SCHOOL LAUNCH · LIFE SCIENCE K–8

Grade 5 Life Science: The Human Body

A year of true stories about the body God made, from Robert Hooke’s slice of cork and Vesalius’s great book of anatomy to William Harvey’s beating heart, William Beaumont’s window into a living stomach, Edward Jenner’s milkmaids and Joseph Lister’s clean surgery, each one taken apart to see how it was figured out and then tested at the kitchen table with a stopwatch, a tape measure, a balloon and a notebook.

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 walks through the human body one system at a time across a school year: cells, the skeleton and muscles, the heart and blood, the lungs, digestion, the brain and nerves, the senses, and health and medicine. Each unit is built around real moments in the history of medicine: Robert Hooke looking at a thin slice of cork in 1665 and naming the tiny rooms he saw “cells,” Andreas Vesalius publishing his great illustrated anatomy in 1543, William Harvey showing in 1628 that the blood goes around and around, the army surgeon William Beaumont studying digestion through a wound in Alexis St. Martin’s side after an accident in 1822, Edward Jenner’s first vaccination in 1796, Louis Pasteur’s germs and Joseph Lister’s clean operating room.

Every lesson follows the same path. First comes **the story**: a real person, a real place and a real question. Then **how they figured it out**: what they looked at, what they measured, what they got wrong at first and what changed their minds. Then **the big idea** underneath, explained for a fifth grader. Last, the student **observes and measures** for himself or herself: a cheek cell under a microscope or magnifier, a pulse counted for 15 seconds and multiplied by 4, a breath measured in a jug of water, a reflex tested with the side of a hand, a touch map drawn with two toothpicks. Every experiment ends with numbers in the nature notebook and a sentence about what they mean.

The thread of the year is **order and design**. The body is built from the small to the large: cells make tissues, tissues make organs, organs work together in systems, and the systems work together in one living person. The student will see again and again that every part has a job, that the parts depend on one another, and that the body is made to keep itself in balance: breathing faster when running, shivering when cold, healing a cut and fighting off a germ. The last unit shows how careful observers learned to help the body do what it was made to do.

The faith thread runs underneath it all. The same God who made the living things of the field and the sea made man in His own image. “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 psalmist looked at his own body and said, “I will praise thee; for I am fearfully and wonderfully made” (Psalm 139:14). Studying the body carefully is one way of giving thanks for it, and caring for it, our own and other people’s, is one way of loving our neighbor.

WHO IT IS FOR

Written for students in grade 5 (about ages 10–11) who read on their own, can multiply and divide, read a simple bar graph and measure in centimeters and inches. A parent or teacher reads along, holds the stopwatch, helps with the experiments and supervises anything involving heat, sharp tools, food tastings or the optional cow-eye dissection. Nothing needs to be bought beyond ordinary household items, though a magnifying glass is a great help and a simple student microscope is a welcome extra.

HOW TO USE THIS COURSE

The weekly rhythm. The year has 32 lessons, one a week, in eight units of four, plus an optional ninth unit, the *Nature Lab*, which can be used any time of year. Session 1 (about 45 minutes) is the warm-up, the teaching, the worked examples and the picture study. Session 2 (about 45 minutes) is the experiment, the nature notebook and the practice. In the last week of each unit, add a third session for the unit quiz and the unit project. Families who want a one-quarter version can follow the ★ **quarter path**: the 10 lessons marked with a star, at least one from every unit, which keep the key stories and the core experiments.

The nature notebook. Use one composition book (graph paper is best) for the whole year. Every experiment ends with something drawn, counted or measured: a sketch of a cell, a labeled skeleton, a pulse table, a bar graph of breaths, a touch map of the hand. Date every page, label every column with its unit, and write one sentence saying what the numbers show. Measurements are given in metric with U.S. customary in parentheses, such as 9 meters (about 30 feet).

Experiments and safety. Each experiment names a question, a prediction, the one thing that changes (the variable), what stays the same and what is being compared (the control). A parent is nearby for every experiment. Never share mouthpieces, straws or balloons; check for food allergies before any tasting; use only the flat side of a toothpick for the touch map; never test anyone's blood; and do the optional cow-eye dissection only with a parent, gloves and a specimen from a science supplier. A student who is unwell, or who has a heart or breathing condition, skips the exercise experiments or does them gently with a parent's permission.

Worked examples and practice. Each lesson has two worked examples, solved step by step, and eight practice items. One practice item asks the student to read a data table or graph, and one asks the student to design a fair test by naming the variable and the control. Answers are in the lesson so the student can check his or her own work; a wrong answer is a reason to go back to the worked example, not a failure.

Unit quizzes and unit projects. Each unit ends with a 10-item quiz (50 points) and a unit project that pulls the unit together, such as a model cell, a jointed cardboard hand, a heart-rate investigation, a model lung, a life-size digestive path drawn on paper or a family health poster. Keep the quizzes and project pages in one folder 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 of the Flood (Genesis 6–9). The human body course rarely touches the age of the earth, but museum visits and books in the Nature Lab may use deep-time names such as "Jurassic" or "Ice Age." These 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 actually observe, and how Christians read it.

SCOPE AND SEQUENCE

Unit 1: Cells: The Body's Building Blocks (1–4)

Robert Hooke's cork and the word "cell"; looking at real cells from the inside of the cheek; how cells make tissues and tissues make organs; and the body as fearfully and wonderfully made.

Unit 2: The Skeleton and the Muscles (5–8)

Andreas Vesalius and the great anatomy book of 1543; the 206 bones of the adult skeleton; hinge, ball-and-socket and other joints; and why muscles work in pairs.

Unit 3: The Heart and the Blood (9–12)

William Harvey proves the blood goes around (1628); measuring the pulse at rest and after exercise; red cells, white cells and platelets; and "the life of the flesh is in the blood."

Unit 4: The Lungs and Breathing (13–16)

How the diaphragm moves air, shown with a model lung in a bottle; measuring lung capacity with a jug of water; how exercise changes breathing; and what smoke does to the lungs.

Unit 5: Digestion and Nutrition (17–20)

William Beaumont and Alexis St. Martin, whose healed wound opened a window into the stomach; teeth and their jobs; the 9-meter (about 30-foot) path from mouth to the end of the intestines; and eating well.

Unit 6: The Brain and the Nerves (21–24)

Reflexes and reaction time; how each side of the brain works with the opposite side of the body; how memory is built by practice; and why the body needs sleep.

Unit 7: The Senses (25–28)

The eye as a camera, studied with a model or an optional cow eye; the ear and how sound reaches it; how taste and smell work together; and a two-point touch map of the skin.

Unit 8: Health and Medicine (29–32)

Edward Jenner and the first smallpox vaccination (1796); Louis Pasteur and the germ idea; Joseph Lister and clean surgery; and handwashing and simple first aid at home.

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

Four outdoor and field-trip lessons for any season: a nature journal walk, a backyard survey, a visit to a zoo, farm or museum, and a small specimen collection, comparing the bodies of animals with our own.

MATERIALS

- **Nature notebook (a graph-paper composition book)**: One for the whole year: sketches, labeled diagrams, data tables, bar graphs and one sentence about what each experiment showed.
- **A stopwatch or a phone timer**: Used for pulse, breathing and reaction-time experiments in Units 3, 4 and 6.
- **A metric tape measure and a 30-centimeter (12-inch) ruler**: For measuring arm spans, chest size, the ruler-drop test and the 9-meter (about 30-foot) digestive path.
- **A magnifying glass; a simple student microscope if you have one**: For Hooke's cork, cheek cells and the Nature Lab. A magnifier is enough to complete every lesson.
- **A clear plastic bottle, two balloons, a straw or tube and some modeling clay**: For the model lung in Unit 4 and other small models.
- **A large jug or 2-liter bottle, a dishpan and a length of flexible tubing**: For measuring lung capacity by pushing water out of an upside-down bottle. Each person uses a clean tube or straw.
- **Cardboard, string, paper fasteners, rubber bands and tape**: For a jointed cardboard hand, muscle-pair models and the unit projects.
- **Kitchen supplies for small tests**: Cotton swabs, toothpicks, food coloring, a few foods for taste and smell tests (check for allergies first), soap and a basic first-aid kit.
- **Optional: a preserved cow eye from a science supplier, with disposable gloves and blunt scissors**: For Lesson 7.1, with a parent. A paper and magnifying-glass model of the eye works just as well.
- **Optional: one of the books or resources listed in a unit**: Never required. See the list in each unit.

GRADING

Grades come from the experiments, the nature notebook, the unit quizzes and the unit projects, because the body is learned by observing and measuring as well as by reading. An experiment whose results surprised the student but are honestly recorded and explained earns full credit.

- Experiments (prediction, careful measuring, a fair test and the explain-it step): 30%
- Nature notebook (dated pages, labeled diagrams and tables, honest records): 20%
- Unit quizzes (eight quizzes of 50 points each): 30%
- Unit projects: 20%

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

- Grade the process, not just the result. Did the student predict, name the variable and the control, measure carefully, record honestly and explain what the numbers mean?
- A notebook page earns full marks when it has a date, a title, a labeled drawing or table with units, and one sentence about what was learned.

- Unit quizzes may be done orally for a student who writes slowly; the parent writes down the answers.
- Practice items are for learning, not for grading. Check them together and go back to the worked examples when something is missed.
- The Nature Lab is optional and may be graded as extra notebook pages or not at all.

A NOTE TO PARENTS

You do not need to be a doctor or a biology teacher to teach this course. Read the story aloud together, look at the picture, and then be the student's lab partner: hold the stopwatch, read the tape measure and write down the numbers. Ask "What do you predict?", "How could we make it a fair test?" and "What do the numbers show?" Those three questions are most of what a good science teacher does.

Please preview two things. Rembrandt's *The Anatomy Lesson of Dr. Nicolaes Tulp* (1632) shows a body being studied by surgeons, and some of Vesalius's plates show the body without skin; both are great works of history and art, but you know best when your child is ready to see them. The optional cow-eye dissection in Lesson 7.1 can always be replaced by the model. Questions about growing up and the body's private parts are left to you, the parent, and are not part of this course.

