Answer: The mosasaur drawing is 10 inches long. The plesiosaur drawing is 2 and a half inches long.

PRACTICE

1. **EASY** What does the name *Mosasaurus* mean, and how did it get that name?
2. **EASY** Name two parts of a mosasaur's mouth that helped it hold on to slippery prey.
3. **MEDIUM** Use the bar graph. List the four animals in order from shortest to longest.
(Use the map or drawing "Use the graph to order the animals." shown earlier in this lesson.)
4. **MEDIUM** Using the scale 1 inch = 4 feet, how long would you draw a 20-foot great white shark?
5. **HARD** Here is sample data from a Shape Race. Pointed against ball: pointed won 3 of 3. Pointed against pancake: pointed won 3 of 3. Ball against pancake: ball won 3 of 3. Which shape was fastest? Which was slowest? Why is it wise to race each pair 3 times instead of once?
6. **CHALLENGE** Write two ways a mosasaur and a plesiosaur were alike and two ways they were different.

COMMON MISTAKES

- Calling a mosasaur a dinosaur or a fish. A mosasaur was a sea-going lizard, a marine reptile that breathed air.
- Thinking the Maastricht skull was found by scientists on an expedition. It was found by quarry workers digging chalk; scientists studied it afterward.
- Thinking the chalk you write with is the same as chalk rock. Much classroom chalk today is made of gypsum, a different mineral. Natural chalk is made of tiny sea shells.

Make it a game · Mosasaur or Plesiosaur?. A parent reads a clue, such as "I had an extra hinge in my jaw," "I had a very long neck with many bones," "I swam mostly with my tail," or "I breathed air." Call out "Mosasaur!", "Plesiosaur!" or "Both!" Score a point for each right answer. Then switch: you make up clues for your parent.

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 God made, from tiny shelled plankton that formed the chalk to great sea lizards like the mosasaur.

Practice answers

1. "Lizard of the Meuse." It was named for the Meuse River, which flows past Maastricht, where the famous skull was found.
2. The extra hinge in each side of the lower jaw, and the extra teeth on the roof of the mouth.
3. *Plesiosaurus* (10 ft), great white shark (20 ft), *Elasmosaurus* (34 ft), *Mosasaurus* (40 ft).
4. $20 \div 4 = 5$, so 5 inches long.
5. The pointed shape was fastest and the pancake was slowest. Racing 3 times makes sure one lucky or unfair drop does not fool us; if the same shape wins every time, we can trust the result more.

6. Alike (any two): both were marine reptiles, both breathed air, both had four flippers, both gave birth to live babies. Different (any two): a mosasaur pushed itself mainly with its tail, while a plesiosaur swam mainly with its four flippers; many plesiosaurs had very long necks and short tails, while a mosasaur had a short neck and a long tail; a mosasaur was a kind of lizard with a hinged lower jaw.

7.3 PTEROSAURS: WINGS OF SKIN

OBJECTIVES

- Tell how Cosimo Collini described the first pterosaur fossil in 1784 and how Georges Cuvier showed it was a flying reptile.
- Compare the wings of a bird, a bat and a pterosaur and explain how a pterosaur's wing was held up by one very long finger.
- Compare wingspans in feet and meters and test how wing size changes the speed of a fall.

Warm-up. Stand up and stretch your arms out wide. Have a helper measure from the tip of one middle finger to the tip of the other with a tape measure. That is your “wingspan.” Write it down in feet and inches. Now hold up your hand and look at your ring finger. Imagine it growing longer than your whole arm. That is the secret of a pterosaur's wing.

Video. Coming soon. Pterosaurs: Pteranodon, Quetzalcoatlus and how pterosaur wings worked; compare bird and bat wings in flight; search the Smithsonian, the Natural History Museum (London), SciShow Kids, Homeschool Pop (Alternate), Science Max for gliders and air resistance, and slow-motion nature footage of bats and birds flying.

KEY TERMS

pterosaur

A flying reptile with wings made of skin. The name means “winged lizard.” Pterosaurs were not birds and not dinosaurs.

wing membrane

The thin, strong sheet of skin that made a pterosaur's or a bat's wing.

wing finger

The very long fourth finger of a pterosaur's hand, which held up the front edge of its wing.

wingspan

The distance from the tip of one wing to the tip of the other when the wings are spread out.

air resistance

The push of the air against something moving through it. A big wing meets more air resistance than a small one.

CORE IDEAS

The story. In the 1700s, quarry workers in Bavaria, in southern Germany, split thin, flat slabs of the fine-grained rock called Solnhofen limestone. In one slab they found a small, strange skeleton: a long head with tiny teeth, a long neck, short legs, and one finger on each hand that was longer than the whole arm. The fossil ended up in the natural history

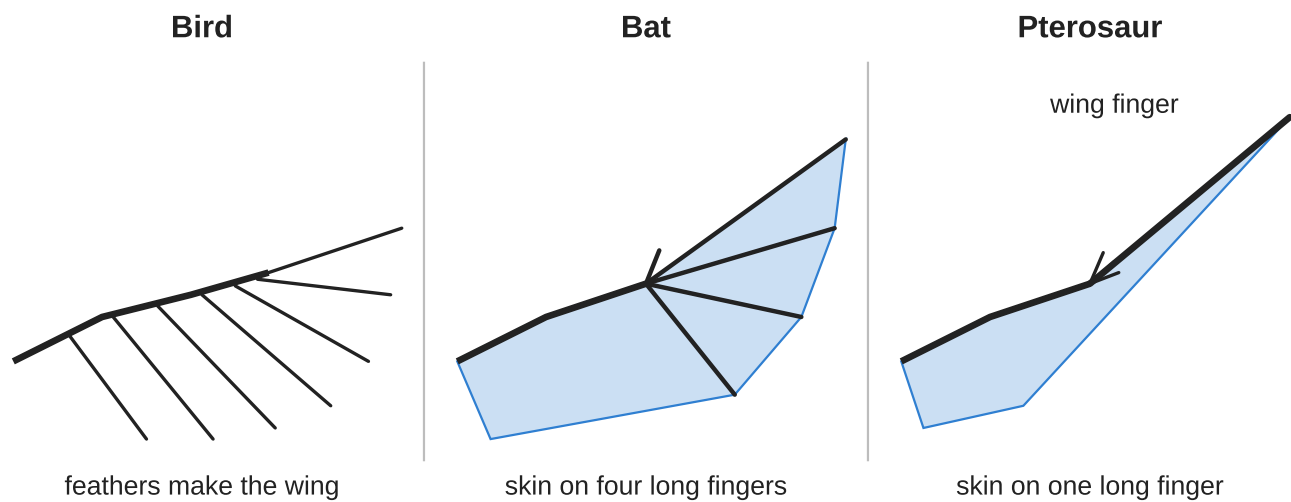
collection of a prince in the city of Mannheim. The keeper of that collection, an Italian named Cosimo Collini, studied it and in 1784 wrote the first description of it. Collini could not decide what it was. He wondered if it was a sea animal that used its long arms as paddles.

How they figured it out. Years later, the French scientist Georges Cuvier looked at Collini's careful drawing. The same Cuvier who studied the mosasaur skull compared the bones with birds, bats and lizards. He saw that the bones were a reptile's, and that the long finger must have held up a wing of skin. This was a flying reptile! Cuvier named it *Ptero-dactyle*, which means "wing finger." Today we call the whole group **pterosaurs**, "winged lizards."

The big idea. Birds, bats and pterosaurs all fly, but their wings are built in three different ways (see the figure). A bird's wing is made of feathers on a short arm and hand. A bat's wing is skin stretched between four long fingers. A pterosaur's wing was a **wing membrane** of skin held up by just one enormous **wing finger**, its fourth finger, and stretched back toward its legs. Its other three fingers were small and clawed, good for grabbing and climbing. Its bones were hollow and thin-walled, light for flying, and its body was covered with fine fuzz. Footprints in rock show that pterosaurs walked on all fours when they were on the ground.

In the world today. In the 1870s, fossil hunters found *Pteranodon* in the Kansas chalk, the same rock that holds mosasaurs. It had no teeth, a long pointed crest on its head and a **wingspan** of about 20 feet (6 meters) in big adults. In 1971 a student named Douglas Lawson found the bones of an even bigger pterosaur in Big Bend National Park in Texas. It was named *Quetzalcoatlus*, and its wingspan was about 33 feet (10 meters), as wide as a small airplane. Museum signs say pterosaurs lived in the "Jurassic" and "Cretaceous"; see the Thinking About Time box.

God's handiwork. God asked Job, "Doth the hawk fly by thy wisdom?" (Job 39:26). Flight is hard. Engineers work for years to design light, strong wings. The pterosaur, with its hollow bones and wings of living skin, flew by the wisdom of the One who made it.



Three ways to build a wing. Count the long fingers that hold up the skin in the bat and the pterosaur.

Thinking About Time

What the sign says. Museum signs say pterosaurs lived during the “Jurassic” and “Cretaceous” periods, in what they call “the age of dinosaurs,” and died out a very, very long time before people lived.

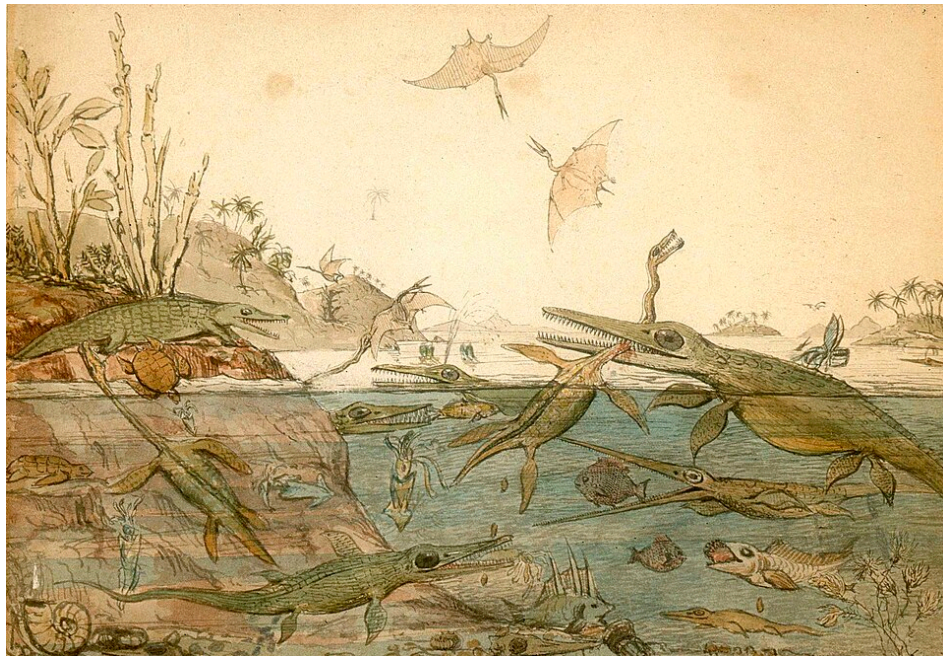
What we observe. We find pterosaur bones in rock layers such as the fine limestone of Solnhofen and the chalk of Kansas. Their thin, hollow bones break easily, so a whole skeleton is rare. Finding delicate bones kept so well tells us they were covered quickly by fine mud.

How Christians read it. Many Christians believe God made flying creatures on the fifth day of creation (Genesis 1:20-21) and that many pterosaurs were buried quickly in the Flood, which would explain how such fragile bones were kept so well.

Try it. Hold a dry leaf on a table and slowly cover half of it with a thin layer of flour or sand. Notice how quick, gentle covering keeps its shape.

Genesis 1:20

PICTURE STUDY



Duria Antiquior (A More Ancient Dorset), Henry De la Beche, 1830 · Watercolor; later printed as a lithograph · Amgueddfa Cymru – National Museum Wales, Cardiff

Henry De la Beche was an English scientist who knew Mary Anning and studied her fossils. In 1830 he painted this picture to show what the sea near Lyme Regis might have looked like when its creatures were alive. It is one of the very first pictures ever made to show fossil animals as living creatures.

De la Beche had copies of the picture printed and sold, and he gave the money to help Mary Anning, who was having a hard year. A picture made from careful science also became an act of kindness.

Look closely

- Find the flying reptiles in the sky. How many can you count?
- Find the long-necked plesiosaurs. Which animal from Lesson 7.1 are they like?
- Look at the line where the water meets the air. What is happening above it, and what is happening below?
- Look at the wings of the flying creatures. Do they look like feathers or like skin?

Talk about it

1. Why do you think the painter put so many animals into one small scene?
2. Which parts of this picture come from bones that were found, and which parts did the artist have to imagine?
3. How did this painting help Mary Anning?

Safety first. Drop your wings while standing on the floor. Do not climb on chairs, tables or stairs to get more height; ask a tall adult to drop them instead.

EXPERIMENT: WING SIZE DROP TEST

Big pterosaurs had huge wings. Does a bigger wing catch more air and slow a fall?

Question: Do bigger paper wings fall more slowly than smaller ones carrying the same paper clip?

You will need

- 3 sheets of printer paper
- Ruler and pencil
- Scissors
- 3 paper clips (all the same size)
- Tape
- A stopwatch or a phone timer (or count “one-Mississippi”)
- Science notebook

Steps

1. **Predict.** Write which wing you think will take the longest to fall.
2. Measure and cut three paper squares: 4 inches on each side, 6 inches on each side and 8 inches on each side.
3. Tape one paper clip to the middle of each square. The paper clip is the “body.” Every wing carries the same paper clip. (The bigger squares are a little heavier because they use more paper, but they fall more slowly anyway.)

4. Hold one square flat, clip side down, at the same height every time, such as the top of your head or an adult's reach. Let go and time how long it takes to reach the floor.
5. Drop each wing 3 times. Write the times in a table with columns: Wing size, Try 1, Try 2, Try 3.
6. **What we changed:** the size of the wing. **What we kept the same:** the paper, the paper clip and the drop height. **What we measured:** the time to fall, in seconds.
7. Write a sentence: Did the bigger wing fall more slowly? How might big wings have helped *Pteranodon* glide over the sea?

Tips

- If the squares flip and tumble, gently bend the edges up a tiny bit to make a shallow dish.
- Time is easier to measure from a higher drop, so an adult may hold the wings up high.

Check your work

- I made a prediction before I tested.
- I used the same kind of paper clip and the same height.
- I recorded three tries for each wing size.
- I can explain how wing size changed how fast the wing fell.

NATURE NOTEBOOK

1. Copy the three-wing figure. Color the skin wings one color and the feathers another. Label the wing finger on the pterosaur.
2. Trace your own hand. Draw a pretend line showing how long your ring finger would need to be to hold up a pterosaur wing.
3. Draw *Pteranodon* gliding over the sea, with its crest, long beak and wide wings. Write its wingspan in feet and meters underneath.

From history. In December 1828, Mary Anning found the first pterosaur skeleton ever discovered outside Germany, on the beach at Lyme Regis. The scientist William Buckland described it the next year. Later scientists gave it its own name, *Dimorphodon*, which means "two kinds of teeth," because it had big teeth in the front of its jaws and small teeth behind them.

WORKED EXAMPLES

Example 1. Look at the three-wing figure. For each animal, how many long fingers hold up the wing? Which wing has no skin at all?

(Use the map or drawing “Count the fingers holding up each wing.” shown earlier in this lesson.)

1. Bird: the wing is made of feathers on a short hand, so no long fingers hold up skin.
2. Bat: four long fingers spread out with skin between them.
3. Pterosaur: one very long finger holds up the front edge of the skin. Its three small fingers are not in the wing.
4. The bird wing has no skin wing; it is made of feathers.

Answer: Bird: 0, bat: 4, pterosaur: 1. The bird’s wing is made of feathers, not skin.

Example 2. *Quetzalcoatlus* had a wingspan of about 33 feet. *Pteranodon* had a wingspan of about 20 feet. How much wider was *Quetzalcoatlus*? If a third grader’s arm span is about 4 feet, about how many children holding hands with arms spread would match *Quetzalcoatlus*?

1. Subtract: $33 - 20 = 13$ feet wider.
2. Count by 4s: 4, 8, 12, 16, 20, 24, 28, 32. That is 8 children for 32 feet.
3. 32 feet is just 1 foot short of 33 feet, so about 8 children.

Answer: *Quetzalcoatlus* was about 13 feet wider. About 8 children with arms spread would match its wingspan.

PRACTICE

1. **EASY** What does “pterosaur” mean? What does “ptero-dactyl” mean?
2. **EASY** Which finger held up a pterosaur’s wing? What was its wing made of?
3. **MEDIUM** A bald eagle’s wingspan is about 7 feet. *Pteranodon*’s was about 20 feet. How much wider was *Pteranodon*’s wingspan?
4. **MEDIUM** *Quetzalcoatlus* had a wingspan of about 10 meters. *Pteranodon* had a wingspan of about 6 meters. How many meters wider was *Quetzalcoatlus*?
5. **HARD** Here is sample data from a Wing Size Drop Test (average of 3 tries): 4-inch wing, 1 second; 6-inch wing, 2 seconds; 8-inch wing, 3 seconds. What pattern do you see? Name two things that had to stay the same for this to be a fair test.
6. **CHALLENGE** Your friend says, “Pterosaurs were flying dinosaurs, a kind of bird.” Write two or three sentences to explain why that is not right.

COMMON MISTAKES

- Calling pterosaurs “flying dinosaurs.” Scientists put pterosaurs in their own group of flying reptiles, separate from the dinosaurs.
- Thinking a pterosaur was a bird. Birds have feathers; a pterosaur’s wing was a sheet of skin on one long finger.
- Using “pterodactyl” as the name for every flying reptile. *Pterodactylus* is one kind; the whole group is called pterosaurs, and it includes *Pteranodon* and *Quetzalcoatlus*.

Make it a game · Bird, Bat or Pterosaur?. A parent reads a clue, such as “My wing is skin on four long fingers,” “My wing is made of feathers,” “I had one giant finger,” or “I still fly today.” Flap your arms like the right animal and call out its name. Score a point for each right answer. Bonus: name a pterosaur from this lesson and say how wide its wings were.

Scripture. “Doth the hawk fly by thy wisdom, and stretch her wings toward the south?” (Job 39:26, KJV)

Every creature that flies, from the hawk to the great pterosaur, flies by God’s wisdom, not ours. Studying wings helps us see how wise He is.

Practice answers

1. Pterosaur means “winged lizard.” Pterodactyl means “wing finger.”
2. The very long fourth finger (the ring finger). The wing was a thin sheet of skin, a wing membrane.
3. $20 - 7 = 13$ feet wider.
4. $10 - 6 = 4$ meters wider.
5. The bigger the wing, the longer it took to fall (bigger wings fell more slowly because they met more air resistance). Things kept the same (any two): the paper clip (one each), the kind of paper, the drop height, the way it was dropped.
6. Pterosaurs were flying reptiles, a group of their own, not dinosaurs. They were not birds either: birds have wings made of feathers, but a pterosaur’s wing was skin held up by one very long fourth finger.

7.4 LEVIATHAN: THE GREAT CREATURE OF JOB 41

OBJECTIVES

- Read and explain the description of leviathan in Job 41, and tell why God spoke to Job about it.
- Compare the clues in Job 41 with animals we know, such as the crocodile, the whale and the great sea reptiles, the way a scientist compares a fossil with living animals.
- Test how overlapping scales protect a body, and compare animal lengths in feet and meters.

Warm-up. Play “Mystery Animal.” A parent thinks of an animal and gives you one clue at a time, such as “It lives in water,” “It has scales,” “It has sharp teeth.” After each clue, say your best guess and why. How many clues did you need? Talk about it: why is it hard to be sure what an animal is from words alone, without a picture?

Video. Coming soon. Crocodile scales and armor, crocodiles hunting in rivers, and great whales at sea, to compare with the description of leviathan in Job 41; search nature footage of Nile and saltwater crocodiles, Smithsonian National Zoo, SciShow Kids, Moody Science classics, and a KJV audio reading of Job 38–41.

KEY TERMS

leviathan

A great and fearsome water creature described in Job 41 and named in the Psalms and Isaiah. The Bible does not say exactly which animal it was.

description

Words that tell what something looks like or does. Scientists write careful descriptions so others can picture what they saw.

scales

Small, hard plates that cover the skin of reptiles and many fish and help protect the body.

armor

A hard covering that protects a body from harm, such as a crocodile’s thick, bony scales.

compare

To look at two or more things side by side to see how they are alike and how they are different.

CORE IDEAS

The story. The Bible tells of a man named Job who lived in the land of Uz. Job loved God, but terrible troubles came to him, and he longed to ask God why. At last “the LORD answered Job out of the whirlwind” (Job 38:1). God did not explain Job’s troubles. Instead He asked Job question after question about the world He had made: the stars, the sea, the snow, the lion,

the hawk and the eagle. Last of all, God described two mighty creatures, behemoth (Job 40) and leviathan (Job 41).

How they figured it out. Job 41 reads like a careful **description**. God asks, “Canst thou draw out leviathan with an hook?” (Job 41:1). Leviathan’s skin cannot be filled with spears (41:7). Its teeth are “terrible round about” (41:14). Its **scales** are so close together that “no air can come between them” (41:16). It makes the deep sea boil like a pot (41:31), and “upon earth there is not his like” (41:33). Bible readers have long tried to match these clues to an animal, the same way Cuvier matched a strange skull to the animals he knew.

The big idea. Many Bible teachers think leviathan was a great crocodile. A Nile crocodile has thick, bony **armor**, rows of fierce teeth and scales set close together, and it is very hard to catch. Others point to Psalm 104:26, which puts leviathan in the great sea: “There go the ships: there is that leviathan.” They think of a whale. Some Christians wonder whether leviathan was a great sea reptile like the ones in this unit. The verses about smoke and flames (41:18–21) may be a poetic picture of a terrifying beast, or they may describe something we do not yet understand. The Bible does not give us a drawing, so a wise reader holds these ideas humbly. The **main point** is clear: no man can tame leviathan, but God made it and rules over it.

Try it and see. Look at real armor in God’s creation. A crocodile’s back is covered with rows of thick, bony scales. Fish scales and roof shingles overlap, each one covering the edge of the next, so water runs off. In this lesson’s project you will test whether overlapping scales really keep water out, just as Job 41:16–17 describes scales “joined one to another.”

God’s handiwork. God said, “whatsoever is under the whole heaven is mine” (Job 41:11). Plesiosaurs, mosasaurs, pterosaurs, crocodiles, whales and leviathan all belong to Him. Job learned that if God can make and rule such creatures, He can be trusted with our troubles too.



Thinking About Time

What the sign says. Museum signs say the great sea reptiles, like plesiosaurs and mosasaurs, died out a very, very long time before any people lived, so no person could ever have seen one alive.

What we observe. We have two kinds of evidence to compare. We have bones of great sea reptiles buried in rock layers, and we have the words of Job 41, an ancient written description. We can compare both with animals living today, but we cannot travel back to watch.

How Christians read it. Christians who read Genesis as history believe God made the sea creatures and the first people in the same week of creation (Genesis 1:21, 27). If so, people long ago could have seen great creatures that are now gone, so a sea-reptile reading of leviathan is possible, though many still think of the crocodile. Either way, the point of Job 41 is God’s power.

Try it. Make a two-column chart: “What we see in the bones” and “What we read in Job 41.” Fill in three items in each column.

Genesis 1:21

PICTURE STUDY



The Destruction of Leviathan, Gustave Doré, 1865 · Wood engraving, from an illustrated Bible · Printed in Doré’s illustrated Bible (first published in France in 1866); copies are kept in many libraries

Gustave Doré was a French artist who made hundreds of pictures for famous books, including more than two hundred for the Bible. He drew his pictures in fine detail, and skilled workers carved them into blocks of wood so they could be printed.

This picture shows Isaiah 27:1, where the prophet says the LORD will punish “leviathan the piercing serpent” with His “sore and great and strong sword.” Doré chose to draw leviathan as a giant sea serpent. That is an artist’s idea; Job 41 does not give us a picture.

Look closely

- Find leviathan. How did Doré show how big and strong it is?
- Look at the sea. Is it calm or wild? Which verse of Job 41 does it remind you of?
- Find the light in the picture. Where does it come from, and who is in it?
- Look at all the fine lines. How did the engraver make dark and light parts with only black ink?

Talk about it

1. Which clues from Job 41 did Doré use in his picture? Which did he leave out?

2. Does Doré's leviathan look more like a crocodile, a whale or a sea reptile? Why do you think he drew it this way?
3. What does this picture tell us about who is stronger, leviathan or God?

Safety first. An adult should help with the scissors. Wipe up spills right away so no one slips.

EXPERIMENT: THE CLOSE-SEAL SCALE TEST

Job 41:16 says leviathan's scales are so near to one another "that no air can come between them." Do overlapping scales really make better armor? **Question:** Do overlapping scales keep out more water than scales placed side by side with small gaps?

You will need

- Aluminum foil or thin cardboard from a cereal box
- Scissors and a ruler
- 2 paper towels
- 2 thick books and a baking tray or tub
- A cup of water with a few drops of food coloring
- A spoon
- Science notebook and pencil

Steps

1. **Predict.** Write which scale pattern you think will keep the paper towel drier.
2. Cut 24 scales, each about 1 inch by 1 inch. Round one end of each scale if you like.
3. Lay one paper towel on the tray and prop the top edge on a book so it slopes like an animal's back. Do the same with the second paper towel.
4. Towel A: lay 12 scales in rows, starting at the bottom. Each scale should overlap the edge of the one below it, like shingles on a roof.
5. Towel B: lay 12 scales side by side in rows with a small gap, about the width of a pencil line, between each scale.
6. Pour 3 spoonfuls of colored water slowly across the top row of each towel.
7. Carefully lift off the scales. Count the colored wet spots on each towel, or measure the widest wet spot in inches.
8. **What we changed:** how the scales were placed. **What we kept the same:** the number of scales, the amount of water, the slope and the kind of towel. **What we measured:** the wet spots on each towel.
9. Write a sentence: Which pattern made better armor? How does this help you understand Job 41:16-17?

Tips

- Pour the water very slowly so it runs down over the scales instead of splashing.

- Look at a pinecone, a fish or a picture of a crocodile's back. How are their scales arranged?

Check your work

- I made a prediction before I tested.
- I used the same number of scales and the same amount of water for both towels.
- I recorded my results.
- I can explain why overlapping scales make good armor.

NATURE NOTEBOOK

1. Read Job 41:12–34 with a parent. Draw leviathan the way you picture it, and label at least three body parts with the verse that describes each one.
2. Make a clue chart with three columns: Clue from Job 41, Crocodile, Whale. Put a check under each animal that matches a clue.
3. Draw the scales from your project: one drawing of overlapping scales and one of scales with gaps. Draw arrows to show where the water went.

From history. When the King James Bible was translated in 1611, the translators did not try to replace the Hebrew word for this creature with the name of an English animal. They kept the Hebrew word itself: “leviathan.” In the King James Bible it appears in four verses: Job 41:1, Psalm 74:14, Psalm 104:26 and Isaiah 27:1.

WORKED EXAMPLES

Example 1. A student made this clue chart. Clue 1, lives in the water: crocodile ✓, whale ✓. Clue 2, scales close together: crocodile ✓, whale ✗. Clue 3, terrible teeth all around: crocodile ✓, whale ✗. Clue 4, very hard to catch with a hook: crocodile ✓, whale ✓. How many clues match each animal? Which animal matches more clues on this chart?

1. Count the crocodile's checks: clues 1, 2, 3 and 4. That is 4.
2. Count the whale's checks: clues 1 and 4. That is 2.
3. Compare: 4 is greater than 2, so the crocodile matches more clues.
4. A careful scientist adds: this chart has only 4 clues, and Job 41 has many more. A different chart could give a different answer.

Answer: Crocodile: 4 clues. Whale: 2 clues. On this chart the crocodile matches more clues.

Example 2. A large Nile crocodile can be about 16 feet long. A large saltwater crocodile can be about 20 feet long. *Mosasaurus* was about 40 feet long. How much longer is the saltwater crocodile than the Nile crocodile? How many 20-foot saltwater crocodiles laid nose to tail would match one *Mosasaurus*?

1. Subtract: $20 - 16 = 4$ feet.
2. Count by 20s up to 40: 20, 40. That is 2 crocodiles.
3. Check: $20 + 20 = 40$ feet.

Answer: The saltwater crocodile is about 4 feet longer. Two saltwater crocodiles laid nose to tail would match one *Mosasaurus*.

PRACTICE

1. **EASY** In which book and chapter of the Bible is leviathan described most fully?
2. **EASY** Who spoke to Job about leviathan, and from where?
3. **MEDIUM** Name two clues from Job 41 about leviathan's body.
4. **MEDIUM** A large saltwater crocodile is about 6 meters long. A large Nile crocodile is about 5 meters long. Together, how many meters long are they if laid nose to tail?
5. **HARD** Here is sample data from the Close-Seal Scale Test. Overlapping scales: 0 wet spots. Scales with gaps: 6 wet spots. Which pattern made better armor? Name one thing that had to stay the same for the test to be fair.
6. **CHALLENGE** Christians do not all agree about what animal leviathan was. Write two or three sentences: Why is it hard to be sure? What is the main point of Job 41 that everyone can agree on?

COMMON MISTAKES

- Thinking the Bible tells us exactly which animal leviathan was. It gives a description, not a name we know today, so careful readers compare clues and hold their ideas humbly.
- Thinking that because readers disagree about the animal, the chapter is unclear. The main point, God's power over everything He made, is plain.
- Thinking a picture of leviathan by an artist, such as Doré's sea serpent, is a photograph of the real creature. Artists show their own ideas.

Make it a game • Who Made It? Who Rules It?. Take turns naming creatures from this unit and others you know: plesiosaur, mosasaur, pterosaur, crocodile, whale, leviathan, bee, hawk. For each one, the other player gives one true fact about it and then everyone says together, "God made it, and God rules it!" Score a point for each correct fact. Finish by reading Job 41:11 aloud together.

Scripture. “Who hath prevented me, that I should repay him? whatsoever is under the whole heaven is mine.” (Job 41:11, KJV)

God owes no one anything, and everything under heaven is His, from the smallest scale to the mightiest leviathan. A God that strong and wise can be trusted.

Practice answers

1. Job, chapter 41.
2. The LORD (God) spoke to Job out of the whirlwind (Job 38:1).
3. Any two: its scales are close together so no air can come between them; its teeth are terrible round about; its skin cannot be filled with barbed irons or spears; it cannot be drawn out with a hook; it makes the deep boil like a pot.
4. $6 + 5 = 11$ meters.
5. The overlapping scales made better armor because no water got through. Things kept the same (any one): the number of scales, the amount of water, the slope, the kind of paper towel.
6. It is hard to be sure because Job 41 gives a description in words and poetry, not a picture, and some creatures people saw long ago may no longer be alive. Different clues seem to point to a crocodile, a whale or a great sea reptile. The main point is clear: no man can tame leviathan, but God made it and rules over it, so Job (and we) can trust God.

UNIT 7 REVIEW

Answer each question. Show your work for number problems and use complete sentences for explanations. Each question is worth 4 points. The quiz is worth 40 points.

1. (4 pts) Who found the first nearly complete plesiosaur skeleton? Where and in what year?
2. (4 pts) Name four parts of a plesiosaur's body. Was it a dinosaur, a fish or a marine reptile?
3. (4 pts) *Elasmosaurus* had about 72 neck bones. A giraffe has 7. How many more neck bones did *Elasmosaurus* have?
4. (4 pts) Where was the famous giant skull of *Mosasaurus* found, and what does the name *Mosasaurus* mean?
5. (4 pts) Name two features of a mosasaur's jaws or mouth that helped it catch and hold prey, and tell what body part it mainly used to push through the water.
6. (4 pts) Using the scale 1 inch = 4 feet, how long would you draw a mosasaur that was 32 feet long?
7. (4 pts) How was a pterosaur's wing different from a bird's wing and a bat's wing?
8. (4 pts) *Quetzalcoatlus* had a wingspan of about 33 feet. *Pteranodon* had a wingspan of about 20 feet. How much wider was *Quetzalcoatlus*? In the Wing Size Drop Test, did bigger wings fall faster or more slowly?
9. (4 pts) Name two clues from Job 41 that describe leviathan, and name two animals that Bible readers have compared it with.
10. (4 pts) What is the main point of Job 41? Why did God tell Job about leviathan?

UNIT PROJECT: MY FIELD GUIDE TO SEA MONSTERS AND FLYING REPTILES

Make a small field guide book with at least four pages: plesiosaur, mosasaur, pterosaur and leviathan. On each animal page, draw the creature carefully and label at least four body parts, write its length or wingspan in feet and in meters (for leviathan, list clues from Job 41 instead), tell how it swam or flew, and name the person or Bible passage connected to it (Mary Anning, Cuvier and the Maastricht skull, Collini, Job 41). Add one page showing the results table from your favorite experiment in this unit, and a last page that copies Genesis 1:21 or Job 41:11.

- **Accuracy:** Body parts, lengths, names and stories are correct, and each fossil animal is called a marine reptile or flying reptile, not a dinosaur.
- **Observation and drawing:** Drawings are careful and clearly labeled, like a real naturalist's notebook.
- **Experiment record:** The experiment page shows the question, prediction, what was changed, what was kept the same, and a complete results table.
- **Care and faith:** The book is neat and complete, and the Scripture page is copied exactly with its reference.

Answer key

1. Mary Anning, at Lyme Regis on the south coast of England, in 1823.
2. Any four: small head, long neck, wide body, four flippers, short tail. It was a marine reptile.
3. $72 - 7 = 65$ more neck bones.
4. In a chalk quarry under Saint Peter's Mountain near Maastricht, in the Netherlands.
Mosasaurus means "lizard of the Meuse," after the Meuse River.
5. An extra hinge partway along each side of the lower jaw, and extra teeth on the roof of the mouth. It pushed itself mainly with its long tail, which had a fin (tail fluke) at the end.
6. $32 \div 4 = 8$, so 8 inches long.
7. A pterosaur's wing was skin held up by one very long fourth finger. A bird's wing is made of feathers. A bat's wing is skin stretched between four long fingers.
8. $33 - 20 = 13$ feet wider. Bigger wings fell more slowly, because they met more air resistance.
9. Clues (any two): it cannot be drawn out with a hook; its scales are so close no air can come between them; its teeth are terrible round about; its skin cannot be filled with barbed irons; it makes the deep boil like a pot. Animals (any two): the crocodile, the whale, a great sea reptile.
10. No man can tame or capture leviathan, but God made it and rules over it; everything under heaven is His (Job 41:11). God showed Job His power and wisdom so that Job would trust Him even when he did not understand his troubles.

NATURE JOURNAL

All year long you have studied plants and animals: roots and seeds, bees and butterflies, owls and porcupines, sea monsters and flying reptiles. In this unit you will learn the tool that every great naturalist used to study them: the **nature journal**. The Bible says, “The works of the LORD are great, sought out of all them that have pleasure therein” (Psalm 111:2). A journal is how a naturalist seeks out those works, one careful page at a time.

You will sit beside young Samuel Scudder as Louis Agassiz makes him look at one fish for three days and discover that “a pencil is one of the best of eyes.” You will winter with Lewis and Clark at Fort Clatsop and see how they described a new fish part by part. You will read Thomas Jefferson’s thermometer on July 4, 1776, and learn why every entry needs a date and the weather. Then you will join the Junior Naturalist Clubs, whose members paid their dues with letters about what they saw.

By the end of the unit you will draw from life, label parts with neat leader lines, measure in inches and centimeters, record the date, time, place and weather, read a thermometer and a rain gauge, and share your journal with a bar graph of something you counted. These skills will carry you straight into the Nature Lab and every science year after this one.