Above all, the course hopes your child will come away with wonder and gratitude: wonder at a heart that beats about a hundred thousand times a day without being told, and gratitude to the God who made it. Along the way the student learns the habits that keep a body well, such as washing hands, sleeping enough, eating sensibly, moving every day and caring for others when they are hurt or sick, as the good Samaritan did.

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Unit 9: Bonus: Nature Lab (optional)

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

★ quarter path · ⏳ Thinking About Time box

UNIT 1

Cells (first look)

“I will praise thee; for I am fearfully and wonderfully made” (Psalm 139:14). This year you will study the human body, and you will begin with its smallest living parts: **cells**. In 1665 Robert Hooke sliced a piece of cork, looked at it through his microscope, and saw rows of tiny empty boxes. He called them cells. You will cut cork as he did, then make a stained slide of cells from your own cheek and find the membrane, the cytoplasm and the nucleus, just as Antonie van Leeuwenhoek and Robert Brown found the small wonders hidden in ordinary things.

Next you will see how cells are put together. Cells of one kind make a **tissue**, tissues make an **organ**, organs make an **organ system**, and all the systems make you. You will hunt for tissues in a chicken wing the way the young French doctor Xavier Bichat sorted the body’s “fabrics” around 1800. Finally you will learn the cell theory of Schleiden, Schwann and Virchow, discover why the body is built of trillions of small cells instead of a few big ones, and see how each kind of cell is shaped for its job. In every lesson you will observe, draw, measure and test like a real scientist, and you will have good reason to say with David, “marvellous are thy works.”

BEFORE YOU BEGIN

- Can multiply and divide whole numbers and simple decimals (such as 0.45 ÷ 9)
- Can measure in millimeters and centimeters with a ruler
- Knows that living things grow, need food and water, and reproduce “after their kind”
- Can record observations in a simple table

MASTERY CHECKLIST

- I can tell how Robert Hooke discovered and named cells in cork in 1665.
- I can make a stained cheek cell slide, find the cells under a microscope, and label the cell membrane, cytoplasm and nucleus.
- I can explain how a plant cell differs from an animal cell.
- I can find total magnification and use the field of view to estimate the size of a cell.
- I can put cell, tissue, organ, organ system and organism in order and name the four main kinds of tissue.
- I can state the cell theory and explain why the body is made of many small, specialized cells.

OPTIONAL BOOKS AND RESOURCES

- ***Micrographia* by Robert Hooke (free at Project Gutenberg)** (https://www.gutenberg.org/ebooks/15491): Free. Hooke’s own book from 1665. A parent can read aloud Observation XVIII on the texture of cork (Lesson 1.1) and show the plates of the flea and the fly’s eye. The old spelling is fun to puzzle out together.

- **Foldscope paper microscope** (https://foldscope.com/): A low-cost folding paper microscope that magnifies about 140×. A good choice if your family does not own a microscope, though a basic school microscope with a 40× objective shows cheek cells more clearly (Lesson 1.2).

1.1 Hooke's Cork (1665) ★

OBJECTIVES

- Tell how Robert Hooke looked at a thin slice of cork through his microscope and named the tiny boxes he saw "cells" in his book *Micrographia* (1665).
- Define cell, cell wall, microscope and magnification, and find the total magnification of a microscope by multiplying the eyepiece and the objective lens.
- Use Hooke's own count of cork cells to estimate how many cells fit in an inch and about how wide one cell is.

Warm-up. Hold a natural bottle cork (or a scrap of corkboard) in one hand and a piece of wood about the same size in the other. Which feels lighter? Squeeze each one hard. Which one gives a little and springs back? Drop both into a bowl of water and see which floats higher. Write one guess in your notebook: what might be hidden inside cork that makes it so light and springy?

Video. Coming soon. Robert Hooke, Micrographia and the cork cells, plus how a compound microscope works and how to view cork under a microscope; search history-of-science channels, Science History Institute, Royal Society, Homeschool Pop (Alternate), SciShow Kids and Moody Science classics.

KEY TERMS

cell
The smallest unit of a living thing that can carry on life. Every plant, animal and person is built of cells.

cell wall
A stiff outer layer around each plant cell that gives the cell its shape. The walls are what Hooke saw in cork.

cork
The light, springy outer bark of the cork oak tree, used for bottle stoppers and corkboards.

microscope
An instrument with one or more lenses that makes a magnified image of something too small to see well with the eye alone.

magnification
How many times bigger an image looks than the real object. A 10× lens makes things look 10 times wider.

CORE IDEAS

The story. In 1665 a young Englishman named Robert Hooke published a large book called *Micrographia*, which means "small drawings." Hooke was the Curator of Experiments for the

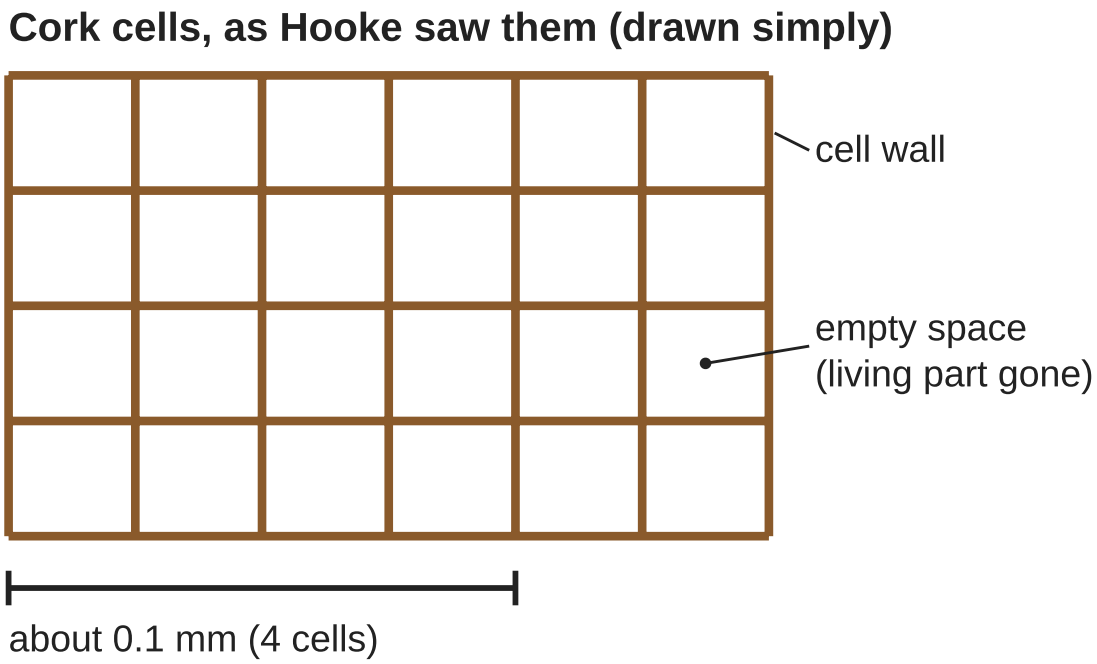
Royal Society of London, a club of men who met to test ideas about nature by experiment. His book was full of big, careful drawings of things seen through his microscope: the point of a needle, the eye of a fly, a flea, a louse and the edge of a razor. One of the plainest things in the whole book turned out to be the most important. Hooke took an ordinary piece of cork, sharpened his penknife until it was as keen as a razor, and cut a slice so thin that light could pass through it.

How they figured it out. Cork is pale, so Hooke laid his slice on a black plate to make it stand out, and he cast light onto it through a thick, rounded lens. Through the lenses he saw that the cork was not solid at all. It was full of tiny empty boxes with thin walls, rather like a honeycomb but less regular. He called the little boxes **cells**, from a Latin word for a small room. Then Hooke did what a good scientist does: he measured. He counted about 60 cells lined up in one eighteenth of an inch, which is more than a thousand cells in a single inch. He worked out that a cube of cork one inch on each side must hold more than twelve hundred million cells. And he used his discovery to explain what everyone already knew about cork: it is light, it floats, and it springs back when squeezed, because millions of tiny walled boxes are full of trapped air.

The big idea. Today we know that a **cell** is the smallest unit of a living thing that can carry on life. Every plant, animal and person is built of cells. The cork cells Hooke saw were actually dead. Cork is the outer bark of the cork oak tree, and by the time bark becomes cork, the living insides of its cells are gone. What remains are the stiff **cell walls**, the same kind of walls that hold up every plant. Hooke had found the empty rooms of a house; it would take other scientists many years to learn about the busy life that once went on inside them. In the next lessons you will see living cells from your own body.

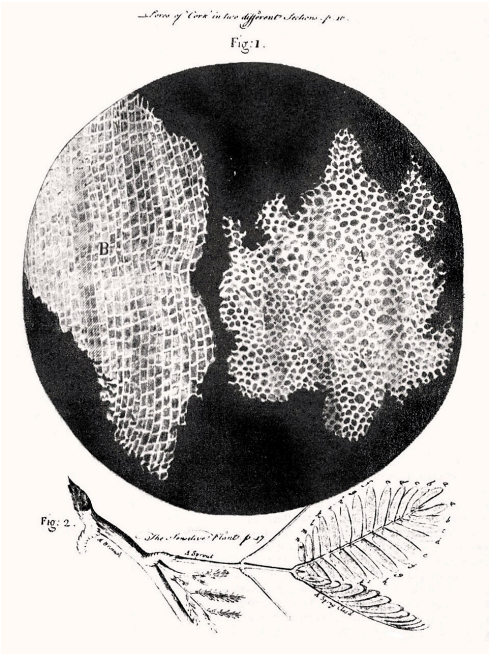
Try it and see. A **microscope** makes things look bigger because of its lenses. Most school microscopes have two lenses working together: the eyepiece you look into and an objective lens near the slide. To find the total **magnification**, multiply them. A 10× eyepiece with a 40× objective gives 10 × 40 = 400×, so a cell 0.02 millimeter wide looks 8 millimeters wide. A hand lens magnifies about 10×, enough to see the tiny holes in the end of a cork. In this lesson you will slice cork as Hooke did and test whether all that trapped air really makes it float higher than wood.