BEFORE YOU BEGIN

- Can measure with a ruler to the nearest inch
- Can add and subtract numbers up to 100
- Knows the months of the year and can write a date
- Can name the main parts of a plant (root, stem, leaf, flower) from Unit 1

MASTERY CHECKLIST

- I can draw a real object by looking more than I draw, and write its size in inches and centimeters.
- I can label the parts of an insect, a fish, a flower and a bird with straight leader lines that do not cross.
- I can begin every entry with the date, time, place and weather.
- I can read a thermometer in °F and °C and a rain gauge in inches, and tell which way the wind is coming from.
- I can tell an observation from an inference.
- I can turn tally marks into a bar graph and share my journal clearly and honestly.

OPTIONAL BOOKS AND RESOURCES

- **NOAA SciJinks** (<https://scijinks.gov/>): Free. Weather pages, pictures and games from NOAA and NASA for children. Good for learning cloud types, how rain forms and how weather is measured (Lesson 8.3).

- **The Journals of the Lewis and Clark Expedition (University of Nebraska-Lincoln)** (<https://lewisandclarkjournals.unl.edu/>): Free. The full text of the expedition journals online. A parent can look up the late February 1806 entries from Fort Clatsop about the eulachon and read a few lines aloud (Lesson 8.2). The old spelling is part of the fun.
- ***The Natural History of Selborne* by Gilbert White (free at Project Gutenberg)** (<https://www.gutenberg.org/ebooks/search/?query=natural+history+of+selborne>): Free. A country minister's letters about the birds, insects and weather of his English village. Read a short letter aloud as a model of a shared nature journal (Lesson 8.4).

8.1 DRAWING WHAT I SEE ★

OBJECTIVES

- Tell how Louis Agassiz taught Samuel Scudder to see by having him look at one fish for days and draw it.
- Make a careful nature drawing of a real object by looking more than drawing, and record its size in inches and centimeters.
- Explain why drawing helps a scientist notice details that a quick look misses.

Warm-up. Look at a coin, a leaf or a spoon for just ten seconds. Then hide it and write down everything you remember about it. Now take it out and look at it for one whole minute without talking. Add every new thing you notice to your list. How many new things did the longer look give you?

Video. Coming soon. How to start a nature journal for kids: drawing leaves, feathers and shells from life; search nature journaling channels for children, Smithsonian education, SciShow Kids and Homeschool Pop (Alternate), plus close-up nature footage to draw from.

KEY TERMS

nature journal

A notebook where you draw and write about real plants, animals, rocks and weather that you have seen with your own eyes.

observe

To look, listen, touch or smell carefully so you notice what is really there.

detail

A small part or fact you can notice only by looking closely, such as the tiny teeth on the edge of a leaf.

sketch

A quick, simple drawing that shows the shape and the important parts of something. A science sketch is for seeing, not for showing off.

life size

Drawn the very same size as the real thing.

CORE IDEAS

The story. In the late 1850s, a young man named Samuel Scudder walked into the museum of Louis Agassiz at Harvard College in Cambridge, Massachusetts. Agassiz was one of the most famous naturalists in America, and Scudder hoped to study insects with him. But Agassiz did not hand him an insect. He set a small fish in a tin tray in front of him and told him to look at it. Then the professor walked away. Scudder looked for ten minutes and was

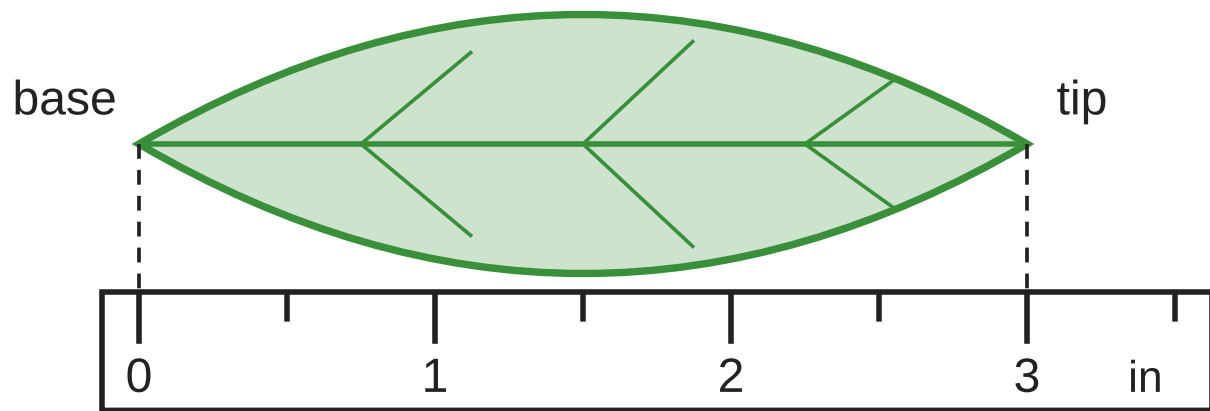
sure he had seen everything there was to see in that fish. Hours passed, and he grew bored. At last he picked up a pencil and began to draw it, and with surprise he started to find things he had never noticed. Just then Agassiz came back. "That is right," he said. "A pencil is one of the best of eyes."

How they figured it out. Agassiz asked Scudder to tell him what he had seen. Scudder listed what he knew. Agassiz listened and said he still had not looked carefully. So Scudder looked again, the next day and the day after that, for three long days. Each time he found more: the rows of scales, the shape and place of every fin, the eyes with no lids, and the way the two sides of the fish matched each other like a mirror. Whenever Scudder wanted something new to do, Agassiz's answer was to look again: "Look at your fish!" Scudder grew up to be an expert on grasshoppers and butterflies, and he called those days with one fish the best lesson in studying insects he ever had.

The big idea. Drawing is a way of looking. When you draw, your eyes must go back to the real thing again and again, and each trip shows you something new. That is why a **nature journal** is the first tool of a naturalist. Here are the rules a good observer follows. Draw what you *see*, not what you *think* a thing looks like: a real leaf is not a plain oval, but has its own edges, veins and spots. Look more than you draw. Start with the big shape, then add the **details**. Finally, write down the size. Lay a ruler beside your object and write how long it is, such as "3 inches (about 7½ cm)." One inch is about 2½ centimeters.

Try it and see. You do not need to be good at art to keep a nature journal. Scudder's fish drawing was not hung in a gallery; it helped him see. Pick one thing, such as a leaf, a pinecone, a shell or a flower, and sit with it for ten minutes. Around your sketch, write three short notes: *I notice...*, *I wonder...* and *It reminds me of...*

God's handiwork. The Bible says, "The hearing ear, and the seeing eye, the LORD hath made even both of them" (Proverbs 20:12). God gave us eyes to see, and He filled the world with things worth seeing. Look at a plastic toy through a magnifying glass and you will find only rough plastic. Look at a leaf or a feather the same way and you will find more and more beauty the closer you get. A nature journal is a way of slowing down to notice what God has made.



length: 3 inches (about 7½ cm)

Measure from the base of the leaf to the tip. This leaf is 3 inches long, about 7½ centimeters.

PICTURE STUDY



A Star-of-Bethlehem and Other Plants, Leonardo da Vinci, about 1506–1512 · Red chalk with 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 was an Italian artist and inventor who filled notebooks with drawings of plants, water, birds and the human body. He drew this sheet of wildflowers while studying plants closely, perhaps to help him paint them truly in a picture.

Leonardo looked so carefully that people who study plants today can still tell which kinds he drew. He did it the same way Scudder learned to study his fish: by looking, and looking again, and letting the pencil show him what was there.

Look closely

- Find the star-shaped flowers. Count the petals on one of them.
- Follow the long, thin leaves with your finger. Which way do they curl?
- Find a different plant near the edge of the page. How is its leaf shape different?
- There is almost no color here. How did Leonardo show light and shadow with only lines?

Talk about it

1. Do you think Leonardo could have drawn these plants from memory? Why or why not?
2. What is one detail in this drawing you did not notice at first glance?
3. If you drew this flower in your nature journal, what notes would you write beside it?

Safety first. If you go outdoors to find something to draw, take an adult with you. Do not pick plants you do not know, and stay away from any plant with leaves in groups of three, which may be poison ivy. Never touch wild animals, dead animals or droppings. Wash your hands after handling things from outdoors.

EXPERIMENT: QUICK LOOK, LONG LOOK

Agassiz said a pencil is one of the best of eyes. Let's test it. You will draw the same object twice: once after a quick look, and once after a long look. Then you will count the details in each drawing and see which one shows more.

You will need

- One natural object: a leaf, flower, pinecone, shell, rock or feather you find on the ground
- Your nature journal (any notebook with plain paper) and a pencil
- A ruler marked in inches and centimeters
- A timer or clock
- A magnifying glass (optional)
- Colored pencils (optional)

Steps

1. Write the question at the top of a new page: *Will I see more details if I look longer?*
2. Write your prediction: *I think my long-look drawing will have ___ details more than my quick-look drawing.*
3. Write what you will change (how long you look and draw) and what you will keep the same (the same object, the same pencil, the same size box on the page).

4. Quick look: draw a box about 3 inches by 3 inches. Set the timer for 1 minute and draw your object in the box. Stop when the timer rings.
5. Long look: draw a second box the same size. Set the timer for 10 minutes. This time, look at the object at least as much as you look at your paper. Turn it over. Use the magnifying glass if you have one.
6. Measure the object with the ruler. Write its length beside the second drawing in inches and in centimeters.
7. Count the details in each drawing: every vein, edge, spot, scale, hole or part counts as one. Write the two numbers in a small table: Drawing, Minutes, Details.
8. Subtract to find how many more details the long look found. Was your prediction close?
9. Under the long-look drawing, write *I notice...*, *I wonder...* and *It reminds me of...*

Tips

- If a line is wrong, leave it and draw a better line next to it. Scientists do not waste time erasing.
- Draw feathers where you find them instead of taking them home. In the United States it is against the law to keep the feathers of most wild native birds.
- Hold a leaf up to a window to see the veins more clearly.

Check your work

- I drew the same object twice and kept everything the same except the time.
- I counted the details and found the difference.
- I wrote the size of my object in inches and centimeters.

NATURE NOTEBOOK

1. Draw one leaf life size. Trace its outline lightly first, then look closely and add every vein you can see. Write its length in inches and centimeters.
2. Draw Scudder's fish from memory as you imagine it. Then write three things you would look for if you had the real fish in front of you for three days.
3. Sit by a window for five minutes and sketch one bird, cloud or tree you see. Write one *I notice* and one *I wonder* beside it.

From history. Louis Agassiz was born in Switzerland and became famous in Europe for his careful study of fossil fishes before he came to America. In 1859 he founded the Museum of Comparative Zoology at Harvard, which is still open today. Samuel Scudder told the story of his fish lesson in a short piece called "In the Laboratory with Agassiz," printed in 1874. Teachers of science have shared it with their students ever since.

WORKED EXAMPLES

Example 1. Eli drew a pinecone after a 1-minute look and counted 5 details. Then he drew it again after a 10-minute look and counted 13 details. How many more details did the long look show him?

1. We want to know how many more, so we subtract the smaller number from the larger one.
2. $13 - 5 = 8$.
3. Check by adding: $5 + 8 = 13$. ✓

Answer: The long look showed 8 more details.

Example 2. Look at the leaf and ruler. How long is the leaf in inches? About how many centimeters is that? If you draw the leaf twice life size, how long will your drawing be?

(Use the map or drawing “Line up the base of the leaf with 0 on the ruler and read the number at the tip.” shown earlier in this lesson.)

1. The base of the leaf is at 0 and the tip is at the 3 mark, so the leaf is 3 inches long.
2. One inch is about $2\frac{1}{2}$ centimeters. $3 \times 2\frac{1}{2} = 2\frac{1}{2} + 2\frac{1}{2} + 2\frac{1}{2} = 7\frac{1}{2}$. So the leaf is about $7\frac{1}{2}$ cm long.
3. Twice life size means the drawing is 2 times as long as the real leaf: 2×3 inches = 6 inches (about 15 cm).

Answer: The leaf is 3 inches (about $7\frac{1}{2}$ cm). A drawing twice life size is 6 inches (about 15 cm) long.

PRACTICE

1. **EASY** Agassiz told Scudder, “A pencil is one of the best of ____.” Fill in the blank. What did he mean?
2. **EASY** Which is the better nature journal habit? (a) Drawing a leaf from memory at the kitchen table. (b) Drawing a leaf while you look at the real leaf.
3. **MEDIUM** A feather you find on a walk is 4 inches long. One inch is about $2\frac{1}{2}$ centimeters. About how many centimeters long is the feather?
4. **MEDIUM** Ana drew a shell for 2 minutes and counted 4 details. Then she drew the same shell for 10 minutes and counted 11 details. How many more details did she find? What did she change, and what did she keep the same?
5. **HARD** A beetle is 1 inch long. You draw it 3 times life size so you can show its legs clearly. How long is your drawing? What should you write next to it?
6. **CHALLENGE** In two or three sentences, explain why a scientist draws things in a nature journal instead of just looking at them once.

COMMON MISTAKES

- Drawing what you think something looks like instead of what is really there. Many children draw every leaf as a plain oval or every flower with five round petals. Count the petals and look at the edges first.
- Thinking you must be “good at art” to keep a nature journal. A science sketch is for seeing and remembering, not for being beautiful. Plain, honest drawings are the most useful.
- Forgetting to write the size. Without a size note, a drawing of a beetle and a drawing of a turtle could look the same size on the page.

Make it a game • Nature Tray Memory. A parent puts eight small natural things on a tray: a leaf, a rock, a seed, a twig, a shell and so on. You get one minute to study the tray. Then the tray is covered, and you list or draw everything you remember. Uncover it and score one point for each thing you got right and one bonus point for each detail you remember about it, such as “the rock had a white stripe.” Switch places and let your parent try.

Scripture. “The hearing ear, and the seeing eye, the LORD hath made even both of them.” (Proverbs 20:12, KJV)

Our eyes are a gift from God. When we take time to look closely at His creation, we use that gift the way it was meant to be used.

Practice answers

1. Eyes. He meant that drawing something makes you look at it closely, so you see more.
2. (b). You should draw what you really see, while looking at the real thing.
3. $4 \times 2\frac{1}{2} = 10$. The feather is about 10 cm long.
4. $11 - 4 = 7$ more details. She changed how long she looked and drew. She kept the same shell (and the same pencil and paper).
5. $3 \times 1 \text{ inch} = 3 \text{ inches}$ (about $7\frac{1}{2} \text{ cm}$). Write “3 times life size” and “real beetle: 1 inch (about $2\frac{1}{2} \text{ cm}$)” so readers know the true size.
6. Sample answer: Drawing makes you look at the real thing again and again, so you notice details a quick look misses. The drawing also keeps a record you can look at later and compare with other things. Like Scudder with his fish, the longer you draw, the more you see.

8.2 LABELING PARTS

OBJECTIVES

- Tell how Meriwether Lewis and William Clark described new plants and animals part by part on their journey west, and why that helped scientists back home.
- Label the main parts of a fish, an insect, a flower and a bird on a drawing, using neat leader lines that point to the exact part.
- Add a title, a common name and a size note to a journal drawing so that another person can understand it.

Warm-up. Draw a quick picture of a bicycle, a chair or a teapot. Now write the names of five of its parts around the drawing and draw a line from each name to its part. Was there a part you did not know the name of? What did you write instead?

Video. Coming soon. Parts of an insect, a fish, a flower and a bird for kids, and Lewis and Clark's journals of plants and animals; search SciShow Kids, Homeschool Pop (Alternate), Smithsonian education, National Park Service Lewis and Clark trail videos and nature footage of fish and insects.

KEY TERMS

label

A word written beside a drawing that names one part of it.

leader line

A straight line drawn from a label to the exact part it names. Leader lines should not cross each other.

specimen

A real thing you study, such as a leaf, a shell, a feather or a fish.

common name

The everyday name people use for a living thing, such as “robin” or “candlefish.” It can change from place to place.

scientific name

A two-part name, usually in Latin, that scientists all over the world use for one kind of living thing, such as *Turdus migratorius* for the American robin.

CORE IDEAS

The story. In the winter of 1805 to 1806, Meriwether Lewis, William Clark and their company of explorers camped in a small log fort near the mouth of the Columbia River, in what is now Oregon. They called it Fort Clatsop, after the Clatsop people who lived nearby. It rained almost every day. President Thomas Jefferson had asked them to write careful notes about the plants and animals they met, and the long wet winter gave them time. In late

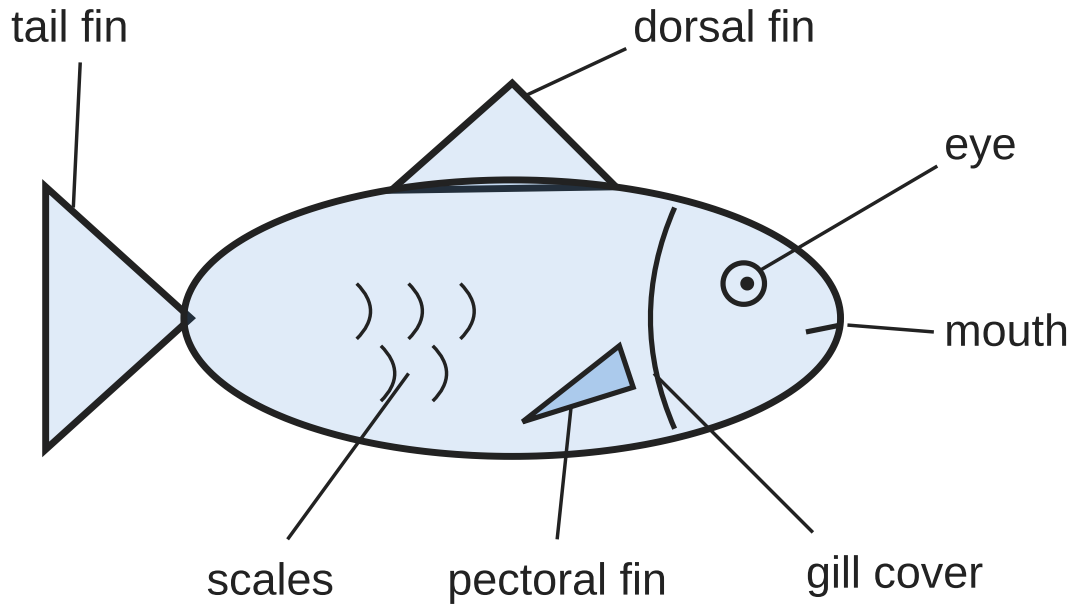
February 1806, Native fishermen brought them some small, silvery, very oily fish from the river. Today we call this fish the **eulachon** (say YOO-luh-kon), or candlefish. Lewis roasted several on a wooden stick and wrote that he had never tasted a better fish.