God’s handiwork. Hooke noticed something wonderful when he compared things people make with things God makes. Under his microscope, the sharp point of a fine steel needle looked blunt and rough, and a printed period looked like a smudge of ink on a rough field. But the smallest living things he examined, like the cork, a fly’s eye and the hairs on a nettle leaf, were orderly and finely made no matter how closely he looked. The more closely we study creation, the more design we find.



Cork cells drawn simply. Hooke saw rows of empty boxes. Only the walls were left; the living insides were gone.

PICTURE STUDY



The Texture of Cork, from Micrographia, Robert Hooke, 1665 · Engraving printed in a book · Published in London for the Royal Society; copies are kept in many libraries

Robert Hooke drew his own pictures for *Micrographia*, and skilled engravers cut them into copper plates for printing. Here he shows a thin slice of cork as he saw it through his microscope. One view shows the cork cut straight across, where the cells look like the

openings of a honeycomb. The other shows it cut the long way, where the same cells look like rows of little boxes stacked end to end.

This simple picture is the first drawing ever printed of the things we now call cells.

Look closely

- Find the two views of the cork. How are the shapes in one view different from the shapes in the other?
- Are all the cells exactly the same size and shape, or do they vary a little?
- Look at the walls between the cells. Are they thick or thin compared with the empty spaces?
- Hooke had no camera. What did he have to do to make a drawing this careful?

Talk about it

1. Why do you think Hooke chose the word “cell,” meaning a small room, for these boxes?
2. How would a cube shape in one view look like a long box when cut a different way? Try it with a stack of sugar cubes or blocks.
3. What would you have to draw very carefully if you wanted other scientists to trust your observations?

> **Safety first.** An adult should cut the cork and wood slices with a sharp knife or craft blade on a cutting board, cutting away from the hands. Glass slides and coverslips can break; handle them by the edges. Wipe up spilled water so no one slips.

EXPERIMENT: CORK UNDER THE LENS: DOES TRAPPED AIR MAKE CORK FLOAT HIGHER?

First you will look at cork the way Hooke did and draw what you see. Then you will run a small experiment to test Hooke’s explanation: if cork is full of tiny air-filled cells, it should float higher in water than wood of the same size.

Question: Does cork float higher than pine wood of the same size? **Prediction:** write yours before you begin. **What we change:** the material (cork or pine). **What we keep the same:** the size and shape of each piece, the water and the bowl. **What we measure:** how many millimeters of each piece stick up above the water.

You will need

- A natural cork stopper or a piece of corkboard (not a plastic stopper)
- A small block of pine wood (a scrap from a hardware store or woodshop)
- Sharp knife or craft blade and cutting board (adult use)
- Hand lens (about 10×) and a microscope if you have one, with a glass slide
- A sheet of black paper
- A clear glass or plastic bowl of water

- Metric ruler marked in millimeters
- Notebook and pencil

Steps

1. Ask an adult to cut the thinnest slice of cork possible from the end of the stopper, as thin as a sheet of paper if they can.
2. Lay the slice on black paper, just as Hooke used a black plate. Look at it with the hand lens. Draw what you see in a circle in your notebook.
3. If you have a microscope, place the slice on a slide and look at it at low power, then higher power. Hold a flashlight at the side if the light is dim. Draw the cells and write the total magnification beside your drawing.
4. Now ask the adult to cut a cube of cork and a cube of pine, each 2 centimeters (about 3/4 inch) on every side. If you cannot cut cubes, use two pieces of the same size and shape.
5. Write your prediction: which will float higher?
6. Float the cork cube in the bowl. Hold the ruler straight up beside it and measure how many millimeters stick up above the water. Record it.
7. Do the same with the pine cube. Then repeat each test two more times and record all six numbers in a table with columns for Material, Try 1, Try 2 and Try 3.
8. Find the average for each material by adding its three numbers and dividing by 3.
9. Write two sentences: Was your prediction right? How do Hooke’s cells explain your result?

Tips

- Some bottle stoppers are made of plastic or of tiny cork bits glued together. A natural cork stopper or plain corkboard works best.
- Read the ruler at eye level, not from above, for an honest measurement.
- Repeating each test three times helps you catch a mistake in one measurement.

Check your work

- I can describe what Hooke saw in cork and why he called the boxes cells.
- I can find total magnification by multiplying the eyepiece and the objective.
- I measured, recorded and averaged my results and explained them using cells.

NATURE NOTEBOOK

1. Draw your cork slice as you saw it through the lens or microscope. Label a cell wall and an empty cell, and write the magnification.
2. Copy Hooke’s count in your notebook: 60 cells in 1/18 inch. Show the multiplication that gives the number of cells in a whole inch.
3. Draw a microscope and label the eyepiece, the objective lens, the stage where the slide sits and the light. Write how to find total magnification.

From history. *Micrographia* was a best-seller in its day. In January 1665 the London diarist Samuel Pepys bought a copy and sat up until two o'clock in the morning reading it. He wrote in his diary that it was "the most ingenious book that ever I read in my life." Hooke went on to help rebuild London after the Great Fire of 1666 as a surveyor working with Christopher Wren.

WORKED EXAMPLES

Example 1. Hooke counted about 60 cork cells lined up in a row in 1/18 of an inch. About how many cells would line up in 1 inch? About how wide is each cell in millimeters? (1 inch = 25.4 millimeters)

(Use the map or drawing "Four cells of about 0.024 millimeter each make about 0.1 millimeter." shown earlier in this lesson.)

1. One inch holds 18 pieces that are each 1/18 inch long.
2. Each piece holds about 60 cells, so 1 inch holds 60 × 18 = 1,080 cells.
3. One inch is 25.4 millimeters. Share 25.4 millimeters among 1,080 cells: 25.4 ÷ 1,080 ≈ 0.024 millimeter.
4. Check: 1,080 cells × 0.024 millimeter ≈ 26 millimeters, close to 25.4. The answer makes sense.

Answer: About 1,080 cells in one inch (Hooke wrote that it was more than a thousand). Each cell is about 0.024 millimeter wide, roughly one thousandth of an inch.

Example 2. A microscope has a 10× eyepiece and a 40× objective lens. What is the total magnification? How wide will a cork cell 0.024 millimeter across look through it?

1. Total magnification is the eyepiece times the objective: 10 × 40 = 400×.
2. The image looks 400 times wider than the real cell: 0.024 × 400 = 9.6 millimeters.
3. 9.6 millimeters is almost 1 centimeter, or about 3/8 inch.

Answer: 400×. The cork cell will look about 9.6 millimeters (about 3/8 inch) wide.

PRACTICE

1. EASY What did Robert Hooke look at through his microscope, and in what book and year did he publish his drawing of it?
2. EASY Why is the word "cell" a good name for what Hooke saw?
3. EASY Were the cork cells Hooke saw alive? Explain.
4. MEDIUM A microscope has a 10× eyepiece and a 10× objective. What is the total magnification? How wide will a hair 0.08 millimeter thick look?

5. MEDIUM A student floated three cubes, each 2 centimeters on a side, and measured how much stuck up above the water:
   Cork: 1.6 cm
   Pine: 0.8 cm
   Oak: 0.4 cm
   (a) Which floated highest? (b) How many times higher did the cork float than the oak? (c) Which material probably has the most air trapped in its cells?
6. MEDIUM Sam wants to find out whether thinner slices of cork let more light through. Name the variable Sam should change, what Sam should measure, and two things Sam must keep the same.
7. HARD Using what Hooke discovered, explain in two or three sentences why cork is light and springy.
8. CHALLENGE Hooke found about 1,080 cells in a row one inch long. How many cells would cover a square one inch on each side?

COMMON MISTAKES

- Thinking Hooke saw living cells. The cork cells were dead and empty; he saw only their walls.
- Adding the two lenses to find magnification. A 10× eyepiece and a 40× objective give 10 × 40 = 400×, not 50×.
- Thinking a microscope makes the object itself bigger. The cell stays the same size; only the image you see is magnified.

> **Make it a game · Magnification Race.** Make cards for eyepieces (5×, 10×, 15×) and objectives (4×, 10×, 40×, 100×). Each player draws one of each and says the total magnification as fast as possible. Correct answers score a point; the highest magnification of the round earns a bonus point. For an extra challenge, the parent names a real size, such as a cork cell of 0.02 millimeter, and the player says how big it will look.

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

Hooke found that even a bit of tree bark is full of order and design. Two centuries later, the physicist James Clerk Maxwell had this verse carved in Latin over the doors of the Cavendish Laboratory at Cambridge, because seeking out God’s works is what scientists do.

Practice answers

1. A very thin slice of cork. He published the drawing in *Micrographia* in 1665.
2. The cork was full of tiny walled boxes, like little rooms or the openings of a honeycomb. “Cell” comes from a Latin word for a small room.
3. No. Cork is dead outer bark. The living insides of the cells were gone, and only the stiff cell walls were left.
4. 10 × 10 = 100×. The hair will look 0.08 × 100 = 8 millimeters wide.

5. (a) Cork. (b) 1.6 ÷ 0.4 = 4 times higher. (c) Cork, because more trapped air makes a material lighter for its size, so it floats higher.
6. Change: the thickness of the slice. Measure: how much light comes through (for example, whether printed letters can be read through the slice, or a light-meter reading). Keep the same: the same piece of cork, the same lamp at the same distance, the same room lighting and the same way of looking.
7. Cork is made of millions of tiny cells whose walls trap air inside. Air is very light, so cork weighs little for its size and floats high. When you squeeze cork, the trapped air is pressed into a smaller space, and when you let go it pushes the thin walls back out, so the cork springs back.
8. 1,080 rows of 1,080 cells: 1,080 × 1,080 = 1,166,400 cells, more than a million in one square inch.

1.2 Cheek Cell Slide

OBJECTIVES

- Tell how Antonie van Leeuwenhoek looked at scrapings from his own teeth in 1683 and how Robert Brown named the nucleus in 1831.
- Prepare and stain a cheek cell slide and identify the cell membrane, cytoplasm and nucleus, and tell how an animal cell differs from a plant cell.
- Use a microscope's field of view to estimate the size of a cell, and compare stained and unstained slides in a fair test.

Warm-up. Run your tongue along the inside of your cheek. It feels smooth and soft, but it is made of thousands of thin, flat cells, and some of them are rubbing off right now. Lick the back of your hand and let it dry: you have left cheek cells behind. In your notebook, guess what one of those cells looks like and draw your guess. You will check it with a microscope later.

Video. Coming soon. How to make a stained cheek cell slide and what human cheek cells look like under a microscope, plus Antonie van Leeuwenhoek and his single-lens microscopes; search microscopy and biology-lab channels, Science History Institute, Rijksmuseum Boerhaave, Homeschool Pop (Alternate), SciShow Kids and Science Max.

KEY TERMS

cell membrane
The thin, flexible outer edge of a cell that holds it together and lets some things in and out.

cytoplasm
The jelly-like material that fills the cell, where much of the cell's work is done.

nucleus
The control center of the cell, usually a round body near the middle. It holds the cell's instructions.

stain
A dye, such as iodine or methylene blue, that colors some parts of a cell more than others so they are easier to see.

field of view
The bright circle you see when you look into a microscope. The higher the magnification, the smaller the field of view.

CORE IDEAS

The story. In the Dutch town of Delft lived a cloth merchant named Antonie van Leeuwenhoek. He had no university training, but he had patient eyes and clever hands. He ground tiny glass lenses, each smaller than a pea, and mounted them in little metal plates.

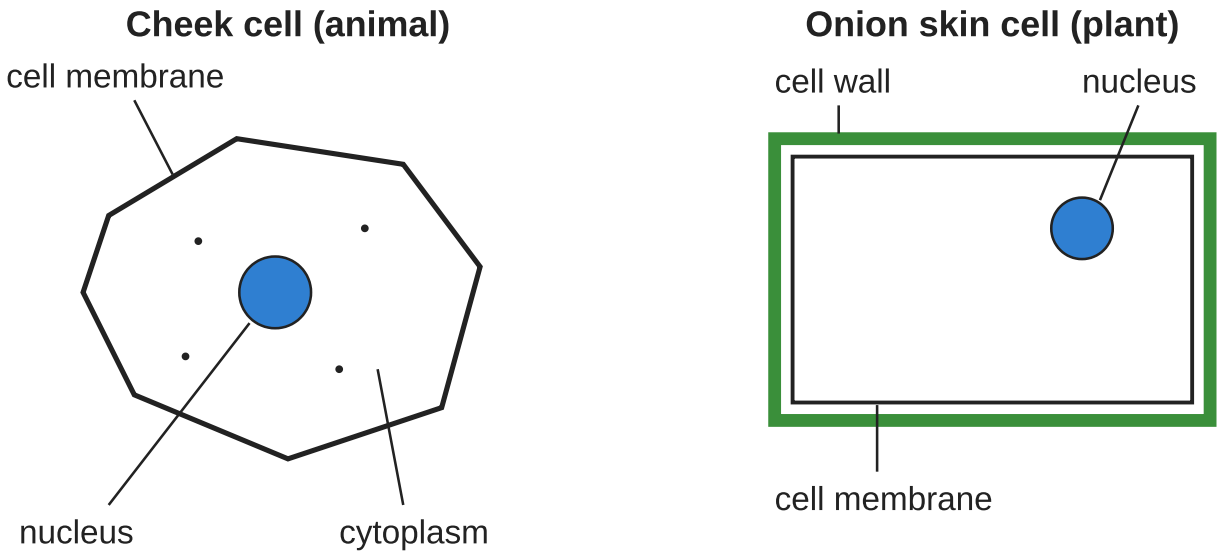
These simple microscopes could magnify more than 200 times, better than any other microscope of his day. In 1683 he scraped a little white matter from between his own teeth, mixed it with clean rainwater, and held it up to a lens. To his amazement the drop was crowded with tiny living things, darting and spinning. He described them in a letter to the Royal Society of London, with drawings. Today we know they were **bacteria**, living things far smaller than our own cells.

How they figured it out. Leeuwenhoek showed that the world is full of small living things, but seeing the parts inside a cell took much longer. In 1831 a Scottish botanist named Robert Brown was studying the leaves of orchids. In cell after cell he noticed one small round spot. He named it the **nucleus**, from a Latin word meaning “kernel,” like the kernel of a nut. Scientists soon found that nearly every living cell in plants and animals has one. Later they learned to color cells with dyes called **stains**. A stain soaks into the nucleus more than the rest of the cell, so the nucleus shows up dark and clear.

The big idea. The inside of your cheek is lined with thin, flat cells that fit together like paving stones. They rub off all the time and are replaced by new ones from below, so gently scraping a few away does not harm you. A cheek cell is a typical **animal cell**. Its outer edge is the soft **cell membrane**. Inside is the jelly-like **cytoplasm**, and near the middle is the **nucleus**, the cell’s control center, which holds the instructions the cell follows. A plant cell has these same three parts, but it also has a stiff **cell wall** outside the membrane, like the walls Hooke saw in cork. You are held up by bones, so your cells do not need stiff walls. A cheek cell is about 0.05 millimeter (about 1/500 inch) across, so about 20 of them side by side would stretch only 1 millimeter.

Try it and see. To make a slide, gently rub the inside of your cheek with a flat toothpick or clean cotton swab, smear it on a glass slide, add a drop of stain, and lay a thin coverslip on top. Start with the lowest power to find the cells, then turn to higher power. You will see flat, uneven shapes, mostly clear, with a dark dot near the middle of each. That dot is the nucleus. You may also see tiny specks clinging to the cells. Those are bacteria from your mouth, the same kind of thing Leeuwenhoek saw. Perfect round circles with thick black rings are air bubbles, not cells. To estimate a cell’s size, use the **field of view**: if the bright circle is 0.45 millimeter wide and 9 cells fit across it, each cell is about $0.45 \div 9 = 0.05$ millimeter wide.

God’s handiwork. Each tiny cheek cell, too small to see, has its own boundary, its own working space and its own instructions. It does its job, rubs away and is replaced without your ever noticing. Leeuwenhoek spent fifty years looking at small things and never ran out of new wonders to report.



A cheek cell (animal) and an onion skin cell (plant). Both have a membrane, cytoplasm and a nucleus. Only the plant cell has a stiff cell wall.

PICTURE STUDY



Portrait of Antonie van Leeuwenhoek, Jan Verkolje, about 1680–1686 · Oil on canvas · Rijksmuseum, Amsterdam

Jan Verkolje was a painter from Delft, the same town where Leeuwenhoek lived and worked. He painted this portrait when Leeuwenhoek was about fifty years old and already famous across Europe for his letters to the Royal Society. The painter shows him as a respected gentleman of Delft, dressed in fine clothes.

It is worth remembering that the man in this rich portrait did his greatest work with lenses smaller than a pea, often looking at things as ordinary as rainwater, pepper water and the

scrapings from his teeth.

Look closely

- Look at Leeuwenhoek's face. What words would you use to describe him?
- Look at his clothes and wig. What do they tell you about how people saw him?
- Find his hands. What are they doing?
- Where does the light fall brightest in the painting? Why might the painter have chosen that?

Talk about it

1. Leeuwenhoek was a cloth merchant, not a professor. What does his story teach about who can become a good scientist?
2. If an artist painted your portrait as a scientist, what tools would you want in the picture with you?

> **Safety first.** Use only your own new, clean toothpick or swab, scrape gently, and never share it. Iodine and methylene blue stain skin and clothing and are harmful if swallowed; an adult should handle the stain bottle, and you should wear old clothes. Glass slides and coverslips can break and cut; hold them by the edges. Put used swabs and toothpicks in the trash and wash your hands when you finish.

EXPERIMENT: DOES A STAIN HELP US SEE THE NUCLEUS?

You will make two cheek cell slides, one with stain and one without, and count how many cells show a clear nucleus on each. This is a fair test, so everything except the stain must be the same.

Question: Does a stain make the nucleus easier to see? **Prediction:** write yours first. **What we change:** stain or no stain. **What we keep the same:** the person, the way of scraping, the amount of liquid, the magnification and the light. **What we measure:** out of 10 cells, how many show a clear nucleus. The unstained slide is our **control**, the slide we compare against.

You will need

- Microscope with 40×, 100× and 400× settings (a 10× eyepiece with 4×, 10× and 40× objectives)
- 2 glass slides and 2 coverslips
- Flat toothpicks or clean cotton swabs
- Stain: tincture of iodine from a pharmacy, or methylene blue sold for aquarium fish
- Medicine dropper and a cup of clean water
- Paper towels
- Notebook and colored pencils

Steps

1. Label one slide “stained” and one “unstained” with a marker on the very end.
2. Gently rub the inside of your cheek with a new toothpick or swab five or six times. Smear it in a small circle in the middle of the first slide. Do the same, with a new toothpick, on the second slide.
3. On the unstained slide add one drop of water. On the stained slide add one drop of stain (an adult may add it).
4. Lower a coverslip onto each drop at a slant, touching one edge first, so it does not trap air bubbles. Blot any extra liquid at the edges with a paper towel.
5. Put the unstained slide on the stage. Start at 40× and focus, then turn to 100× and then 400×. Look at 10 cells and count how many show a clear nucleus. Record the number.
6. Repeat with the stained slide at the same magnification and with the same light. Count 10 cells and record.
7. At 400×, count how many cells fit across the field of view. If your microscope’s field at 400× is about 0.45 millimeter, divide to estimate one cell’s width.
8. Draw one stained cell large in your notebook. Label the cell membrane, cytoplasm and nucleus, and write the magnification.
9. Write your results as fractions (for example, 9 out of 10) and write two sentences answering the question.

Tips

- If you see only perfect circles with thick dark rings, those are air bubbles. Move the slide a little to find the flat, uneven cells.
- Cells often lie in clumps. Look near the edges of a clump, where single cells lie flat.
- Too much stain makes everything dark. One small drop is enough.

Check your work

- I made a cheek cell slide and found the cells under the microscope.
- I can label the cell membrane, cytoplasm and nucleus and say what each does.
- I counted and compared stained and unstained cells fairly and explained my result.