How they figured it out. Lewis did not just write “a good little fish.” He studied it part by part. He wrote down its length, its color, the shape and place of its fins, how many thin bones held up each fin, how tiny its scales were, and what its eyes, mouth and teeth looked like. He compared it to fish people already knew. A pen drawing of the fish was made right in the journal beside the words. Because the words and the drawing named each part, a scientist who had never been west of Philadelphia could read the page and know exactly what kind of fish it was. Lewis and Clark described many plants and animals that scientists in the eastern United States had never seen before.

The big idea. A drawing becomes a science drawing when it is **labeled**. Good labels follow simple rules. Use the real name of the part when you know it. Print neatly. Write labels outside the drawing, lined up along the sides, so they do not cover the details. Draw a straight **leader line** from each label right to its part, and do not let the lines cross. At the top, write a title with the **common name**, and add the date, the place and the size. Each kind of creature has its own parts to look for. An insect has three body parts (head, thorax and abdomen), six legs and two antennae. A fish has an eye, a mouth, a gill cover, fins, a tail fin and scales. A flower has petals, a stem and leaves. A bird has a beak, wings, a tail and feet.

Try it and see. Labeling makes you look again. To label “legs” on a beetle, you have to count them. To label “gill cover” on a fish, you have to find where the head ends. If you do not know the name of a part, do not guess. Write what it looks like with a question mark, such as “fuzzy yellow dots?”, and look it up later in a field guide. That honest question mark is real science.

God’s handiwork. The very first person to name the animals was Adam. God “brought them unto Adam to see what he would call them” (Genesis 2:19). Giving names is part of the work God gave people from the beginning. When you learn the names of the parts of a fish or a flower, you are doing that same good work, and you will find you notice and care for those creatures more.



A labeled fish. Each label sits outside the drawing, and each leader line points to the exact part.

PICTURE STUDY



Methodus Plantarum Sexualis (Linnaeus's classes of flowering plants), Georg Dionysius Ehret, 1736 · Hand-colored engraving · First printed in Leiden, the Netherlands; copies are kept in natural history libraries

Georg Dionysius Ehret was a German gardener who became one of the finest plant artists who ever lived. In 1736, in the Dutch city of Leiden, he met the Swedish scientist Carl Linnaeus. Linnaeus sorted flowering plants into groups by counting the tiny parts inside each flower that make pollen and the parts that become seeds. Ehret drew a sheet that showed every group at once.

Instead of writing long labels beside each drawing, Ehret marked each little picture with a capital letter. A key explained what each letter meant. This is another good way to label: when the space is crowded, use letters or numbers and write the names in a list.

Look closely

- Count the small drawings in one row. How many rows are there?
- Find a letter beside one drawing. Why might Ehret use letters instead of whole words here?
- Look closely at the flower parts. Can you find drawings with just one or two parts and others with many?
- Notice how much empty space is around each drawing. How does that help your eyes?

Talk about it

1. When is a letter key better than writing labels with leader lines? When is it worse?
2. Why would scientists in many countries want a sheet like this?
3. How would you label the parts of a flower from your yard?

Safety first. Never use a magnifying glass to look at the sun or to focus sunlight on anything; it can hurt your eyes and start fires. If you use a fish from the grocery store, keep it on a plate, do not cut it, and wash your hands and the table with soap and water when you finish. Do not pick up live insects that sting or bite.

EXPERIMENT: CAN YOU FIND IT? A LABELING TEST

Lewis labeled his fish so that people who had never seen it could understand it. Will your labels work that well? You will draw and label a specimen, then test your drawing on someone in your family.

You will need

- One specimen: a whole fish from the grocery store, a flower with its stem and leaves, a dead insect you find on a windowsill, or a large clear photo of a bird
- Your nature journal and a sharp pencil
- A ruler marked in inches and centimeters
- A magnifying glass (optional)
- A field guide or a library book about fish, insects, flowers or birds
- A timer

Steps

1. Write the question: *Can someone find the parts of my specimen using only my drawing?*
2. Write your prediction: *I think my helper will find ___ of the parts in one minute.*
3. Draw your specimen large, in the middle of the page. Leave wide space on both sides for labels.

4. Make a copy of the outline on a second page with no labels at all. This is your unlabeled drawing.
5. On the first drawing, label at least six parts. Print each label at the side and draw a straight leader line to the exact part. Use the field guide to find names you do not know.
6. Add a title with the common name, plus the date, the place and the size (for example: "Length: 8 inches, about 20 cm").
7. Test it. Hand your helper the unlabeled drawing and the real specimen. Read out six part names. Count how many your helper points to correctly in one minute.
8. Now hand your helper the labeled drawing and test again with the same six names. Count again.
9. Record both numbers in a table: Drawing, Parts found. Which drawing helped more? Was your prediction right?

Tips

- Keep the same helper, the same specimen and the same six part names for both tests, so the only thing that changes is the labels.
- Use a ruler to make leader lines straight. If two lines would cross, move one label higher or lower.
- If the drawing is crowded, use letters (A, B, C) by the parts and write a key, as Ehret did.

Check your work

- My drawing has at least six labels with straight leader lines that do not cross.
- My page has a title, a date, a place and a size.
- I tested my labels and recorded the results.

NATURE NOTEBOOK

1. Draw an insect (from a real insect or a good photo) and label the head, thorax, abdomen, legs and antennae. Count the legs and write the number.
2. Draw a flower with its stem and leaves and label at least four parts. Write its common name at the top.
3. Look up the scientific name of one animal or plant you see often, such as a robin, an oak or a honeybee, and write both names under a small drawing.

From history. Before the journey, Meriwether Lewis spent part of 1803 in Philadelphia learning from the best scientists in America, including the botanist Benjamin Smith Barton, so that he would know how to describe and preserve plants. Many of the dried plants he pressed on the journey survived the trip home. They are still kept today at the Academy of Natural Sciences in Philadelphia, where scientists can study them more than two hundred years later.

WORKED EXAMPLES

Example 1. Josh drew a little crawling animal from the garden. His drawing shows 2 body parts and 4 legs on each side. He labeled it “insect.” Is his label correct?

1. Count the legs: 4 on one side and 4 on the other. $4 + 4 = 8$ legs.
2. Recall the rule: an insect has 6 legs and 3 body parts (head, thorax, abdomen).
3. Josh’s animal has 8 legs and 2 body parts. That matches a spider, not an insect.

Answer: No. With 8 legs and 2 body parts, it is a spider. The label should say “spider.”

Example 2. Look at the labeled fish. Which label names the flap that covers the gills? The real fish is 8 inches long, and your drawing of it is 4 inches long. Is the drawing life size? What size note should you write?

(Use the map or drawing “Follow each leader line from the word to the part.” shown earlier in this lesson.)

1. Follow the leader lines. The flap behind the head is labeled “gill cover.”
2. Compare the sizes: the drawing is 4 inches and the fish is 8 inches. $4 + 4 = 8$, so the drawing is half as long as the fish. It is not life size; it is half life size.
3. Change inches to centimeters: $8 \times 2\frac{1}{2} = 20$, so the real fish is about 20 cm long.

Answer: The “gill cover” label. The drawing is half life size. Write: “Half life size. Real fish: 8 inches (about 20 cm).”

PRACTICE

1. **EASY** Name the three body parts of an insect, in order from front to back.
2. **EASY** What is a leader line? Give one rule for drawing leader lines.
3. **MEDIUM** On Mia’s flower drawing, the label “root” has a line that points to a petal. What is wrong, and how should she fix it?
4. **MEDIUM** A maple leaf is 5 inches long, and you draw it life size. About how many centimeters long is your drawing?
5. **HARD** Lewis wrote down the length, color, fins, scales, eyes and teeth of the eulachon. How many different things did he describe in that list? Why did listing parts help scientists far away?
6. **CHALLENGE** In America, “robin” means a large thrush with an orange breast. In England, “robin” means a much smaller bird of a different kind. Explain why scientists give each kind of living thing a scientific name.

COMMON MISTAKES

- Calling every small crawling animal an “insect.” Insects have 6 legs and 3 body parts. Spiders have 8 legs and 2 body parts, and they are not insects.
- Writing labels on top of the drawing or letting leader lines wander near a part without touching it. Keep labels outside and make each line end right on its part.
- Guessing a name and writing it as if it were certain. If you do not know, write a description with a question mark and look it up later.

Make it a game · Sticky Note Label Race. Write part names on sticky notes, such as leaf, stem, flower and pot for a houseplant, or seat, leg and back for a chair. Set a timer for one minute and race to stick each label on the right part. Then a parent checks every label. Score one point for each correct label and lose a point for each wrong one. Next round, try a harder object, like a bicycle or a fish picture from a book.

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)

Naming creatures was one of the first jobs God gave to man. Learning and writing the right names in your journal is part of the same good work.

Practice answers

1. Head, thorax, abdomen.
2. A straight line from a label to the exact part it names. Rules: draw it straight; touch the exact part; do not let leader lines cross.
3. The label names the wrong part; the line points to a petal, not a root. She should change the word to “petal” (or move the line to the root, which grows underground below the stem).
4. Life size means the drawing is also 5 inches. $5 \times 2\frac{1}{2} = 12\frac{1}{2}$, so about $12\frac{1}{2}$ cm.
5. 6 things (length, color, fins, scales, eyes, teeth). Naming each part let scientists who had never seen the fish picture it and tell it apart from other fish.
6. Common names can mean different creatures in different places, so people get mixed up. A scientific name (such as *Turdus migratorius* for the American robin) belongs to only one kind, so scientists everywhere know exactly which creature is meant.

8.3 DATING ENTRIES AND RECORDING WEATHER

OBJECTIVES

- Tell how Thomas Jefferson recorded the temperature in Philadelphia on July 4, 1776, and why dated records are useful to scientists.
- Begin every journal entry with the date, time, place and weather, and read a thermometer in degrees Fahrenheit and Celsius and a rain gauge in inches.
- Use dated entries to find how much the temperature changed and how many days passed between two events.

Warm-up. Look out a window. In one minute, describe today's weather in as many words as you can: Is the sky clear or cloudy? Is anything falling? Are the trees moving? Does it feel hot, warm, cool or cold? Now write today's full date, with the month, the day and the year. Could someone reading your words a year from now tell what kind of day it was?

Video. Coming soon. How to read a thermometer and make a rain gauge, and weather observing for kids; search NOAA SciJinks, the National Weather Service, NASA Space Place weather pages, Science Max, SciShow Kids and Homeschool Pop (Alternate), plus Monticello videos on Jefferson's weather records.

KEY TERMS

entry

One dated page or section in a journal that records what you observed at one time.

temperature

How hot or cold something is, measured with a thermometer in degrees Fahrenheit (°F) or degrees Celsius (°C).

precipitation

Water falling from clouds as rain, snow, sleet or hail. Rain is measured in inches or millimeters with a rain gauge.

wind direction

The direction the wind is blowing *from*. A north wind blows from the north toward the south.

record

A written list of observations kept over time, so you can compare days, seasons and years.

CORE IDEAS

The story. On July 4, 1776, in Philadelphia, the men of the Continental Congress approved the Declaration of Independence. One of them was Thomas Jefferson, who had written most of it. Jefferson loved science, and that same day he paid for a new thermometer at a shop in the city. In his small account book he wrote down the temperature four times: 68 degrees at

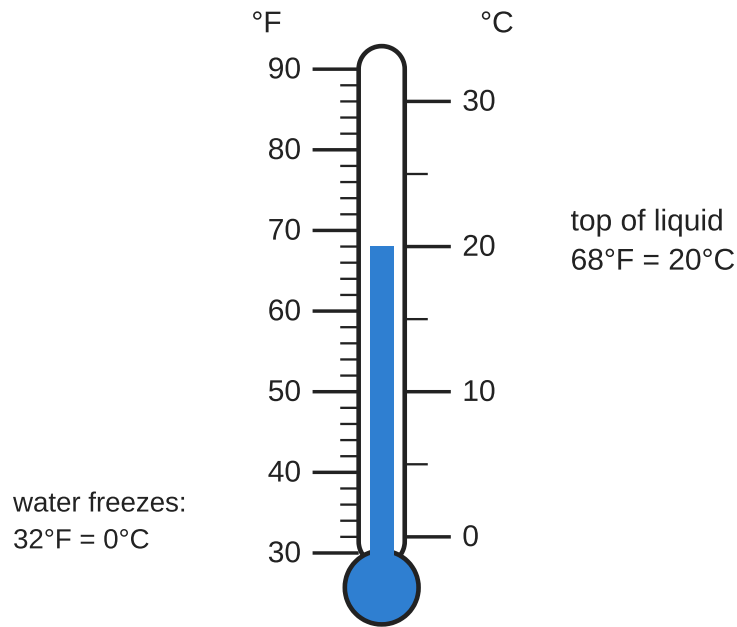
6 in the morning, 72¼ at 9 in the morning, 76 at 1 in the afternoon, and 73½ at 9 at night. Because he wrote the date and the time beside each number, we know what the weather was like on one of the most famous days in American history.

How they figured it out. Jefferson kept weather records for many years. At his home, Monticello, in Virginia, he read his thermometer in the early morning, about the coldest time of day, and again in the afternoon, about the warmest. He wrote down the wind, the clouds, rain and snow, and when trees bloomed and birds came back in spring. He wanted people in different places to keep records the same way so they could compare them. One number tells you about one day. Many dated numbers show you a **pattern**: which month is warmest, how much rain falls in spring, when the first frost comes.

The big idea. Every journal entry begins with four things: the **date** (month, day and year), the **time**, the **place** and the **weather**. To record weather, use your senses and simple tools. Read a **thermometer** hung in the shade. In the United States we usually use degrees Fahrenheit; most of the world uses degrees Celsius. Water freezes at 32°F, which is 0°C, and a comfortable room is about 68°F, which is 20°C. Look at the sky and write clear, partly cloudy or cloudy. Measure rain or snow with a **rain gauge** in inches. Watch a flag or the treetops for the wind, and remember that a wind is named for the direction it comes *from*.

Try it and see. Dates turn a pile of drawings into a story. If you write the day you planted a bean and the day it sprouted, you can count how long it took. If you write the day you saw the first robin this spring, you can compare it with next spring. Weather and living things go together: crickets chirp faster on warm nights than on cool ones, many flowers open on sunny days, and birds fluff up their feathers when it is cold. A dated entry with the weather helps you notice why animals and plants do what they do.

God's handiwork. After the Flood, God promised Noah, "While the earth remaineth, seedtime and harvest, and cold and heat, and summer and winter, and day and night shall not cease" (Genesis 8:22). The weather changes every day, but the seasons come back in their order, year after year. When you keep a dated record, you can see God's faithfulness written right on the page.



Read the number where the top of the liquid stops. Here it is 68°F on the left scale and 20°C on the right scale.

PICTURE STUDY



Cloud Study, John Constable, 1822 · Oil paint on paper, mounted on board · Tate, London, England

John Constable was an English painter who grew up in the countryside, where his father owned mills that depended on the wind and the river. In the summers of 1821 and 1822 he lived at Hampstead, on a hill near London, and went out again and again to paint nothing but the sky. He called it “skying.”

Constable worked quickly, because clouds change in minutes. On the back of many of his cloud studies he wrote notes like a weather observer: the date, the time of day and which way the wind was blowing. This study was painted on a windy day, so fast that part of the sky was left unfinished. His paintings are works of art and weather records at the same time.

Look closely

- Find the brightest part of the clouds. Where do you think the sun is?
- Look at the bottoms of the clouds. Are they flat or puffy? Are they lighter or darker than the tops?
- How much of the sky is blue and how much is cloud? Would you record this sky as clear, partly cloudy or cloudy?
- Look for brushstrokes. Does the painting look slow and careful or fast?

Talk about it

1. Why would Constable write the date, the time and the wind on the back of a painting?
2. What weather would you write in a journal for this day? What clues in the painting helped you decide?
3. Choose a sky outside your window and sketch it. What notes will you write beside it?

Safety first. Never look straight at the sun when you observe the sky, not even for a moment, and never through a magnifying glass or binoculars. Use a thermometer without mercury, and ask an adult to help hang it. Stay indoors during thunder and lightning; you can record a storm through a window.

EXPERIMENT: MY WEATHER STATION WEEK

Jefferson read his thermometer in the early morning and again in the afternoon. Is the afternoon really warmer than the morning where you live? You will set up a small weather station and keep a dated weather record for five days.

You will need

- An outdoor thermometer that shows °F and °C (no mercury)
- A straight-sided clear jar or plastic cup and a ruler marked in inches and centimeters (for a rain gauge)
- Tape and a permanent marker
- Your nature journal and a pencil
- A ribbon or strip of cloth tied to a stick or fence (to show the wind)
- A compass, or a parent to show you which way is north

Steps

1. Write the question: *Is it warmer in the afternoon than in the early morning?* Then write your prediction.

2. Write what you will change (the time of day) and what you will keep the same (the same thermometer, in the same shady spot, at the same height, read the same way).
3. Hang the thermometer about as high as your shoulders in a shady place out of the wind, such as the north side of a house or under a porch roof.
4. Make a rain gauge: tape the ruler to the outside of the jar with 0 at the bottom. Set it in an open spot away from trees and roofs.
5. Rule a table with these columns: Date, Time, Temperature °F, Temperature °C, Sky, Wind from, Rain (inches).
6. Each day for five days, read the thermometer soon after breakfast and again in the middle of the afternoon. Fill in a row each time.
7. Check the rain gauge once a day at the same time. Write how many inches of water are in it, then empty it.
8. At the end of the week, circle the warmest and coldest readings. Subtract to find the difference each day. Was your prediction right?
9. Draw one small picture each day of something alive you saw: a bird, a bud, an insect. Write the date beside it.