NATURE NOTEBOOK

1. Draw a cheek cell and an onion skin cell (from the figure or your own slide) side by side. Label the parts each one has and circle the part only the plant cell has.
2. Draw your microscope’s field of view as a circle with the cells you saw inside. Write the magnification and your estimate of one cell’s width.
3. Draw one of Leeuwenhoek’s tiny microscopes: a small metal plate with a bead of glass in it and a pin to hold the sample. Write one sentence about what he saw in 1683.

From history. Leeuwenhoek wrote about 190 letters to the Royal Society of London over some fifty years, all in Dutch, because he did not know Latin, the language of most scholars. The Society had his letters translated and printed, and in 1680 it made him a Fellow, a great honor for a merchant with no university degree. He made hundreds of microscopes but kept his best lens-making methods secret all his life.

WORKED EXAMPLES

Example 1. At 400×, the field of view of a microscope is about 0.45 millimeter across. A student counts 9 cheek cells lying side by side across the field. About how wide is one cheek cell? How many such cells would fit across 1 centimeter?

1. Share the width of the field among the cells: 0.45 ÷ 9 = 0.05 millimeter per cell.
2. 1 centimeter is 10 millimeters. Divide by the width of one cell: 10 ÷ 0.05 = 200.
3. Check: 200 cells × 0.05 millimeter = 10 millimeters. Correct.

Answer: One cheek cell is about 0.05 millimeter (about 1/500 inch) wide, and about 200 of them would fit across 1 centimeter (about 3/8 inch).

Example 2. A student compared two slides. On the unstained slide, 4 out of 20 cells showed a clear nucleus. On the stained slide, 18 out of 20 did. What percent showed a nucleus on each slide? What does the result show?

1. Unstained: 4 out of 20. Since 20 × 5 = 100, multiply both numbers by 5: 20 out of 100, or 20%.
2. Stained: 18 out of 20 becomes 90 out of 100, or 90%.
3. Everything else was kept the same, so the stain is the likely reason for the difference.

Answer: Unstained 20%, stained 90%. The stain made the nucleus much easier to see.

PRACTICE

1. EASY Name the three parts of a cheek cell and give the job of each.
2. EASY What did Leeuwenhoek see in 1683 when he looked at matter scraped from between his teeth? What do we call those things today?
3. EASY Who named the nucleus, in what year, and what kind of cells was he studying?
4. MEDIUM Look at the figure of the cheek cell and the onion skin cell. Which part does the onion cell have that the cheek cell does not? Why does a plant need it?
   (Use the map or drawing "Animal cell and plant cell compared." shown earlier in this lesson.)
5. MEDIUM This table shows the field of view of one microscope at three settings:
   40× : 4.5 mm
   100× : 1.8 mm

400× : 0.45 mm
(a) What happens to the field of view as the magnification goes up? (b) How many times wider is the field at 100× than at 400×? (c) How many times wider at 40× than at 400×?

6. MEDIUM On a slide you see a perfectly round circle with a thick black ring and an empty center. Is it a cell? How can you tell?
7. HARD Design a fair test to find out whether iodine or methylene blue makes the nucleus easier to see. Name what you change, what you keep the same (at least three things), what you measure, and the control.
8. CHALLENGE A cheek cell is about 0.05 millimeter wide. A bacterium on it is about 0.001 millimeter long. How many bacteria lined up end to end would stretch across one cheek cell? Why did Leeuwenhoek need such strong lenses to see them?

COMMON MISTAKES

- Thinking air bubbles are cells. Bubbles are perfect circles with thick black rings; cells are flat, uneven and have a nucleus.
- Thinking cells are naturally blue or brown. The color comes from the stain; living cheek cells are nearly clear.
- Thinking animal cells have cell walls. Only plant cells (and some other living things) have stiff cell walls; animal cells have just a soft membrane.

Make it a game · Microscope Detective. The parent describes something a student might see on a slide, such as “a perfect circle with a thick black ring,” “a dark dot in the middle of a flat shape,” “tiny moving specks,” or “a stiff box with a thick outline.” The student names it: air bubble, nucleus, bacteria or plant cell wall. Each correct answer earns a point. Switch roles and let the student describe for the parent.

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

God hid whole worlds of small wonders in a drop of water and a scraping from a cheek. Searching them out with patience, as Leeuwenhoek did, is an honor.

Practice answers

1. Cell membrane: the thin outer edge that holds the cell together and controls what goes in and out. Cytoplasm: the jelly-like filling where much of the cell’s work is done. Nucleus: the control center that holds the cell’s instructions.
2. Great numbers of tiny living things moving in the drop. Today we call them bacteria.
3. Robert Brown, a Scottish botanist, in 1831. He was studying cells in orchid leaves.
4. The cell wall. A plant has no bones, so stiff cell walls give each cell its shape and help hold the whole plant up.
5. (a) It gets smaller: you see a smaller area, but it looks bigger. (b) 1.8 ÷ 0.45 = 4 times wider. (c) 4.5 ÷ 0.45 = 10 times wider. (These match the magnifications: 400 ÷ 100 = 4 and 400 ÷ 40 = 10.)

6. Probably not. It is most likely an air bubble. Air bubbles are perfectly round with thick dark edges and no nucleus. Cheek cells are flat, uneven shapes with a thin edge and a dark nucleus.
7. Change: the kind of stain (iodine or methylene blue). Keep the same: the person giving the cells, the way of scraping, one drop of stain, the same microscope at the same magnification, the same light, and the same number of cells counted. Measure: how many cells out of 20 show a clear nucleus on each slide. Control: a third slide with plain water and no stain.
8. 0.05 ÷ 0.001 = 50 bacteria. Bacteria are far smaller than our cells, so they can be seen only with a lens that magnifies them hundreds of times. Leeuwenhoek’s lenses magnified more than 200 times, enough to see them moving.

1.3 Tissues and Organs

OBJECTIVES

- Tell how Xavier Bichat, a young French doctor working around 1800, showed that the body is built from a small number of different tissues.
- Name the four main kinds of tissue (epithelial, connective, muscle and nervous) and give an example and a job for each.
- Put the levels of the body in order (cell, tissue, organ, organ system, organism) and sort real examples into the right level.

Warm-up. Look closely at a piece of cloth, such as a dish towel or the sleeve of a shirt, with a hand lens. You will see that it is woven from many threads lying side by side. Now look at the back of your hand. Can you find places where the skin bends, where a vein shows through, or where a tendon moves when you wiggle your fingers? Write a guess: is your hand made of one material or several?

Video. Coming soon. Levels of organization in the human body (cells, tissues, organs, organ systems) and the four basic tissue types for kids; search Homeschool Pop (Alternate), SciShow Kids, Science Max, Crash Course Kids style channels and university histology microscope tours.

KEY TERMS

tissue
A group of similar cells working together to do one job, such as muscle tissue that pulls or nervous tissue that carries messages.

organ
A body part made of two or more kinds of tissue working together to do a job, such as the heart, stomach, brain or skin.

organ system
A group of organs working together for one big task, such as the digestive system, which breaks down food.

organism
A whole living thing, such as a person, a dog or an oak tree.

connective tissue
Tissue that supports, joins and protects other parts of the body. Bone, fat, tendons and blood are all connective tissues.

CORE IDEAS

The story. Around the year 1800, a young French doctor named Marie-François-Xavier Bichat worked at the Hôtel-Dieu, the great old hospital of Paris beside the cathedral of

Notre-Dame. Bichat wanted to understand what the body is really made of. He noticed that the same kinds of material show up again and again in different organs. The thin, smooth lining of the chest looked and behaved like the lining of the belly. The tough, white cords that tie muscles to bones were alike all over the body. He called each of these materials a **tissue**, from a French word meaning “woven cloth,” because the body seemed to be sewn together from many different fabrics.

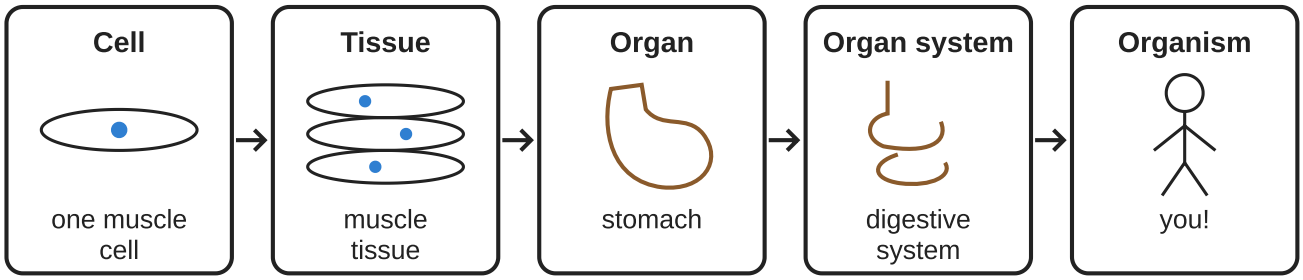
How they figured it out. Bichat did not trust the microscopes of his day, so he tested tissues another way. He dried them, boiled them, soaked them in water, acids and other liquids, and watched what each one did. A tissue that acted the same way under every test, no matter which organ it came from, was the same tissue. By this patient sorting he counted 21 kinds of tissue and described them in his book *General Anatomy* in 1801. He died the next year, only 30 years old, but his idea lived on. A few decades later, better microscopes showed what Bichat could not see: every tissue is made of cells.

The big idea. Your body is built in levels, like letters making words, words making sentences and sentences making a book. **Cells** of the same kind work together as a **tissue**. Two or more tissues work together as an **organ**. Organs work together as an **organ system**. And all the systems together make the whole **organism**: you. Scientists today group tissues into four main kinds. **Epithelial tissue** covers and lines, like your skin and the inside of your cheek. **Connective tissue** supports and joins, like bone, fat, tendons and even blood. **Muscle tissue** pulls to make things move. **Nervous tissue** carries messages, like the brain and nerves.

Try it and see. Your stomach is a good example of an organ, because it uses all four kinds of tissue. Epithelial tissue lines the inside and makes juices that help break down food. Layers of muscle tissue in the wall squeeze and churn the food. Connective tissue holds the layers together and carries blood vessels. Nervous tissue tells the muscles when to squeeze. The stomach is one organ in the **digestive system**, along with the mouth, esophagus, intestines and liver. You can find the same kinds of tissue in a chicken wing from the grocery store: skin, fat, muscle, tendon and bone. In this lesson you will find them and test one way two of them differ.