Tips

- Wait a minute after you look at the thermometer and read it again; your hand or breath can warm it.
- Read the number at the very top of the liquid with your eyes level with it, not from above or below.
- Write the full date each time, including the year. In a year you will be glad you did.

Check your work

- Every row in my table has a date and a time.
- I kept the thermometer in the same shady place for every reading.
- I compared morning and afternoon temperatures and wrote what I found.

NATURE NOTEBOOK

1. Start a new journal page with a heading box: date, time, place, temperature, sky and wind. Fill it in, then draw one thing you see outside.
2. Sketch today's sky and the shapes of the clouds. Write how much of the sky is covered: none, some or all.
3. Make a small weather key with your own symbols for sunny, partly cloudy, cloudy, rain, snow and windy. Use it at the top of every entry this week.

From history. In England, at about the same time as Jefferson, a country minister named Gilbert White kept a weather and nature diary in the village of Selborne. He used a printed notebook called *The Naturalist's Journal*, designed by his friend Daines Barrington, with a column for each day's date, temperature, wind and weather, and space to note which plants were in flower and which birds had returned. White filled in its

pages from 1768 until shortly before his death in 1793. Scientists still read his dated notes to compare springs long ago with springs today.

WORKED EXAMPLES

Example 1. On July 4, 1776, Jefferson's thermometer read 68°F at 6 in the morning and 76°F at 1 in the afternoon. How many degrees warmer was it in the afternoon? The thermometer in the picture shows the 6 a.m. reading. What is it in degrees Celsius?

(Use the map or drawing "The liquid stops at 68°F , the same level as 20°C ." shown earlier in this lesson.)

1. To find how much warmer, subtract: $76 - 68 = 8$.
2. Check by adding: $68 + 8 = 76$. ✓
3. Find the top of the liquid on the Fahrenheit side: it is at 68. Look straight across to the Celsius side: it lines up with 20.

Answer: It was 8°F warmer at 1 p.m. The 6 a.m. reading of 68°F is 20°C .

Example 2. Grace checked her rain gauge each evening. April 3: 1 inch. April 4: $\frac{1}{2}$ inch. April 5: no rain. April 6: $\frac{1}{2}$ inch. How much rain fell in all? About how many centimeters is that?

1. Add the amounts: $1 + \frac{1}{2} + 0 + \frac{1}{2}$.
2. $\frac{1}{2} + \frac{1}{2} = 1$, so the total is $1 + 1 = 2$ inches.
3. One inch is about $2\frac{1}{2}$ cm, so 2 inches is about $2\frac{1}{2} + 2\frac{1}{2} = 5$ cm.

Answer: 2 inches of rain fell, about 5 cm.

PRACTICE

1. **EASY** Name the four things every nature journal entry should begin with.
2. **EASY** Water freezes at $\text{___}^{\circ}\text{F}$, which is $\text{___}^{\circ}\text{C}$.
3. **MEDIUM** The weather report says there is a west wind. Which direction is the wind coming from, and which way will the leaves blow?
4. **MEDIUM** On a spring day the thermometer read 54°F at 7 a.m. and 71°F at 3 p.m. How many degrees did it warm up?
5. **HARD** Sam planted bean seeds on April 28 and saw the first sprout on May 5. April has 30 days. How many days did the bean take to sprout?
6. **CHALLENGE** Ben wrote the date he saw the first robin each spring: March 12 in one year, March 9 the next year, and March 15 the year after. Which date was earliest? How many days apart were the earliest and latest dates? Why would this record be useless if Ben had written only "a Tuesday in March"?

COMMON MISTAKES

- Hanging a thermometer in the sun. Sunlight heats the thermometer itself, so it reads hotter than the air. Air temperature is always measured in the shade.
- Naming the wind for where it is going. A north wind comes *from* the north. If the flag points south, the wind is from the north.
- Writing “today” or “Saturday” instead of the full date. A record is only useful later if it has the month, the day and the year.

Make it a game · Junior Weather Reporter. Stand by a window like a TV weather reporter. In thirty seconds, give the full date, the time, the place, the temperature in °F (and °C if your thermometer shows it), the sky, the wind direction and any rain. Your family listens with a checklist and gives one point for each item you remember. Try for a perfect score of seven, then let someone else be the reporter tomorrow.

Scripture. “While the earth remaineth, seedtime and harvest, and cold and heat, and summer and winter, and day and night shall not cease.” (Genesis 8:22, KJV)

Weather changes from day to day, but the seasons keep their order just as God promised. A dated journal lets you watch that promise kept, season after season.

Practice answers

1. The date (month, day and year), the time, the place and the weather.
2. 32°F, which is 0°C.
3. The wind comes from the west, so the leaves blow toward the east.
4. $71 - 54 = 17$. It warmed up 17°F.
5. From April 28 to April 30 is 2 days, and from April 30 to May 5 is 5 more days. $2 + 5 = 7$ days, which is one week.
6. March 9 was earliest. $15 - 9 = 6$ days apart. Without the full date (month, day and year), Ben could not tell which year was which or count the days between them, so he could not compare the springs.

8.4 SHARING MY JOURNAL

OBJECTIVES

- Tell how children in the Junior Naturalist Clubs at Cornell University shared their nature observations by writing letters to “Uncle John” Spencer.
- Choose journal entries and present them clearly, using drawings, labels, dates and a bar graph made from tally marks.
- Tell an observation apart from an inference, and ask and answer good questions about another person’s journal.

Warm-up. Look at a family photo or a picture in a book for one minute. Say three things you can *see* for sure, such as “there are four people” or “the dog is brown.” Then say one thing you *guess*, such as “they are happy” or “it is summer.” How could you find out whether your guess is right?

Video. Coming soon. Kids sharing nature journals, making tally charts and bar graphs, and observation versus inference; search SciShow Kids, Homeschool Pop (Alternate), Cornell Lab of Ornithology bird-count videos for families, Smithsonian education and nature journaling channels for children.

KEY TERMS

observation

Something you notice with your senses or measure with a tool, such as “the nest has three blue eggs.”

inference

An idea you figure out from your observations, such as “a robin probably laid these eggs.”
An inference can be wrong, so you test it by observing more.

tally mark

A short line you draw to count things as you see them. Every fifth mark crosses the first four, making a bundle of five.

bar graph

A chart that uses bars of different heights to show and compare numbers.

presentation

A time when you show and tell others what you observed and learned.

CORE IDEAS

The story. In the late 1890s, at Cornell University in Ithaca, New York, a fruit grower named John Walton Spencer had a happy idea. He wanted the children of New York’s farms and towns to love the fields and woods around them. So he helped start the Junior Naturalist Clubs. Any child could join, and there was one rule about dues. Members did not pay money.

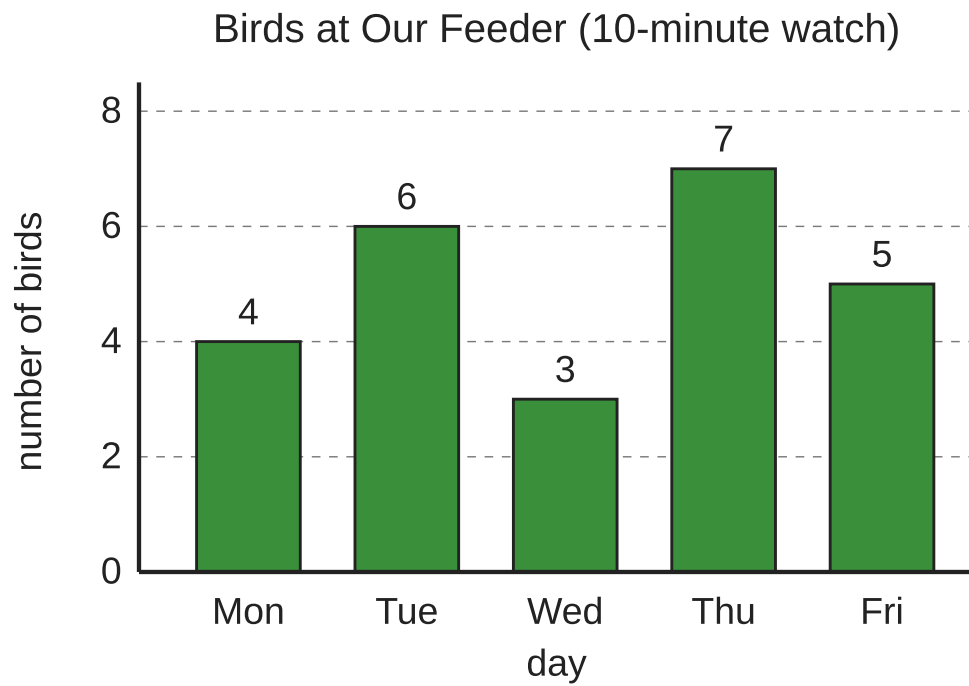
Instead, they paid by writing a letter telling something they had seen in nature with their own eyes. The children called Mr. Spencer “Uncle John,” and letters poured into Cornell by the thousands, telling about bird nests, tadpoles, seeds and caterpillars.

How they figured it out. Uncle John and his helpers read the letters and wrote back. One of those helpers was Anna Botsford Comstock, a teacher and artist at Cornell. The letters showed what children noticed and what they wondered about, so the Cornell team wrote little leaflets for schools to answer those questions and teach children to look more closely. In 1911 Mrs. Comstock gathered many of these lessons into a big book called the *Handbook of Nature Study*. Homeschool families still use it today. It all grew from children who shared what they saw.

The big idea. Real scientists share their work so others can check it, learn from it and add to it. When you share your journal, be clear and be honest. Show the date and the place of each entry, your labeled drawings and your measurements. Tell the difference between an **observation** and an **inference**. “Three blue eggs are in the nest” is an observation. “A robin laid them” is an inference unless you watched the robin. If you counted something, turn your **tally marks** into a **bar graph** so your listeners can see the numbers at a glance. And report what really happened, even if your seed never sprouted or the bird never came. That is true and useful too.

Try it and see. Choose your three best entries. For each one, tell what you saw, what you measured and what you still wonder. Hold up your journal so everyone can see the drawings. When you listen to someone else, ask a real question, such as “How long was it?” or “What was the weather that day?” Give a kind compliment that names something specific: “Your labels made it easy to find the antennae.” Good questions and kind words help everyone become a better observer.

God’s handiwork. The psalmist wrote, “One generation shall praise thy works to another, and shall declare thy mighty acts” (Psalm 145:4). When you show your family a drawing of a spider’s web or tell your grandmother how many birds came to the feeder, you are telling about God’s works. Your journal is a gift you can share now and keep for the people who come after you.



A bar graph made from a week of tally marks. Each bar shows how many birds came during a 10-minute watch.

PICTURE STUDY



The Country School, Winslow Homer, 1871 · Oil on canvas · Saint Louis Art Museum, St. Louis, Missouri

Winslow Homer was an American painter who grew up in Massachusetts and loved painting everyday country life. After the Civil War he painted children at play and at school in the small farm towns of New England and New York.

This painting shows a one-room schoolhouse, where children of many ages learned together in a single room. Older children often helped younger ones, and lessons were shared out loud. A few years later, nature-study leaflets like the ones from Cornell would arrive in country schools just like this one.

Look closely

- Find the teacher. What is she holding? Where is she standing?
- Count the children you can see. Are they all the same age?
- Look at the windows and the light on the floor. What time of day do you think it is?
- Is there anything from nature inside the schoolroom? Look on the desk and by the walls.

Talk about it

1. How is learning in a one-room school like learning at home with brothers and sisters?
2. Which things in this painting are observations, and which are inferences? (Is the teacher kind? How do you know?)
3. If a child in this school joined the Junior Naturalists, what might he or she write about?

EXPERIMENT: FEEDER COUNT AND JOURNAL SHARING DAY

The Junior Naturalists paid their dues with true observations. You will make a careful count, turn it into a bar graph, and share it along with your best journal pages at a family Journal Sharing Day.

You will need

- Your nature journal with at least three dated entries from this unit
- A window with a view of a bird feeder, a tree, a flower bed or a busy patch of sky
- A timer
- Grid paper or plain paper and a ruler
- Colored pencils
- A bird or insect field guide (optional)

Steps

1. Write the question: *Do more birds (or insects) visit in the morning or in the afternoon?* Write your prediction.
2. Write what you will change (the time of day) and what you will keep the same (the same window, the same spot to watch and the same 10 minutes of watching).
3. For five days, watch for 10 minutes in the morning and 10 minutes in the afternoon. Make a tally mark for every bird that lands. Write the date, time and weather each time.
4. Add up the tally marks for each watch and write the totals in a table.

5. Make a bar graph. Write a title. Label the bottom with the days and the side with numbers starting at 0. Draw each bar as tall as its number.
6. Look at your graph. Which day had the most visitors? Was the morning or the afternoon busier? Was your prediction right?
7. Choose your three best journal entries from this unit. Practice telling about each one: what I saw, what I measured, what I still wonder.
8. Hold Journal Sharing Day. Show your entries and your graph to your family. Point out one observation and one inference.
9. Invite your listeners to ask questions. Write their best question in your journal and a plan to find the answer.

Tips

- If one bird flies away and comes back, decide ahead of time whether to count it again, and do it the same way every day.
- Speak slowly and hold your journal still and high enough for everyone to see.
- It is fine to say “I don’t know yet.” That is how new observations begin.

Check your work

- My bar graph has a title, labels and numbers that start at 0.
- I told the difference between an observation and an inference.
- I shared three dated entries and answered at least one question.

NATURE NOTEBOOK

1. Write a short letter to “Uncle John” about one thing you observed this week, the way a Junior Naturalist would. Include the date, the place and a small labeled drawing.
2. Make a two-column chart titled “I Saw / I Think.” Fill it with three observations and three inferences about one plant or animal.
3. Make a tally chart of something you can count in ten minutes, such as cars, birds, ants or falling leaves, and turn it into a bar graph.

From history. Sharing nature notes by letter is an old tradition. In England, Gilbert White of Selborne wrote long letters about the birds, insects and weather of his parish to two other naturalists, Thomas Pennant and Daines Barrington. In 1789 he gathered them into a book called *The Natural History of Selborne*. It has been printed again and again ever since, and it has taught many readers to watch their own back gardens more closely.

WORKED EXAMPLES

Example 1. Use the bar graph of birds at the feeder. How many birds came in all during the five watches? Which day had the most birds? How many more birds came on Thursday than on Wednesday?

(Use the map or drawing “Read the top of each bar against the numbers on the side.” shown earlier in this lesson.)

1. Read each bar: Monday 4, Tuesday 6, Wednesday 3, Thursday 7, Friday 5.
2. Add: $4 + 6 = 10$; $10 + 3 = 13$; $13 + 7 = 20$; $20 + 5 = 25$.
3. The tallest bar is Thursday, with 7 birds.
4. Subtract: $7 - 3 = 4$.

Answer: 25 birds in all. Thursday had the most (7). Thursday had 4 more birds than Wednesday.

Example 2. Lily wrote four sentences about a nest she found. Sort each into observation or inference. (a) The nest is about 4 inches across. (b) There are three blue eggs in it. (c) A robin built this nest. (d) The mother bird is sad that I came close.

1. An observation is something seen or measured. An inference is an idea figured out from what was seen.
2. (a) She measured the nest: observation.
3. (b) She counted and saw the color: observation.
4. (c) She did not see who built it. Blue eggs are a clue, so this is an inference she could test by watching.
5. (d) She cannot see feelings. This is an inference, and not one she can easily check.

Answer: (a) and (b) are observations. (c) and (d) are inferences.

PRACTICE

1. **EASY** How did children pay their dues to join the Junior Naturalist Clubs?
2. **EASY** Observation or inference? “The maple leaf has 5 points.”
3. **MEDIUM** Jake’s tally for one watch was two bundles of five and 3 more marks. How many birds did he count?
4. **MEDIUM** Use the bar graph of birds at the feeder. How many more birds came on Tuesday than on Monday?
5. **HARD** On Saturday, 9 birds came to the feeder. If you add a Saturday bar to the graph, will it be taller or shorter than Thursday’s bar, and by how many birds? What will the new total for all six days be?

6. **CHALLENGE** Your friend shows you a journal page with a drawing of a caterpillar on a milkweed leaf. Write two good questions you could ask and one kind, specific compliment you could give.

COMMON MISTAKES

- Mixing guesses with observations. “The bird is hungry” is an inference. Say what you saw, “the bird pecked at the seeds for two minutes,” and then say what you think it means.
- Leaving out results that did not turn out as expected. If no birds came, or a seed did not sprout, that is real data and should be shared.
- Making a bar graph with no title, no labels or numbers that do not start at 0. Without them, readers cannot tell what the bars mean.

Make it a game • Naturalist Twenty Questions. Pick a plant or animal from your journal but keep it secret. Your family may ask up to twenty yes-or-no questions about it, such as “Does it have six legs?” or “Did you see it in the rain?” Answer only with what you truly observed or recorded; if you do not know, say “I didn’t observe that.” The person who guesses it first picks the next secret creature.

Scripture. “One generation shall praise thy works to another, and shall declare thy mighty acts.” (Psalm 145:4, KJV)

Sharing what you have seen of God’s creation is a way of praising Him and passing the wonder on to others, young and old.

Practice answers

1. By writing a letter to “Uncle John” Spencer telling something they had observed in nature themselves.
2. Observation. You can see and count the points.
3. $5 + 5 + 3 = 13$ birds.
4. Tuesday $6 - \text{Monday } 4 = 2$ more birds.
5. Taller, by $9 - 7 = 2$ birds. New total: $25 + 9 = 34$ birds.
6. Sample answer: Questions: “How long was the caterpillar?” and “What was the date and the weather when you found it?” (or “Was it eating the leaf?”). Compliment: “Your stripes are so clear that I could tell it is a monarch caterpillar.” Good questions ask about real observations; good compliments name something specific.

UNIT 8 REVIEW

Answer each question. Show your work for any math, and use complete sentences for explanations. The quiz is worth 40 points, 4 points per question.

1. (4 pts) What did Louis Agassiz mean when he told Samuel Scudder, “A pencil is one of the best of eyes”?
2. (4 pts) A pinecone is 4 inches long. One inch is about $2\frac{1}{2}$ centimeters. About how long is it in centimeters? If you draw it twice life size, how long is your drawing in inches?
3. (4 pts) Name two rules for making a good nature journal drawing.
4. (4 pts) Name the three body parts of an insect and tell how many legs it has. A garden creature has 8 legs. Is it an insect?
5. (4 pts) What is a leader line? Give one rule for drawing it.
6. (4 pts) Why did Lewis describe the eulachon fish part by part instead of just writing “a good little fish”?
7. (4 pts) List the four things every journal entry should begin with. Why must the date include the year?
8. (4 pts) The thermometer read 59°F at 7 a.m. and 75°F at 3 p.m. How many degrees warmer was the afternoon? Where should the thermometer hang, and why?
9. (4 pts) A flag is blowing toward the south. What is the name of this wind? Your rain gauge caught $\frac{1}{2}$ inch on Monday and $1\frac{1}{2}$ inches on Tuesday. How much rain fell in all?
10. (4 pts) Sort these into observation or inference: (a) “The caterpillar has 12 stripes.” (b) “The caterpillar is going to turn into a monarch.” Then tell how the Junior Naturalists paid their club dues.

UNIT PROJECT: MY TWO-WEEK NATURE JOURNAL

Keep a nature journal for two weeks with at least eight dated entries. Each entry begins with a heading of date, time, place, temperature ($^{\circ}\text{F}$ and $^{\circ}\text{C}$), sky and wind. Include at least four drawings from life with the size written in inches and centimeters, at least two drawings with six or more labeled parts, a week of rain gauge readings, and one tally count turned into a bar graph. Finish with a Journal Sharing Day where you present your three best entries to your family and answer their questions.

- **Observation:** Drawings are made from real objects, show many true details and include size notes in inches and centimeters.
- **Labels:** Parts are named correctly with neat, straight leader lines that do not cross; each drawing has a title with a common name.
- **Records:** Every entry has a full date, time, place and weather; thermometer and rain gauge readings are complete and correctly added or subtracted.
- **Sharing:** The bar graph has a title, labels and a scale starting at 0; the presentation separates observations from inferences and answers questions honestly.

1. Drawing something makes you look at it closely again and again, so you notice details you would miss with a quick look.
2. $4 \times 2\frac{1}{2} = \text{about } 10 \text{ cm}$. Twice life size: $2 \times 4 = 8 \text{ inches}$.
3. Any two: draw what you really see, not what you think it looks like; look more than you draw; start with the big shape, then add details; write the size; keep going instead of erasing.
4. Head, thorax, abdomen; 6 legs. No, an animal with 8 legs is not an insect (it is a spider or a relative of spiders).
5. A straight line from a label to the exact part it names. Rules: keep it straight, touch the exact part, do not let lines cross, keep labels outside the drawing.
6. So that scientists who had never seen it could picture it exactly and tell it apart from other fish.
7. Date, time, place and weather. The year lets you compare the same date in different years and know exactly when the observation was made.
8. $75 - 59 = 16^\circ\text{F}$ warmer. In the shade, because sunlight heats the thermometer itself and makes it read hotter than the air.
9. A north wind (it blows from the north). $\frac{1}{2} + 1\frac{1}{2} = 2 \text{ inches of rain}$.
10. (a) observation; (b) inference. They paid by writing a letter to "Uncle John" Spencer about something they had observed in nature.

BONUS: NATURE LAB

This bonus unit takes everything you learned this year outdoors. There are no new big ideas to memorize. Instead you will do what real naturalists do: walk slowly with a journal, survey a backyard by day and by night, visit a zoo, farm or museum with a scientist's question, and build a small labeled collection of your own. Each lesson is lighter than a regular lesson and is meant to be done outside as much as possible, in any season.

Along the way you will meet four naturalists who did the same things. Carl Linnaeus marched his students through the Swedish countryside, writing down every plant they found. Gilbert White watched one English village for years and noticed what everyone else missed. Charles Willson Peale dug a mastodon out of a muddy pit and built a museum for ordinary families. And a boy named Theodore Roosevelt measured a dead seal on Broadway and started a museum in his bedroom. In every lesson you will count, measure and label, because "the works of the LORD are great, sought out of all them that have pleasure therein" (Psalm 111:2).

BEFORE YOU BEGIN

- Can keep a simple nature journal page with a drawing and a sentence (Unit 8)
- Can make tally marks and add numbers up to 100
- Can measure with a ruler in inches
- Can name the main parts of a plant and tell a producer from a consumer

MASTERY CHECKLIST

- I can take a nature journal walk and write the date, time, place and weather on every page.
- I can measure distance by counting my steps.
- I can survey the same spot fairly by day and by night and show my counts in a table and a bar graph.
- I can sort animals into wild and domestic and compare their sizes using measurements.
- I can collect, press and label specimens with what, where, when and who, and I know what to leave in nature.

OPTIONAL BOOKS AND RESOURCES

- **All About Birds, from the Cornell Lab of Ornithology** (<https://www.allaboutbirds.org/>): Free. Look up any backyard bird by name, see pictures and hear its song. Helpful for the day survey in Lesson 9.2 and for labeling bird drawings.
- **Smithsonian National Museum of Natural History** (<https://naturalhistory.si.edu/>): Free. If you cannot visit a museum in person for Lesson 9.3, explore the museum's halls and collections online with a parent.

- **iNaturalist and its children's app, Seek** (<https://www.inaturalist.org/>): Free. A parent can use the Seek app to help identify plants, insects and birds from a photo during walks and surveys. Use it after you have drawn and described the creature yourself.

9.1 NATURE JOURNAL WALK

OBJECTIVES

- Take a nature journal walk and record the date, time, place and weather on every page.
- Measure distance on a walk by counting steps and using the length of one step.
- Tell how Carl Linnaeus led his students on nature walks and what each student had to do.

Warm-up. Stand at a window for two minutes and look outside without talking. Then close your eyes and say out loud every living thing you saw: every bird, bug, tree, weed and person. Open your eyes and look again. What did you miss the first time?

Video. Coming soon. Children's nature walk and nature journaling for kids: search nature-journaling channels (John Muir Laws), SciShow Kids, Smithsonian, and Homeschool Pop (Alternate) for how to sketch and record outdoors.

KEY TERMS

nature journal

A notebook where a naturalist draws and writes what he or she sees outdoors, with the date, time, place and weather.

observation

Something you notice carefully with your senses, such as how a leaf looks, feels or smells.

pace

One step. If you know how long your step is, you can count steps to measure how far you walked.

field notes

Quick notes and sketches a scientist makes outdoors, right where the living things are.

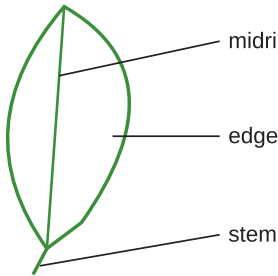
CORE IDEAS

The story. In the 1740s and 1750s, on summer days in Sweden, a crowd of students gathered early in the morning outside the town of Uppsala. Their teacher was Carl Linnaeus, the great naturalist who gave plants and animals their two-part scientific names. Linnaeus did not teach only in a classroom. He led his students on long walks through meadows, woods and marshes, and sometimes a couple hundred people came along. At each stop he showed them a flower, a moss or an insect and told them about it. One student was chosen to write down everything that was found. Others gathered plants and caught insects to study. At the end of the day the whole crowd marched back into town with horns and drums playing, shouting "*Vivat Linnaeus!*" which is Latin for "Long live Linnaeus!"

The big idea. A **nature journal walk** is a walk with your eyes open and your notebook ready. A naturalist walks slowly, stops often and makes **field notes** right where the living

things are. At the top of every page, write four things: the **date**, the **time**, the **place** and the **weather**. Then draw what you see, even if your drawing is not fancy, and label its parts. Write three kinds of sentences: *I notice...*, *I wonder...* and *It reminds me of...*. You can even measure your walk. Count your steps, or **paces**, between two places. If one of your steps is about 2 feet long, then 10 steps is about 20 feet. Scientists use the metric system too: 2 feet is about 60 centimeters.

God's handiwork. Linnaeus loved to say that the study of nature shows the wisdom of the Creator. Every walk is a chance to see that wisdom close up: the veins of a leaf, the way a spider spins, the way a bird hops and tilts its head. The Bible says the creatures themselves can teach us, if we will stop and look. A nature journal is a way of paying attention to what God made.

Date: May 12	Time: 9:30 a.m.
Place: creek path	Weather: sunny, 68°F
Sketch  I notice: the leaf has smooth edges. I wonder: why is one side bigger? It reminds me of: a canoe.	

A good journal page: date, time, place and weather at the top, a labeled sketch in the middle, and notes at the bottom.

PICTURE STUDY



Wing of a Blue Roller, Albrecht Dürer, 1512 (some experts date it about 1500) · Watercolor and gouache on parchment · Albertina, Vienna, Austria

Albrecht Dürer was a German artist who painted living things the way a scientist studies them. Here he painted just one thing: the wing of a bird called a blue roller. He did not paint a whole bird, a tree or a sky. He looked at one wing so long and so carefully that you can count the feathers and see the tiny hairlike barbs along their edges.

This is the same kind of looking you will do on your nature journal walk. You do not have to draw everything. Choose one thing, look at it for a long time, and draw it as truly as you can.

Look closely

- Find the long flight feathers at the end of the wing. How are they different from the small feathers near the top?
- How many different colors can you find? Where does the blue change into green or brown?
- Find one single feather and follow it from its base to its tip with your finger.
- Does the wing look soft or stiff? What in the painting makes you think so?

Talk about it

1. Why do you think Dürer painted only one wing instead of a whole bird?
2. What one thing would you choose to draw very carefully on your walk?
3. How is a painting like this one similar to a page in a nature journal?

Safety first. Walk with an adult and stay together. Do not touch or eat wild mushrooms or berries. Learn to spot poison ivy (“leaves of three, let it be”) and stay away from it. Never

pick up or touch wild animals, even ones that look hurt. Stay well back from deep or fast water. Wash your hands when you get home.

EXPERIMENT: MY MEASURED NATURE WALK

Like Linnaeus's students, you will walk a real path, stop at stations, and write field notes as you go. You will also measure your walk in steps and feet, so that someone else could follow your path and find what you found.

You will need

- Nature journal or a few sheets of paper on a clipboard
- Pencil and colored pencils
- Tape measure or yardstick
- Outdoor thermometer (if you have one)
- Hand lens (magnifying glass), if you have one

Steps

1. **Question:** How many different living things can I find and record along one short path? Write a **prediction** first: "I think I will find about ____."
2. **Measure your step.** Lay out a tape measure on the ground. Walk 10 normal steps beside it and see how many feet you went. Divide by 10 to find the length of one step. Write it in your journal.
3. Choose a path in your yard, a park or along a road with an adult. Pick 5 stopping places, called **stations**, along it.
4. At the top of a fresh page, write the date, time, place and weather. Read the thermometer if you have one.
5. Walk to station 1, counting your steps. Write the number of steps. Stop for 5 minutes. Draw one living thing and write one *I notice* sentence and one *I wonder* sentence.
6. Keep each station the same: the same 5 minutes, the same kind of notes. That is what keeps your walk fair.
7. Do the same at each station. At the end, add up all your steps and multiply by the length of one step to find how far you walked in feet.
8. Count how many different kinds of living things you recorded. Compare it with your prediction.

Tips

- Walk slowly. Most of what a naturalist finds is found while standing still.
- If you do not know a name, draw it and describe it. You can look it up later. Linnaeus's students did not know every name either.

Check your work

- Every page has the date, time, place and weather.

- I measured my step and figured how far I walked.
- I drew and wrote notes at all 5 stations.

NATURE NOTEBOOK

1. Draw one leaf from your walk as large as the page. Label the stem, the vein down the middle (midrib) and the edge.
2. Make a simple map of your walk. Mark the 5 stations with numbers and write the steps between each one.
3. Write three sentences: one that begins “I notice,” one that begins “I wonder,” and one that begins “It reminds me of.”

From history. Linnaeus’s walks around Uppsala followed set routes that he planned so his students would pass through many different places: fields, forests, marshes and lake shores. His students later traveled all over the world, to places such as North America, Africa, Japan and the South Seas, carrying notebooks and sending back plants and notes to their teacher. Linnaeus called some of them his “apostles.” They had learned on those Swedish summer walks how to look closely and write it all down.

WORKED EXAMPLES

Example 1. Mia walked 10 steps beside a tape measure and went 20 feet. Then she walked 35 steps from her back door to an old oak tree. About how far is the oak tree from the door, in feet?

1. Find the length of one step: $20 \text{ feet} \div 10 \text{ steps} = 2 \text{ feet per step}$.
2. Multiply the steps to the tree by the length of one step: $35 \times 2 = 70 \text{ feet}$.
3. Check: 30 steps would be 60 feet and 5 more steps is 10 feet, so $60 + 10 = 70 \text{ feet}$.
4. Metric: 1 foot is about 30 centimeters, so one step of 2 feet is about 60 centimeters.

Answer: The oak tree is about 70 feet from the door (each step is about 2 feet, or about 60 centimeters).

PRACTICE

1. **EASY** Name the four things you should write at the top of every nature journal page.
2. **EASY** On Linnaeus’s walks, what job did one student have? Why was that job important?
3. **MEDIUM** At 9 o’clock in the morning the thermometer on your walk read 64°F . At noon it read 73°F . How many degrees warmer was it at noon?
4. **MEDIUM** Your step is 2 feet long. It is 25 steps from the gate to the pond. About how many feet is that?
5. **HARD** Your friend says, “I don’t need to draw. I can just take a picture.” Give one good reason a naturalist still draws.

COMMON MISTAKES

- Thinking a nature walk should be fast. A naturalist walks slowly and stops often, because most living things are found by standing still and looking.
- Leaving off the date and place. A drawing with no date or place is much less useful to a scientist, because no one can tell when or where the thing was seen.
- Thinking a drawing must be beautiful to be good. A good field sketch is true and labeled, not fancy.

Make it a game · Linnaeus Says. One player is Linnaeus and leads the walk. At each stop, Linnaeus says, “Linnaeus says find something with five petals” (or something fuzzy, something that crawls, a leaf with jagged edges, something that smells sweet). Everyone hunts and points. The first to find it scores a point and becomes the next Linnaeus. If the leader gives a command without saying “Linnaeus says,” anyone who moves loses a point. March home at the end shouting “Vivat Linnaeus!”

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 animals, the birds, the earth and the fish can teach us. They teach us when we stop, look and write down what we see. A nature journal walk is a way of letting creation be our teacher.

Practice answers

1. The date, the time, the place and the weather.
2. One student wrote down everything that was found. It was important so that the class had a record of what they saw and where, and did not have to trust memory.
3. $73 - 64 = 9$. It was 9 degrees warmer at noon.
4. $25 \times 2 = 50$ feet.
5. Sample answer: Drawing makes you look slowly and carefully, so you notice details like how many petals there are or how the veins run. You can also label parts on a drawing.

9.2 BACKYARD SURVEY BY DAY AND BY NIGHT

OBJECTIVES

- Survey the same backyard spot in the daytime and after dark and record what lives there with tally marks.
- Read a data table and a bar graph to compare day creatures and night creatures.
- Tell how Gilbert White studied the plants and animals of one small village for many years.

Warm-up. Turn off the lights in a room and sit quietly for one minute. Listen. Now turn the lights on and listen again. Did you hear different sounds in the dark? Make a guess: Which animals in your yard do you think come out only at night?

Video. Coming soon. Nocturnal and diurnal backyard animals for kids, moth lights and night insects: search SciShow Kids, Smithsonian, Cornell Lab of Ornithology, nature footage channels and Homeschool Pop (Alternate).

KEY TERMS

survey

A careful count of the living things in one place, done the same way each time so the counts can be compared.

diurnal

Active in the daytime and resting at night, like bees, butterflies and robins.

nocturnal

Active at night and resting in the day, like moths, many beetles, owls and bats.

pitfall trap

A cup set into the ground with its rim level with the soil, so small crawling animals tumble in and can be counted and let go.