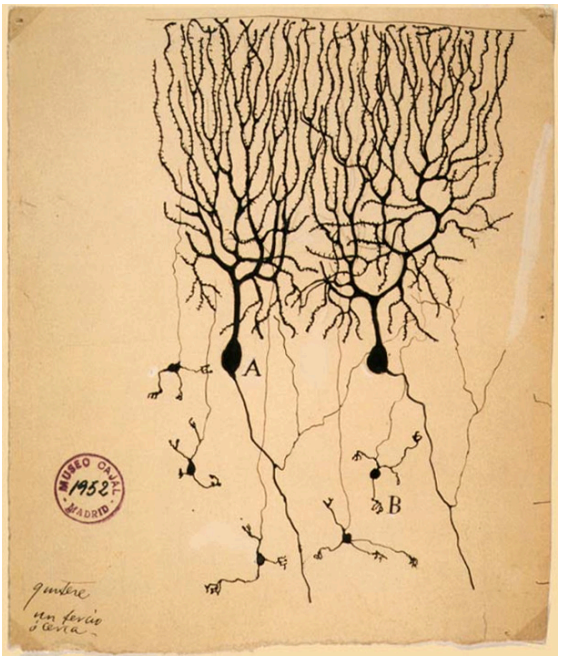
In the world today. The study of tissues is called **histology**. Doctors who study thin, stained slices of tissue under the microscope help find out what is wrong when someone is sick. The largest organ of your body is one you can see: your skin. The largest organ inside the body is the liver, which in a grown-up weighs about 1.5 kilograms (about 3.3 pounds).

God’s handiwork. Job said to God, “Thou hast clothed me with skin and flesh, and hast fenced me with bones and sinews” (Job 10:11). Long before Bichat, Job knew that the body is made of different materials fitted together. Every tissue has its place and its job, and none can say to another, “I have no need of thee.”



Levels of the body, from smallest to largest. Each level is built from the one before it.

PICTURE STUDY



Purkinje Cells and Granule Cells from a Pigeon's Brain, Santiago Ramón y Cajal, 1899 · Ink and pencil on paper · Instituto Cajal, Madrid

Santiago Ramón y Cajal was a Spanish doctor who wanted to be an artist when he was a boy. His father wanted him to study medicine, and in the end he became both a great scientist and a fine artist. He colored thin slices of nervous tissue with a special silver stain that turned a few whole nerve cells black, then drew exactly what he saw through the microscope, branch by branch.

This drawing shows nervous tissue from the part of a pigeon's brain that helps control balance and movement. Cajal's careful drawings helped show that nervous tissue is made of separate cells, just like every other tissue. In 1906 he shared the Nobel Prize for his work.

Look closely

- Find the large cells labeled A. What do their branches remind you of?
- Find the small cells labeled B. How are they different from the large cells?

- Follow one long, thin line from a cell. Where do you think it might carry a message?
- Cajal drew with pen and pencil, not a camera. What do you notice about how carefully he drew each branch?

Talk about it

1. Nervous tissue carries messages. How might all those branches help one cell receive messages from many other cells?
2. Why might a scientist who is also a good artist be able to teach others what he has seen?

> **Safety first.** Raw chicken can carry germs. Work on a washable tray or cutting board, keep the chicken away from other food, and wash your hands, tools and surfaces with hot, soapy water when you finish. An adult should use the knife or kitchen scissors. Do not touch your face while handling raw meat. Throw the chicken away afterward; do not cook or eat it.

EXPERIMENT: TISSUE HUNT IN A CHICKEN WING

A chicken wing from the grocery store is a small organism's limb, and it holds several kinds of tissue you can see without a microscope. You will find and sort them, then run a quick test of one way two tissues differ.

Question: Does fat tissue float in water while muscle tissue sinks? **Prediction:** write yours first. **What we change:** the kind of tissue. **What we keep the same:** the size of each piece, the same cup and the same water. **What we measure:** whether each piece floats or sinks.

You will need

- One raw chicken wing
- Cutting board or tray, kitchen scissors or a small sharp knife (adult use)
- Disposable gloves (optional)
- Toothpicks for pointing and lifting
- Hand lens
- Two clear cups of water at room temperature
- Paper towels, dish soap and hot water for cleanup
- Notebook and pencil

Steps

1. Look at the outside of the wing with the hand lens. Find the skin and the bumps where feathers grew. Skin is epithelial tissue on the outside, with connective tissue beneath it.
2. With an adult, cut and peel back the skin. Look for yellow fat beneath it. Fat is a connective tissue.
3. Find the pink muscle. Notice how it is made of long strands running the same way. Gently pull a strand apart with toothpicks.

4. Follow a muscle toward a joint. Find the shiny white cord at its end. That is a tendon, another connective tissue, which ties muscle to bone.
5. Find the bone under the muscle. Bone is a hard connective tissue. If the bone is cut, look for the softer, darker middle.
6. Look for thin, white, threadlike strands running alongside the muscles. These may be nerves, made of nervous tissue. (They are hard to find; it is fine if you cannot.)
7. Now the test. With the adult's help, cut a piece of fat and a piece of muscle, each about 1 centimeter (about 3/8 inch) across. Drop each into its own cup of water and record whether it floats or sinks.
8. Repeat the test with a second pair of pieces to check your result.
9. Make a chart with columns for Tissue, Kind of tissue (epithelial, connective, muscle or nervous), What it looks like, and Its job. Fill in a row for each tissue you found.
10. Clean up carefully and wash your hands well.

Tips

- Fat is lighter for its size than water, so it floats. Muscle is a little heavier for its size than water, so it sinks.
- A wing is a limb, which is made of several organs: skin, muscles and bones each count as organs.
- Draw as you go. A quick sketch will help you remember where each tissue was.

Check your work

- I found at least four different tissues in the chicken wing and sorted them into the four main kinds.
- I tested whether fat and muscle float or sink and recorded my results fairly.
- I can explain the difference between a tissue and an organ.

NATURE NOTEBOOK

1. Draw the levels chain from cell to organism with your own example at each level, such as nerve cell, nervous tissue, brain, nervous system, you.
2. Draw a cross-section of the chicken wing showing skin, fat, muscle, tendon and bone. Label each and write its tissue type.
3. Make a four-box chart with one box for each tissue type. In each, draw one example from your own body and write its job.

> **From history.** The word **histology**, the study of tissues, comes from the Greek word *histos*, meaning a web or a woven cloth. It was coined less than twenty years after Bichat's death, and it carries his picture of the body as a set of finely woven fabrics. Today every medical student studies histology, looking at stained slices of tissue under the microscope.

WORKED EXAMPLES

Example 1. Sort these into the correct level and put them in order from smallest to largest: the heart, a dog, one heart muscle cell, the circulatory system, heart muscle tissue.

(Use the map or drawing "Use the levels chain to sort any example." shown earlier in this lesson.)

1. One heart muscle cell is a single cell, the smallest level.
2. Heart muscle tissue is many heart muscle cells working together, so it is a tissue.
3. The heart is made of muscle, connective, epithelial and nervous tissue, so it is an organ.
4. The circulatory system is the heart together with the blood vessels, so it is an organ system.
5. A dog is a whole living thing, an organism.

Answer: One heart muscle cell (cell) → heart muscle tissue (tissue) → the heart (organ) → the circulatory system (organ system) → a dog (organism).

Example 2. This table gives the approximate mass of some organs in a grown-up:
Liver: 1.5 kg
Brain: 1.4 kg
Heart: 0.3 kg
One kidney: 0.15 kg
(a) How many times heavier is the liver than the heart? (b) How many times heavier is the heart than one kidney? (c) About how many pounds is the brain? (1 kg ≈ 2.2 lb)

1. (a) Divide: 1.5 ÷ 0.3 = 5.
2. (b) Divide: 0.3 ÷ 0.15 = 2.
3. (c) Multiply: 1.4 × 2.2 = 3.08, about 3 pounds.

Answer: (a) The liver is about 5 times heavier than the heart. (b) The heart is about 2 times heavier than one kidney. (c) The brain is about 3 pounds.

PRACTICE

1. EASY List the five levels of the body in order from smallest to largest.
2. EASY Name the four main kinds of tissue and give one example of each.
3. EASY Who was Xavier Bichat, and why did he call the body's materials "tissues"?
4. MEDIUM Sort each into cell, tissue, organ or organ system: (a) a nerve cell, (b) the skin, (c) blood, (d) the digestive system, (e) the stomach.
5. MEDIUM A student tested pieces of chicken tissue of the same size in water and recorded: Fat: floats (try 1), floats (try 2)

Muscle: sinks (try 1), sinks (try 2)
Bone: sinks (try 1), sinks (try 2)
(a) Which tissue is lighter for its size than water? (b) Why did the student do two tries? (c) Fat and bone are both connective tissue. Does that mean all connective tissues act alike?

6. MEDIUM Name the kind of tissue that does each job: (a) lines the inside of your mouth, (b) carries messages from your toe to your brain, (c) ties a muscle to a bone, (d) squeezes to make your heart beat.
7. HARD Mia wants to test whether chicken skin or chicken muscle stretches farther before tearing. Name what she changes, what she measures, and three things she must keep the same.
8. CHALLENGE Explain in two or three sentences why the stomach could not do its job if it were made of only one kind of tissue.

COMMON MISTAKES

- Mixing up tissues and organs. A tissue is a group of similar cells; an organ is made of two or more kinds of tissue working together.
- Thinking blood and bone are not tissues. Both are connective tissues, even though one is liquid and the other is hard.
- Thinking organs are only inside the body. The skin is an organ, and it is the largest one you have.

> **Make it a game · Level Up!.** The parent calls out a body part, such as “a single skin cell,” “the brain,” “fat,” “the respiratory system,” or “a horse.” The student answers with its level (cell, tissue, organ, organ system or organism) and scores a point. For a bonus point, the student names the kind of tissue (epithelial, connective, muscle or nervous) whenever the answer is a tissue. First to ten points wins.

> **Scripture.** “But now hath God set the members every one of them in the body, as it hath pleased him.” (1 Corinthians 12:18, KJV)

Paul uses the body, with its many parts each doing its own job, as a picture of the church. Tissues and organs show the same truth: every part has its place, and the whole body needs them all.

Practice answers

1. Cell, tissue, organ, organ system, organism.
2. Epithelial (skin, the lining of the cheek), connective (bone, fat, tendon, blood), muscle (the muscle in your arm or heart), nervous (brain, nerves).
3. He was a young French doctor in Paris around 1800 who sorted the body’s materials into 21 kinds. He called them tissues from a French word for woven cloth, because the body seemed to be made of different fabrics.
4. (a) Cell. (b) Organ (the largest organ of the body). (c) Tissue (a connective tissue). (d) Organ system. (e) Organ.

5. (a) Fat. (b) To check that the first result was not a mistake; repeating makes the result more trustworthy. (c) No. Connective tissues share the job of supporting and joining, but they can be very different: fat is soft and floats, while bone is hard and sinks.
6. (a) Epithelial. (b) Nervous. (c) Connective (a tendon). (d) Muscle.
7. Change: the kind of tissue (skin or muscle). Measure: how far each strip stretches, in millimeters, before it tears. Keep the same: the length and width of each strip, the way she pulls (for example, the same slow speed or the same weight hung on it), the same chicken, and the same temperature. She should also repeat each test more than once.
8. The stomach has several jobs that need different tissues. Epithelial tissue lines it and makes digestive juices, muscle tissue churns the food, connective tissue holds the layers together and carries blood, and nervous tissue tells the muscles when to work. With only one kind of tissue, some of these jobs would not get done.

1.4 “Fearfully and Wonderfully Made”

OBJECTIVES

- State the three parts of the cell theory and tell how Schleiden, Schwann and Virchow helped build it between 1838 and 1855.
- Explain how the shapes of red blood cells, nerve cells, muscle cells and skin cells fit their jobs, and why the body is made of many small cells instead of a few large ones.
- Calculate surface area, volume and their ratio for cubes, and use doubling to show how one cell can become many.

Warm-up. Read Psalm 139:14 aloud: “I will praise thee; for I am fearfully and wonderfully made: marvellous are thy works; and that my soul knoweth right well.” Then make a quick list of everything your body has done in the last five minutes without your having to think about it: breathing, blinking, your heart beating, keeping warm. Next to each, guess what kind of cell might be doing that work.

Video. Coming soon. Cell theory history (Schleiden, Schwann, Virchow), specialized human cells such as red blood cells, nerve cells and muscle cells, and why cells are small (surface area to volume, agar or gelatin cube diffusion lab); search Homeschool Pop (Alternate), SciShow Kids, Science Max, Moody Science classics and biology-teacher demonstration channels.

KEY TERMS

cell theory
The foundation of biology: all living things are made of cells, the cell is the basic unit of life, and every cell comes from another cell.

specialized cell
A cell with a special shape and parts that suit it for one job, such as a nerve cell or a red blood cell.

cell division
The way one cell splits to become two new cells. It is how the body grows and repairs itself.

surface area
The total area of the outside of an object. For a cell, it is the size of the membrane through which food, water and oxygen come in.

volume
The amount of space an object takes up. For a cell, it is the amount of living material that must be fed.

CORE IDEAS

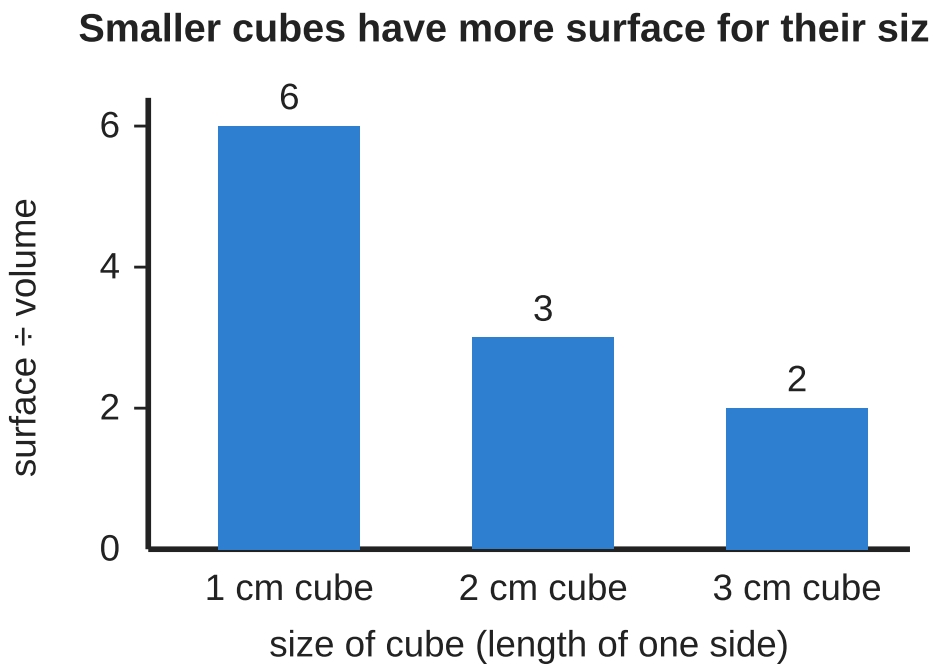
The story. Long ago King David, the shepherd who became king of Israel, sang a song to God about his own body. “For thou hast possessed my reins: thou hast covered me in my mother’s womb,” he wrote. “I will praise thee; for I am fearfully and wonderfully made” (Psalm 139:13–14). David had no microscope. He could not have known that his body was built of trillions of tiny living cells. Yet the more scientists have learned about cells, the truer his words have proved.

How they figured it out. After Hooke named cells and Brown found the nucleus, scientists began to see a pattern. In 1838 the German botanist Matthias Schleiden said that every part of a plant is made of cells. The next year, in 1839, his friend Theodor Schwann, a German scientist and devout Christian, showed with his microscope that animals are made of cells too: skin, muscle, cartilage, nerves and more. Then in 1855 a German doctor named Rudolf Virchow added the last piece: new cells do not appear from nothing. Every cell comes from a cell that was there before it. Together these ideas are called the **cell theory**: (1) all living things are made of cells, (2) the cell is the basic unit of life, and (3) every cell comes from another cell.

The big idea. Scientists estimate that your body has about 30 trillion cells of a few hundred different kinds, and each kind is shaped for its job. **Red blood cells**, the most numerous of all, are tiny round disks thinner in the middle, about 0.008 millimeter across, so they can bend and squeeze through the narrowest blood vessels carrying oxygen. **Nerve cells** have long, thin fibers like wires; the longest run from the bottom of your spine to your toes, about 1 meter (about 3 feet). **Muscle cells** are long and can shorten to pull. **Skin cells** are flat and fit together tightly like tiles on a roof. These are called **specialized cells**. The body keeps renewing many of them by **cell division**. A red blood cell lives about 120 days, and your body makes about 2 million new ones every second. You yourself began as a single cell, which divided again and again, just as Virchow said, until you were the person you are now.

Try it and see. Why is the body made of trillions of small cells instead of a few giant ones? Everything a cell needs, such as food, water and oxygen, must come in through its outer membrane, its **surface**. Everything inside, its **volume**, needs to be fed. When something gets bigger, its volume grows much faster than its surface. A cube 1 centimeter on a side has 6 square centimeters of surface for 1 cubic centimeter of volume. A cube 3 centimeters on a side has 54 square centimeters of surface but 27 cubic centimeters of volume, only 2 squares of surface for each cube inside. A giant cell would starve in the middle. In this lesson you will see this with gelatin cubes soaked in colored water: the color reaches the center of a small cube, but not of a big one. An elephant does not have bigger cells than a mouse; it simply has many more of them.

God’s handiwork. “Fearfully” here means with awe. David looked at his own body with awe, and so may we. Every one of your cells holds its own instructions, makes its own energy, repairs itself and works with its neighbors. Each kind is shaped exactly for its task, and all of them together make one living person, made in the image of God (Genesis 1:27).



As a cube gets bigger, it has less surface for each unit of volume inside. Small cells can feed every part of themselves.

PICTURE STUDY



Praying Hands (Study of the Hands of an Apostle), Albrecht Dürer, 1508 · Brush and gray ink heightened with white on blue prepared paper · Albertina, Vienna

Albrecht Dürer of Nuremberg was one of the greatest artists of Germany. In 1508 he was painting a large altarpiece for a merchant of Frankfurt named Jakob Heller, and he made careful studies on blue paper of the heads, hands and robes of the apostles. This is his study

for the hands of one apostle, who looks up in prayer. The altarpiece itself was later destroyed by fire, but this drawing survived and became one of the most loved pictures in the world.

A popular story says the hands belonged to Dürer's brother, but there is no record of it. What we do know is that Dürer studied real hands with a scientist's patience.

Look closely

- Find the veins on the backs of the hands. What tissue are they carrying?
- Look at the knuckles and the creases in the skin. Where do the fingers bend?
- Find where Dürer used white to show light. Which parts of the hands stand out most?
- Count the fingers you can see. Which ones are hidden?

Talk about it

1. Name all the tissues you think are working inside these hands: skin, muscle, bone, tendon, nerve, blood. Which of the four tissue types is each one?
2. Why might an artist choose hands at prayer to show both the wonder of the body and the One who made it?
3. Look at your own hands. What can they do that no machine you know of can do as well?

> **Safety first.** An adult should pour the hot water to dissolve the gelatin and should cut the cubes with a knife. Food coloring stains skin, clothes and counters; work on a tray and wear old clothes. Do not eat the gelatin after the experiment.

EXPERIMENT: WHY ARE CELLS SMALL? THE GELATIN CUBE TEST

In a living cell, food and oxygen must soak in from the outside. You will use cubes of gelatin as model cells and colored water as the food soaking in, to see whether small cubes or big cubes get "fed" all the way to the center.

Question: Does colored water reach the center of small gelatin cubes more completely than big ones? **Prediction:** write yours first. **What we change:** the size of the cube. **What we keep the same:** the gelatin batch, the strength of the colored water, the soaking time and the temperature. **What we measure:** how deep the color soaks in and how wide the uncolored center is.