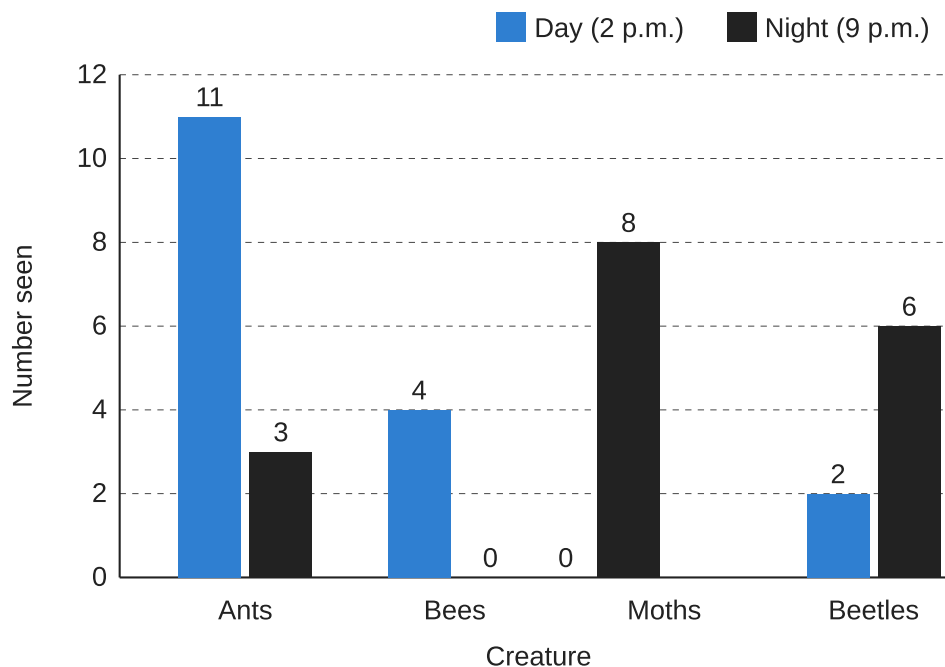
CORE IDEAS

The story. Gilbert White was a minister who lived almost his whole life in Selborne, a small village in the south of England. He never went on a long voyage. Instead, for many years he watched the birds, insects, plants and weather of his own garden and the fields and woods around his village, and he wrote down what he saw. He noted the day the swifts came back each spring and the day they left. He watched bats flying at dusk and field crickets at the mouths of their burrows. He even kept a pet tortoise named Timothy and wrote down when it dug itself into the ground for winter and when it came out in spring. In 1789 his letters were printed as a book, *The Natural History of Selborne*, and people have been reading it ever since. White wrote that “Earth-worms, though in appearance a small and despicable

link in the chain of nature, yet, if lost, would make a lamentable chasm.” He meant that worms look unimportant, but the world would be badly hurt without them.

The big idea. A backyard is not the same place at night as in the day. Some animals are **diurnal**: bees, butterflies, ants and most songbirds work in the sunshine and rest at night. Others are **nocturnal**: moths, crickets, many beetles, slugs, owls and bats come out after dark. A good **survey** counts the same spot, for the same length of time, in the same way. Then, if only one thing changes, such as day or night, you can compare the two counts fairly. You can count flying insects at a porch light, and crawling ones with a **pitfall trap**: a cup buried in the ground up to its rim, checked in the morning, and then emptied so every creature goes free.

God’s handiwork. God made the day and the night, and He filled both with life. When the bees go home, the moths come out to visit night flowers. When the robins sleep, the owls go hunting. The psalm says that when darkness comes, the beasts of the forest “creep forth.” Your yard has a day shift and a night shift, and both are part of His wise design.



Fifteen-minute counts in the same garden spot at 2 p.m. and at 9 p.m. Both counts total 17, but the creatures are different.

PICTURE STUDY



American Robin (Plate 131 from The Birds of America), John James Audubon (engraved by Robert Havell), 1832 · Hand-colored engraving and aquatint · National Gallery of Art, Washington, D.C.

John James Audubon set out to paint every bird in America, life-size, in its own surroundings. The American robin is one of the most common backyard birds, and Audubon showed a male, a female and a young robin the way you might see them on a spring morning, perched in a tree among leaves.

The robin is a **diurnal** bird. It is often one of the first birds singing at dawn and one of the last at dusk. On your day survey you may hear it or see it running across the lawn, stopping, and tilting its head before it pulls up a worm.

Look closely

- Find the robin's breast. What color did Audubon paint it?
- Compare the birds in the picture. Can you see any differences between them?
- Look at the plant the robins are perched on. What parts of it can you name?
- Find the beak. What shape is it? What do you think a beak like that is good for?

Talk about it

1. Have you seen a robin in your yard? Where was it and what was it doing?
2. Why do you think Audubon painted the birds in a tree instead of on a blank page?
3. Would you see a robin on your night survey? Why or why not?

Safety first. Do your night survey only with an adult, and carry a flashlight. Do not touch spiders, wasps, bees or any creature you do not know; look with a hand lens instead. If you use a pitfall trap, ask an adult where to dig, poke a few small holes in the bottom of

the cup so rain drains out, check it first thing the next morning, and let every creature go where you found it. Wash your hands after the survey.

EXPERIMENT: THE DAY SHIFT AND THE NIGHT SHIFT

Like Gilbert White, you will study one small place very closely. You will survey the same spot twice, once in the afternoon and once after dark, and compare the results in a table and a bar graph.

You will need

- Nature journal and pencil
- Watch or timer
- Flashlight and a white sheet or light-colored towel
- A porch light or a lantern (with an adult)
- Two plastic cups and a small trowel (for an optional pitfall trap)
- Hand lens (magnifying glass), if you have one

Steps

1. **Question:** Are different creatures active in my yard at night than in the day? Write your **prediction:** “I think at night I will see more ___ and fewer ___.”
2. Choose one spot near an outdoor light, such as a garden bed or the edge of the lawn by the porch. Hang or spread the white sheet there.
3. **What we change:** the time of day. **What we keep the same:** the spot, the 15 minutes of watching, and the way we count. **What we measure:** how many of each kind of creature we see.
4. Day survey: at about 2 p.m., watch the spot for 15 minutes. Make a tally mark each time you see a creature. Write the weather and temperature.
5. Night survey: about an hour after dark, turn on the light near the sheet and wait 10 minutes. Then watch the same spot for 15 minutes and tally what you see on the sheet, on the plants and on the ground.
6. Optional pitfall trap: with an adult, dig a hole and set one cup inside another so the rim is level with the soil. Set it in the afternoon. The next morning, count what is inside, then tip it out gently and fill in the hole.
7. Make a table with three columns: Creature, Day, Night. Add up each column.
8. Draw a bar graph with two bars for each creature, one for day and one for night. Write one sentence telling whether your prediction was right.

Tips

- Count each creature only once if you can. If a moth flies away and lands again, it is still the same moth.
- If you do not know the name of a creature, give it a nickname, like “tiny brown beetle,” and draw it.

Check your work

- I surveyed the same spot for the same length of time by day and by night.
- My table has a total for each column.
- My bar graph shows day and night bars for each creature, and I wrote what I learned.

NATURE NOTEBOOK

1. Draw one moth from your night survey. Look at its antennae: are they thin like threads or feathery like ferns? Draw them carefully.
2. Draw your survey spot twice, side by side: once in the day and once at night. Add the creatures you saw in each.
3. Copy Gilbert White's sentence about earthworms into your journal. Under it, write in your own words why worms matter.

From history. Gilbert White kept a weather diary and a nature diary for many years, writing almost every day. He was one of the first to notice that two English birds that look almost the same, the chiffchaff and the willow warbler, are really different kinds. He could tell them apart by their songs. A careful listener in a small village found what others had missed, simply by paying attention, day after day, in the same place.

WORKED EXAMPLES

Example 1. Sam surveyed the same garden spot for 15 minutes at 2 p.m. and for 15 minutes at 9 p.m. His table: Ants, day 11, night 3. Bees, day 4, night 0. Moths, day 0, night 8. Beetles, day 2, night 6. (a) Find the total for day and the total for night. (b) Which creature was seen only at night? (c) How many more beetles were seen at night than in the day?

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

1. Day total: $11 + 4 + 0 + 2 = 17$ creatures.
2. Night total: $3 + 0 + 8 + 6 = 17$ creatures.
3. Look for a 0 in the Day column: moths had 0 by day and 8 by night, so moths were seen only at night.
4. Beetles: 6 at night $- 2$ in the day $= 4$ more at night.
5. Notice: the totals are the same, but the creatures are different. The yard has a day shift and a night shift.

Answer: (a) Day 17, night 17. (b) Moths. (c) 4 more beetles at night.

PRACTICE

1. **EASY** Sort these animals into diurnal (day) and nocturnal (night): robin, moth, bee, owl, butterfly, bat.

2. **EASY** Where did Gilbert White do his nature study, and name two things he watched there.
3. **MEDIUM** Use Sam's table from the worked example. How many more ants did Sam see in the day than at night?
4. **MEDIUM** A pitfall trap was checked three mornings in a row. It held 4 ground beetles, then 6, then 5. How many ground beetles were counted in all? What should you do with them after counting?
5. **HARD** Jack watched his yard for 30 minutes in the day and only 5 minutes at night. He says, "There are more animals in the day." Why is his survey not fair? How should he fix it?

COMMON MISTAKES

- Thinking animals disappear at night. Many animals are just starting their work when we go to bed.
- Changing more than one thing at once, such as surveying a sunny lawn by day and a dark shed by night. Then you cannot tell whether day and night or the place made the difference.
- Thinking moths and butterflies are the same. Most moths fly at night and many have feathery antennae; butterflies fly by day and have thin antennae with a knob at the tip.

Make it a game • Day Shift, Night Shift. A parent calls out an animal: owl, bee, robin, moth, bat, butterfly, cricket, squirrel, firefly. If it is a day animal, stand up and stretch like the sun rising. If it is a night animal, crouch down and cover your eyes like you are sleeping in the day. Get it right to score a point. For a bonus point, name one thing that animal does on its shift.

Scripture. "Thou makest darkness, and it is night: wherein all the beasts of the forest do creep forth." (Psalm 104:20, KJV)

Psalm 104 is a song about God's care for every creature. Night is not empty. God made the darkness, and He made creatures that come out in it to find their food.

Practice answers

1. Diurnal: robin, bee, butterfly. Nocturnal: moth, owl, bat.
2. In and around his own village of Selborne in England. He watched things such as the swifts coming and going, bats at dusk, field crickets, earthworms and his tortoise Timothy.
3. $11 - 3 = 8$ more ants in the day.
4. $4 + 6 + 5 = 15$ ground beetles. Let them all go where the trap was.
5. He watched six times longer in the day, so of course he saw more. A fair survey keeps everything the same except day or night: he should watch the same spot for the same number of minutes both times.

9.3 ZOO, FARM OR MUSEUM VISIT

OBJECTIVES

- Plan and make a visit to a zoo, farm or natural history museum and record observations of at least five animals or specimens.
- Tell the difference between wild and domestic animals and compare animal sizes using measurements.
- Tell how Charles Willson Peale dug up a mastodon and built one of America's first natural history museums.

Warm-up. Find three things in your house that came from an animal (such as wool, leather, an egg, milk, a feather or honey). For each one, name the animal it came from and say whether that animal lives on a farm or in the wild.

Video. Coming soon. Natural history museum behind the scenes, how zookeepers care for animals, and farm animal tours for kids: search Smithsonian National Museum of Natural History, zoo channels (San Diego Zoo, Smithsonian's National Zoo), farm tour videos for children and Homeschool Pop (Alternate).

KEY TERMS

museum

A building where real objects, such as bones, shells, rocks and stuffed animals, are kept safe, studied and shown to visitors.

exhibit

A display in a museum or zoo, with a sign that tells what you are looking at.

diorama

A museum display that shows animals in front of a painted background of their home, as if you were looking at a real place.

domestic animal

An animal people have raised and cared for over many generations, such as a cow, sheep, chicken, horse or dog.

CORE IDEAS

The story. Charles Willson Peale was a painter in Philadelphia who painted George Washington many times. He also loved natural history, and in 1786 he opened a museum in his own house, full of birds, insects, shells and rocks. In 1801 Peale heard that farmers near Newburgh, New York, had found giant bones in a muddy pit on John Masten's farm. Peale hurried there. The pit kept filling with water, so his workers built a huge wooden wheel. Men walked inside it like a hamster wheel, and it lifted buckets of water out of the pit. Little by little, they dug out the bones of a **mastodon**, an elephant-like animal with thick legs and

long tusks. Peale put the skeleton together and showed it in his museum, and crowds came to see it. He also set his birds in glass cases with painted pictures of their homes behind them, an early kind of **diorama**, so visitors could see where each bird lived.

The big idea. Zoos, farms and museums let us see living things up close that we might never find in our backyard. At a **zoo** you can watch wild animals from far-off lands move and eat. At a **farm** you can see **domestic animals**, the cows, sheep, goats, pigs and chickens that people have raised for food, wool and work since Bible times. At a **museum** you can see skeletons, fossils and specimens that hold still long enough to draw. Go as a scientist: bring your journal, pick a few animals or **exhibits**, and stay with each one for several minutes. Read the sign, draw what you see, and write what it is doing. Look for measuring signs too: how tall, how long, how heavy. Ask a zookeeper or farmer one good question. They love to answer.

God's handiwork. When God made the animals, He made "cattle after their kind" and "the beast of the earth after his kind" (Genesis 1:25). A farm shows the cattle that serve people; a zoo shows the wild beasts of every land; a museum keeps the bones of creatures that once walked the earth. And God gave people the job of caring for them. A good farmer and a good zookeeper show the kind of care the Bible calls righteous.

Thinking About Time

What the sign says. What the sign says: Many museum signs say mastodons lived during the "Ice Age" and dinosaurs lived in "the age of dinosaurs," and they say these times were very, very long ago, long before any people lived.

What we observe. What we observe: Real bones dug out of mud, clay and rock layers. Peale's mastodon bones came out of a soft, wet pit on a farm. We can measure the bones, count them and put them together, but no one wrote down the date the animal died.

How Christians read it. How Christians read it: Many Christians believe God made all the land animals, dinosaurs too, on the sixth day of creation, not very long ago. They believe many fossils were buried in Noah's Flood, and that mastodons lived after the Flood, during a cold time with great ice sheets that followed it.

Try it. At the museum, find one sign with a museum word like "Ice Age" or "Jurassic." Copy it into your journal and underline what you can actually see in the case.

Genesis 1:25

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 picture of himself when he was an old man, standing in the museum he had built. He holds up a curtain as if to say, “Come in and see!” Behind him stretches a long room in Philadelphia filled with bird cases, and high on the walls hang portraits of famous Americans, many painted by Peale himself.

Peale wanted everyone, not just scholars, to learn about the creatures God made. He arranged his specimens in order, labeled them and painted backgrounds for his birds. His museum was a place to look, learn and wonder.

Look closely

- Find the curtain. What is Peale showing us by lifting it?
- Look at the bottom of the painting. What bones and animals can you find on the floor? (Some are mastodon bones.)
- Find the long rows of cases along the wall. What do you think is inside them?
- Find the visitors in the background. What is the woman in the bonnet doing, and what might she be looking at?

Talk about it

1. Why do you think Peale painted himself inviting us in, instead of standing still in a plain room?
2. If you made a museum in your house, what would you put in it?
3. How is visiting a museum like taking a nature walk? How is it different?

Safety first. Stay with your adult the whole visit. At a zoo, never climb rails or reach into enclosures, and never feed the animals unless a keeper says you may. On a farm, ask before touching any animal, stand beside large animals, not behind them, and keep fingers away from mouths. Always wash your hands with soap and water after touching farm animals or their pens, and before you eat. In a museum, touch only what the signs say you may touch.

EXPERIMENT: MY FIELD TRIP FIELD NOTES

Like Peale's visitors, you will go see creatures you cannot find in your own yard. But you will go as a scientist with a question, a plan and a journal, not just as a tourist.

You will need

- Nature journal or clipboard and pencil
- Colored pencils
- A map of the zoo, farm or museum (often free at the entrance or online)
- A watch or timer
- A tape measure (for a farm visit, if the farmer allows)

Steps

1. **Question:** Before you go, choose one question, such as "How do different animals eat?" or "How big were the biggest animals that ever lived?" Write your **prediction**.
2. Look at the map with your parent and choose 5 animals or exhibits to study. Mark them on the map.
3. At each stop, watch for the same amount of time, about 5 minutes. Keeping the time the same lets you compare fairly.
4. For each one, write: its name, where it comes from (read the sign), what it eats, and one thing it did while you watched. Draw it.
5. Find at least two measurements on signs or by measuring with permission (height, length or weight). Write them down in feet or pounds, and in meters or kilograms if the sign gives them.
6. Ask a zookeeper, farmer or museum guide one question and write down the answer.
7. At home, make a chart of your 5 animals: Name, Wild or Domestic, Food, Size. Write two sentences answering your question.

Tips

- Animals often rest in the middle of the day. Early morning and late afternoon are good times to see them moving and eating.
- In a museum, sit on the floor or a bench and draw one skeleton slowly. Count the ribs or the toes.

Check your work

- I studied 5 animals or exhibits and drew each one.
- I wrote down at least two real measurements.
- I sorted my animals into wild and domestic and answered my question.

NATURE NOTEBOOK

1. Draw one animal from your visit and label at least four parts (such as ears, tail, hooves, horns, beak or tusks).
2. Draw a sign from an exhibit. Underline what you can see for yourself and circle what someone had to figure out.
3. Make a two-column list: Wild Animals I Saw and Domestic Animals I Saw.

From history. Another famous museum maker worked in England. In the early 1850s, the English artist Benjamin Waterhouse Hawkins built life-size models of dinosaurs and sea reptiles, including plesiosaurs, for Crystal Palace Park in London, where the models still stand today. On New Year's Eve, 1853, Hawkins held a dinner for scientists inside the mold of his giant *Iguanodon* model. Some of his models look wrong to us now, because later diggers found more complete bones. But Hawkins, like Peale, wanted ordinary families to see and wonder at the creatures whose bones lie in the earth. And in 1874 the Philadelphia Zoo, often called America's first zoo, opened its gates in Peale's own city.

WORKED EXAMPLES

Example 1. A sign at the zoo says a tall giraffe can be about 18 feet tall. Lily is about 4 feet tall. About how many Lilys standing on each other's heads would reach the top of the giraffe?

1. Count by 4s, one Lily at a time: 4, 8, 12, 16 feet. That is 4 Lilys.
2. 16 feet is 2 feet short of 18 feet. Two feet is half of Lily's height.
3. So it takes 4 Lilys and half of another: 4 and a half.
4. Metric: 1 foot is about 30 centimeters, so 18 feet is about 540 centimeters. That is about 5 and a half meters.

Answer: About 4 and a half Lilys. The giraffe is about 18 feet, or about 5 and a half meters, tall.

PRACTICE

1. **EASY** What animal's bones did Charles Willson Peale dig up in 1801, and how did his workers keep the pit from filling with water?
2. **EASY** Sort these animals into wild and domestic: cow, giraffe, chicken, zebra, sheep, tiger.
3. **MEDIUM** In one barn you see 3 chickens and 2 cows. How many legs is that in all?

4. **MEDIUM** A zoo sign says a large elephant can weigh about 12,000 pounds. A farm horse weighs about 1,000 pounds. About how many horses weigh as much as the elephant?
5. **HARD** A museum sign says: "This mastodon skeleton was found in a muddy pit in New York. Mastodons lived during the Ice Age." Which part is something people saw, and which part is an idea about time? Explain.

COMMON MISTAKES

- Thinking every animal in a museum was once alive in that pose. Skeletons are put together by people, and stuffed animals are posed by artists who studied the living animal.
- Thinking domestic animals are just tame wild animals. Domestic animals like cows, sheep and chickens have been raised by people for a very long time and are different from their wild relatives.
- Reading only the big words on a sign. A scientist also reads the small print, where the measurements and the place the specimen was found are written.

Make it a game · Exhibit Detective. One player secretly picks an animal or exhibit you saw on your visit. The others ask yes-or-no questions: "Is it wild?" "Does it have hooves?" "Is it bigger than a horse?" "Is it a skeleton?" Score a point for guessing in ten questions or fewer. The player who guesses must then say one true fact they read on that animal's sign.

Scripture. "A righteous man regardeth the life of his beast: but the tender mercies of the wicked are cruel." (Proverbs 12:10, KJV)

To "regard the life of his beast" means to pay attention to what an animal needs and take good care of it. Watch how the farmer or zookeeper feeds, cleans and checks each animal. That care is a kind of righteousness.

Practice answers

1. A mastodon. His workers built a big wooden wheel that men walked inside; it lifted buckets of water out of the pit.
2. Domestic: cow, chicken, sheep. Wild: giraffe, zebra, tiger.
3. Chickens: $3 \times 2 = 6$ legs. Cows: $2 \times 4 = 8$ legs. Total: $6 + 8 = 14$ legs.
4. $12,000 \div 1,000 = 12$. About 12 horses.
5. Seen: the skeleton was found in a muddy pit in New York; people dug it up and can see the bones. Idea about time: "lived during the Ice Age" is an interpretation of when it lived, because no one wrote down the date the animal died.

9.4 SPECIMEN COLLECTION

OBJECTIVES

- Collect, press and label a small set of natural specimens the right way, with what, where, when and who on every label.
- Measure specimens in inches and centimeters and sort them into groups.
- Tell how young Theodore Roosevelt started a museum in his bedroom and explain which things we should leave in nature.

Warm-up. Empty your pockets, or a drawer, onto the table. Sort what you find into groups any way you like. Now sort them a different way. Scientists sort collections too, and there is usually more than one good way to do it.

Video. Coming soon. How to press plants and make a leaf collection for kids, and behind the scenes in a natural history museum collection: search Smithsonian National Museum of Natural History, botanical garden channels, SciShow Kids and Homeschool Pop (Alternate).

KEY TERMS

specimen

One real thing collected from nature to study, such as a leaf, a shell, a seed or a rock.

collection

A group of specimens kept together, sorted and labeled so they can be studied and compared.

label

A small card kept with a specimen that tells what it is, where and when it was found, and who found it.

plant press

A stack of paper squeezed flat under weight, used to dry leaves and flowers so they keep their shape.

herbarium

A collection of pressed, dried plants mounted on paper with labels.

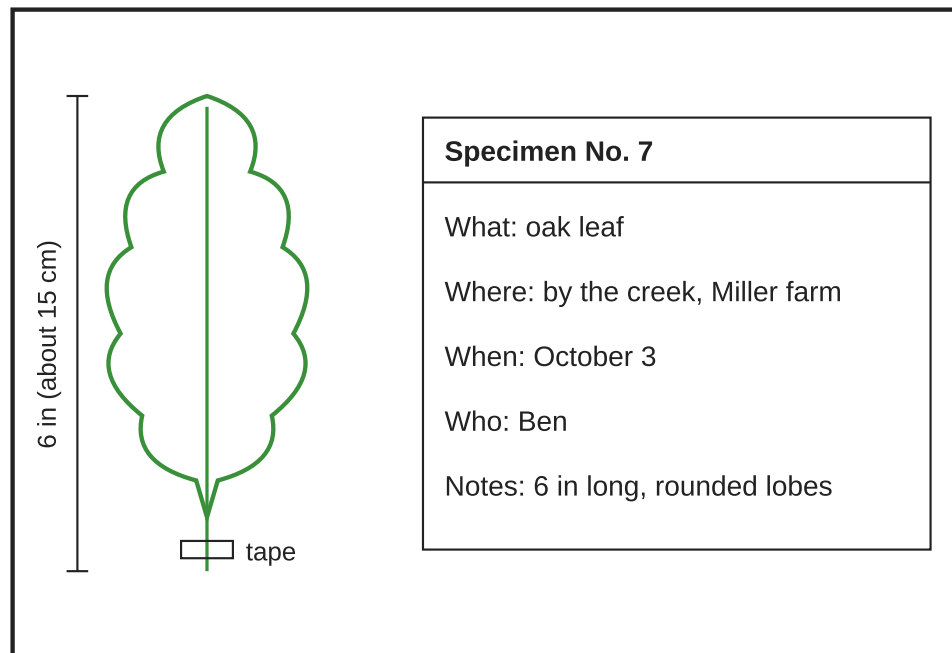
CORE IDEAS

The story. When Theodore Roosevelt was a boy in New York City, he was walking along Broadway one day when he saw a dead seal laid out at a market. He was amazed. He came back day after day to look at it, and he measured it with a folding ruler and wrote down its size. When the seal was gone, he managed to get its skull. With two of his cousins he started the “Roosevelt Museum of Natural History” in his bedroom, with the seal skull, birds’ eggs, insects and other treasures, each one written up in his notebooks. Young Theodore later

learned to prepare bird specimens and kept careful records. He grew up to be President of the United States, and he never stopped being a naturalist. Some of the birds he collected as a young man are still kept in American museums today.

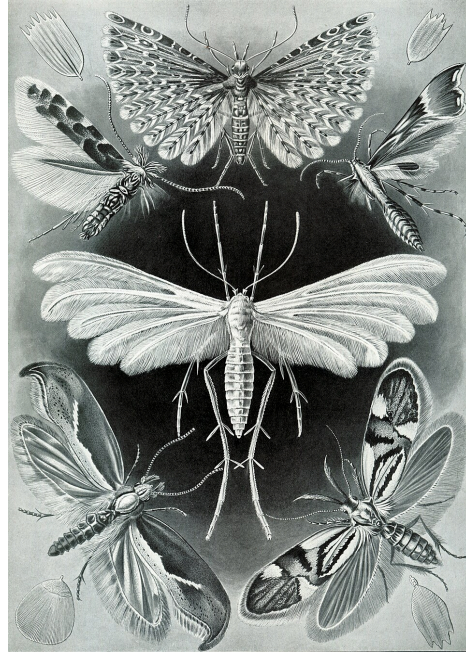
The big idea. A **specimen** is a real thing from nature kept for study. Museums keep millions of them in drawers and cabinets, because scientists can come back years later and measure them again. A specimen without a **label** is almost useless, so every specimen gets a label with four facts: **what** it is (or your best guess), **where** you found it, **when** you found it, and **who** collected it. Leaves and flowers can be dried flat in a **plant press**: lay them between sheets of newspaper inside a heavy book for about two weeks. A good collector also knows what to leave alone. Take only things that are plentiful, such as fallen leaves, seeds, pinecones, acorns and empty shells. Leave living animals, bird nests and eggs where they are. In the United States, it is against the law to keep the feathers, nests or eggs of most wild birds, so draw a feather you find instead of keeping it.

God's handiwork. King Solomon was wise in many things, and one of them was natural history. The Bible says he spoke of trees, from the great cedar down to the little hyssop growing out of a wall, and of beasts, birds, creeping things and fishes. Making a collection is a way of learning the names and differences of the things God made, one specimen at a time.



A mounted specimen and its label. The label answers four questions: what, where, when and who.

PICTURE STUDY



Tineida (small moths), Plate 58 from Kunstformen der Natur (Art Forms in Nature), Ernst Haeckel, Published in parts, 1899–1904 · Color print (lithograph) from Haeckel's drawings · Published in Leipzig, Germany; copies are kept in many libraries

Ernst Haeckel was a German naturalist who drew living things with great care. For his book *Art Forms in Nature* he filled each page with one group of creatures, arranged so neatly that the page looks like a drawer in a museum collection.

On this page are small moths. Moths and butterflies belong to the insect group scientists call Lepidoptera, which means “scale wings.” Haeckel even drew close-ups of the tiny scales that cover a moth’s wing, the way you might look at a specimen through a hand lens.

Look closely

- Find two moths that look almost alike. What small difference can you find between them?
- Find a moth whose wings are split into thin, feathery parts.
- Find the close-up drawings of wing scales. What shape are the scales?
- How did Haeckel arrange the page? Is there a pattern, such as one moth in the middle and others around it?

Talk about it

1. Why is it helpful for a scientist to see many specimens side by side?
2. If you were making a page like this from your own collection, what would you put on it?
3. Haeckel drew insects instead of keeping them all. What could you draw instead of collect?

Safety first. Collect only with an adult and only with permission of the landowner. Do not collect in national or state parks or nature preserves, where taking things is against the rules. Do not touch or pick wild mushrooms, berries you do not know, or poison ivy. Do not keep wild bird feathers, nests or eggs, and leave living animals where you find them. Wash your hands after handling specimens.

EXPERIMENT: MY LABELED LEAF AND SEED COLLECTION

Like young Theodore Roosevelt, you will start your own small museum. You will collect, press, measure, sort and label at least 8 specimens, and you will test a question about drying leaves.

You will need

- Paper bags or envelopes for collecting
- Newspaper and a few heavy books (your plant press)
- Ruler marked in inches and centimeters
- Index cards for labels, pencil, clear tape or glue
- An egg carton or small box for seeds, cones and shells
- Nature journal

Steps

1. **Collect:** With an adult, gather 8 to 10 specimens that are plentiful, such as fallen leaves, seeds, acorns, pinecones, grass heads and empty snail shells. Take only one of each kind from each place. Write the place and date on each bag.
2. **Question:** Does a leaf keep its color better if it is pressed flat or left to dry in the open air? Write your **prediction**.
3. Pick two leaves from the same plant that look alike. **What we change:** one goes in the press, one is left on a shelf. **What we keep the same:** the kind of leaf, the room and the number of days. **What we measure:** the color and shape after two weeks.
4. Press your leaves and flowers: lay each one flat between two sheets of newspaper, close them in a heavy book, and stack more books on top. Change the newspaper after a few days if it feels damp.
5. While you wait, measure each seed, cone and shell in inches and in centimeters, and write the numbers on its label.
6. After about two weeks, open the press. Compare the pressed leaf with the shelf leaf and record what you see.
7. Tape or glue each pressed leaf onto its own sheet of paper. Add a label with a number, what, where, when, who and one measurement.
8. Sort your whole collection into groups (such as leaves, seeds, cones, shells) and list them in a numbered catalog in your journal.

Tips

- Write labels right away. Collectors who say “I’ll remember” almost always forget.
- Thin leaves press best. Thick, juicy leaves and flowers can mold, so change their paper often.

Check your work

- Every specimen has a label with what, where, when and who.
- I measured my specimens in inches and centimeters.
- I compared a pressed leaf with an air-dried leaf and wrote what happened.

NATURE NOTEBOOK

1. Draw your favorite specimen life-size, then measure your drawing to make sure it matches the real thing.
2. Draw a feather or a nest you found but left outside. Write where it was and why you left it.
3. Make a cover page for your collection: “The ___ Museum of Natural History,” with your name as curator.

From history. One of the world’s great collections began with a gift from a man who never visited America. James Smithson, an English scientist who studied minerals, died in 1829 and left his fortune to the United States “to found at Washington, under the name of the Smithsonian Institution, an establishment for the increase and diffusion of knowledge among men.” Congress founded the Smithsonian in 1846. Today its National Museum of Natural History keeps well over a hundred million specimens: plants, animals, fossils, rocks and meteorites, each with its own label.

WORKED EXAMPLES

Example 1. Ben pressed five leaves and measured their lengths: maple 4 inches, oak 6 inches, elm 3 inches, birch 3 inches, sassafras 5 inches. (a) Put them in order from shortest to longest. (b) How much longer is the longest leaf than the shortest? (c) About how long is the oak leaf in centimeters?

(Use the map or drawing “Ben’s oak leaf, mounted and labeled.” shown earlier in this lesson.)

1. Order the numbers: 3, 3, 4, 5, 6. So: elm and birch (3 inches), maple (4), sassafras (5), oak (6).
2. Longest minus shortest: $6 - 3 = 3$ inches.
3. One inch is about 2 and a half centimeters, so 2 inches is about 5 centimeters.
4. 6 inches is three groups of 2 inches: $5 + 5 + 5 = 15$ centimeters.

Answer: (a) Elm and birch, maple, sassafras, oak. (b) 3 inches longer. (c) About 15 centimeters.

PRACTICE

1. **EASY** Name the four facts every specimen label must have.
2. **EASY** Name two things a young naturalist should leave in nature instead of collecting.
3. **MEDIUM** You put leaves in your plant press on May 3. They need about two weeks (14 days) to dry. On what date should you open the press?
4. **MEDIUM** An acorn is 1 inch long and a pinecone is 4 inches long. About how many centimeters long is each? (Use: 1 inch is about 2 and a half centimeters.)
5. **HARD** Your friend found a beautiful leaf in the woods but did not write down where or when. Why is that specimen less useful to a scientist?

COMMON MISTAKES

- Thinking a feather on the ground is free to keep. In the United States the feathers, nests and eggs of most wild birds are protected by law. Draw them instead.
- Collecting too much. A good collector takes one of a plentiful thing and leaves the rest, and takes nothing if there are only a few.
- Forgetting the label. A specimen with no place or date tells a scientist very little.

Make it a game • Museum Curator. Lay out 10 specimens from your collection. One player closes their eyes while another takes one away and hides it. The first player opens their eyes and must name the missing specimen and say one fact from its label: where, when or how long. For a harder round, mix up all the labels and race to match each label to its specimen.

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 knowing God’s creatures, from the tallest tree to the smallest plant on a wall. When you collect, sort and name specimens, you are learning in the same way.

Practice answers

1. What it is, where it was found, when it was found, and who collected it.
2. Any two: living animals, wild bird feathers, bird nests, bird eggs, wild mushrooms, rare plants or anything in a park or preserve.
3. $\text{May } 3 + 14 \text{ days} = \text{May } 17$.
4. Acorn: about 2 and a half centimeters. Pinecone: $4 \times 2 \text{ and a half} = \text{about } 10 \text{ centimeters}$.
5. Without the place and date, no one can tell where that plant grows or what time of year the leaf was found, so it cannot be compared with other specimens or used to learn about that place. It is just a pretty leaf, not a scientific specimen.

UNIT 9 REVIEW

This is a short review of the Nature Lab. Answer each question in a sentence or two, and show your work for calculations. The review is worth 40 points.

1. (5 pts) Name the four things a naturalist writes at the top of every nature journal page, and tell why each one matters.
2. (5 pts) Your step is 2 feet long. You walk 40 steps from your porch to a big maple tree. How far is the tree, in feet?
3. (10 pts) A survey of one garden spot for 15 minutes gave: Bees, day 6, night 0. Moths, day 1, night 9. Crickets, day 2, night 5. (a) Find the day total and the night total. (b) Name one diurnal and one nocturnal creature from the table. (c) Why must both surveys last 15 minutes?
4. (5 pts) What did Charles Willson Peale dig up in 1801, and what did he build so people could see it and many other creatures?
5. (5 pts) Sort these animals into wild and domestic: goat, polar bear, horse, kangaroo, pig, owl.
6. (10 pts) You find a fallen sycamore leaf 8 inches long, a blue jay feather, and an empty snail shell. (a) Which one should you leave outside, and why? (b) About how many centimeters long is the leaf? (Use: 2 inches is about 5 centimeters.) (c) Write a complete label for the leaf.

UNIT PROJECT: MY NATURE LAB FIELD BOOK

Gather your Nature Lab work into one field book: your measured nature walk with its map, your day-and-night survey table and bar graph, your field trip notes with five animals or exhibits, and your labeled specimen collection with its numbered catalog. Add a cover, a table of contents and a final page titled “What I Learned Outdoors,” where you write a paragraph about the most surprising thing you discovered and draw it.

- **Records:** Every journal page and label has the date, place and other needed facts (time and weather for walks; what, where, when and who for specimens).
- **Measurement and data:** Steps, lengths and counts are measured carefully, added correctly and shown in a neat table and bar graph.
- **Observation and drawing:** Drawings are true to life and labeled, and notes show careful looking (“I notice,” “I wonder”).
- **Care and stewardship:** The student collected only plentiful things, left protected things in nature, released every creature, and kept the field book neat and complete.

Answer key

1. Date, time, place and weather. They let anyone know exactly when and where the observation was made and what the conditions were, so it can be compared with other observations.
2. $40 \times 2 = 80$ feet.

3. (a) Day: $6 + 1 + 2 = 9$. Night: $0 + 9 + 5 = 14$. (b) Diurnal: bees. Nocturnal: moths (or crickets). (c) So the survey is fair; if one survey were longer, you could not tell whether the time of day or the extra minutes made the difference.
4. He dug up the bones of a mastodon, an elephant-like animal. He showed it in his natural history museum in Philadelphia, where birds were also displayed in cases with painted backgrounds of their homes.
5. Domestic: goat, horse, pig. Wild: polar bear, kangaroo, owl.
6. (a) The blue jay feather; in the United States it is against the law to keep the feathers of most wild birds, so draw it instead. (b) 8 inches is four groups of 2 inches, so $5 + 5 + 5 + 5 =$ about 20 centimeters. (c) Sample label: What: sycamore leaf. Where: by the creek behind our house. When: October 10. Who: (student's name). Notes: 8 inches (about 20 cm) long.