You will need

- Two packets of plain, unflavored gelatin and water, mixed by the directions on the box
- A small square or loaf pan, so the gelatin sets at least 3 centimeters (about 1 1/4 inches) deep
- Knife and cutting board (adult use) and a metric ruler
- Dark food coloring (blue or green works well) and a bowl of water
- Spoon, paper towels and a tray

- Notebook and pencil

Steps

1. With an adult, make the plain gelatin by the box directions, pour it into the pan, and chill it until firm, a few hours or overnight.
2. Cut three cubes: 1 centimeter, 2 centimeters and 3 centimeters on each side. Measure carefully with the ruler.
3. Before soaking, work out each cube's surface area (6 × side × side), volume (side × side × side) and surface ÷ volume. Record them in a table.
4. Mix a strong batch of colored water, about 10 drops of food coloring in 1 cup (about 250 milliliters) of water.
5. Write your prediction. Then gently place all three cubes in the colored water at the same moment, and start a timer.
6. After 2 hours, lift the cubes out with a spoon and blot them dry.
7. Have the adult cut each cube in half through the middle. Measure how deep the color soaked in from the edge, and how wide the uncolored center is.
8. Record your results and draw each cut cube full size, coloring in what you see.
9. Write two sentences: Which cube was "fed" best? What does this tell you about why living cells are small?

Tips

- Color moves into gelatin slowly. If the color has barely soaked in after 2 hours, put the bowl in the refrigerator and check again after a full night.
- Use the same bowl for all the cubes so they soak in exactly the same water.
- Your numbers will not be the same as anyone else's. What matters is whether the pattern is the same.

Check your work

- I calculated the surface area, volume and ratio for three cubes.
- I measured how far the color soaked in and how wide the center stayed clear, and recorded it fairly.
- I can explain why the body is made of many small cells instead of a few giant ones.

NATURE NOTEBOOK

1. Draw four specialized cells: a red blood cell, a nerve cell, a muscle cell and a flat skin cell. Under each, write its job and how its shape helps.
2. Copy Psalm 139:14 in your best handwriting and decorate the border with drawings of cells from this unit.
3. Draw your three cut gelatin cubes and shade the colored part. Write the surface ÷ volume ratio under each.

From history. Theodor Schwann made more than one great discovery. In 1836, while studying digestion, he found pepsin, a substance in the stomach that helps break down the meat and other proteins we eat. The cells that wrap around many nerve fibers are still called Schwann cells in his honor. Schwann spent most of his later life teaching in Belgium and remained a faithful Christian all his life.

WORKED EXAMPLES

Example 1. Find the surface area, the volume and the surface area ÷ volume for cubes 1 cm, 2 cm and 3 cm on a side. Which cube has the most surface for its size?

(Use the map or drawing "Surface area ÷ volume drops as the cube grows." shown earlier in this lesson.)

1. A cube has 6 square faces. Surface area = 6 × side × side. Volume = side × side × side.
2. 1 cm cube: surface 6 × 1 × 1 = 6 square cm; volume 1 × 1 × 1 = 1 cubic cm; ratio 6 ÷ 1 = 6.
3. 2 cm cube: surface 6 × 2 × 2 = 24 square cm; volume 2 × 2 × 2 = 8 cubic cm; ratio 24 ÷ 8 = 3.
4. 3 cm cube: surface 6 × 3 × 3 = 54 square cm; volume 3 × 3 × 3 = 27 cubic cm; ratio 54 ÷ 27 = 2.

Answer: The ratios are 6, 3 and 2. The smallest cube has the most surface for its size, so food and oxygen can reach all of it most easily. That is why cells are small.

Example 2. One cell divides into 2. Each of those divides, making 4, and so on. How many cells are there after 10 rounds of division? After 20 rounds?

1. Each round doubles the number: 1, 2, 4, 8, 16, 32, 64, 128, 256, 512, 1,024.
2. After 10 rounds there are 1,024 cells.
3. Ten more rounds doubles 1,024 ten more times, which is the same as multiplying by 1,024 again: 1,024 × 1,024 = 1,048,576.

Answer: 1,024 cells after 10 rounds and 1,048,576 (more than a million) after 20 rounds. Doubling grows very fast, which is how one cell can become a whole body.

PRACTICE

1. EASY State the three parts of the cell theory.
2. EASY Match each cell to the shape that fits its job: red blood cell, nerve cell, skin cell, muscle cell. Shapes: (a) long and able to shorten, (b) flat and fitted tightly like tiles, (c) a small bendable disk, (d) long and thin like a wire.

3. EASY Who showed in 1839 that animals are made of cells, and who said in 1855 that every cell comes from a cell?
4. MEDIUM Your body makes about 2 million new red blood cells every second. About how many does it make in one minute?
5. MEDIUM In a gelatin cube test, color soaked 0.5 cm in from every side of each cube. The results:
   1 cm cube: colored all the way through
   2 cm cube: clear center 1 cm wide
   3 cm cube: clear center 2 cm wide
   (a) Which cube was colored all the way through? (b) Show why the 3 cm cube has a clear center 2 cm wide. (c) What does this suggest about a giant cell?
6. MEDIUM Leo wants to test whether a longer soaking time lets the color soak deeper into gelatin cubes. What should he change, what should he measure, and what three things should he keep the same?
7. HARD Find the surface area, volume and surface ÷ volume of a cube 4 cm on a side. Does it continue the pattern of the 1, 2 and 3 cm cubes?
8. CHALLENGE An elephant is far bigger than a mouse. Are its cells far bigger too? Explain using what you learned about surface and volume.

COMMON MISTAKES

- Thinking all cells look alike. Your body has a few hundred kinds of cells, each shaped for its job.
- Thinking bigger animals have bigger cells. A large animal has more cells, not larger ones.
- Thinking new cells can appear from nothing. Every cell comes from a cell that divided, as Virchow taught.

> **Make it a game · Cell Job Charades.** Write the names of cells on slips of paper: red blood cell, nerve cell, muscle cell, skin cell, cheek cell, cork cell. A player draws a slip and acts out the cell’s shape and job without words, such as squeezing through a narrow space for a red blood cell or sending a message down a long line for a nerve cell. The others guess. The guesser who is right must say one fact about that cell to score a point.

> **Scripture.** “I will praise thee; for I am fearfully and wonderfully made: marvellous are thy works; and that my soul knoweth right well.” (Psalm 139:14, KJV)

David did not know about cells, but he knew his body was the work of God. Every discovery in this unit, from Hooke’s cork to the 30 trillion cells in your body, gives one more reason to say with him, “marvellous are thy works.”

Practice answers

1. (1) All living things are made of cells. (2) The cell is the basic unit of life. (3) Every cell comes from another cell.

2. Red blood cell: (c). Nerve cell: (d). Skin cell: (b). Muscle cell: (a).
3. Theodor Schwann showed animals are made of cells (1839). Rudolf Virchow said every cell comes from a cell (1855).
4. 2 million × 60 = 120 million red blood cells in one minute.
5. (a) The 1 cm cube, because its center is only 0.5 cm from the surface. (b) 3 cm − 0.5 cm (one side) − 0.5 cm (other side) = 2 cm. (c) In a giant cell, food and oxygen soaking in from the surface would not reach the middle, so the center would starve.
6. Change: the soaking time (for example, 1 hour, 2 hours and 4 hours). Measure: how deep the color soaks in, in millimeters. Keep the same: the size of the cubes, the same gelatin batch, the strength of the colored water and the temperature.
7. Surface: 6 × 4 × 4 = 96 square cm. Volume: 4 × 4 × 4 = 64 cubic cm. Ratio: 96 ÷ 64 = 1.5. Yes, the ratio keeps going down (6, 3, 2, 1.5) as the cube gets bigger.
8. No. An elephant’s cells are about the same size as a mouse’s; the elephant simply has many more of them. If cells grew very large, their volume would grow much faster than their surface, and food and oxygen coming through the membrane could not reach the middle fast enough. So big animals are made of more cells, not bigger ones.

Unit 1 review

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

1. (5 pts) Who first named cells, in what year, and what was he looking at? Why did he choose the word “cell”?
2. (5 pts) A microscope has a 10× eyepiece and a 40× objective. (a) What is the total magnification? (b) How wide will a cell 0.02 millimeter across look?
3. (5 pts) Hooke counted about 60 cork cells in 1/18 of an inch. About how many cells line up in one inch? Were these cells alive?
4. (5 pts) Draw or describe a cheek cell and label its three parts. Give the job of each part.
5. (5 pts) At 400× the field of view is 0.45 millimeter wide, and 9 cheek cells fit across it. About how wide is one cell?
6. (5 pts) You want to know whether a stain makes the nucleus easier to see. Name what you change, the control, what you measure, and two things you keep the same.
7. (5 pts) Put these in order from smallest to largest and name each level: the stomach, you, a muscle cell, the digestive system, muscle tissue.
8. (5 pts) Name the four main kinds of tissue, give the job of each, and give one example of each.
9. (5 pts) State the three parts of the cell theory, and name one scientist who helped build it.
10. (5 pts) Find surface area ÷ volume for a 1 cm cube and a 3 cm cube. Use your answer to explain why the body is made of many small cells instead of a few giant ones.

Unit project: my cell field book

Make a small lab book of everything you observed in this unit. Include your drawing of cork cells with the magnification, your stained cheek cell drawing with its three parts labeled, your table comparing stained and unstained slides, your chicken wing tissue chart, and your gelatin cube table and drawings. Finish with a full-page chart of the levels of the body (cell, tissue, organ, organ system, organism) with your own example at each level, and copy Psalm 139:14 on the last page with a paragraph explaining one thing in this unit that made you say “marvellous are thy works.”

- **Observation**: Drawings are made from real observation, are labeled correctly, and show the magnification or scale.
- **Records**: Data tables for the cork, cheek cell, tissue and gelatin tests are complete, with measurements in metric units and fair-test variables named.
- **Understanding**: The levels chart is in the right order with correct examples, and the paragraph explains the cell theory or why cells are small in the student’s own words.
- **Care**: The field book is neat, dated and easy to read, with a title page and a page for each lesson.

Answer key

1. Robert Hooke, in 1665 (in his book *Micrographia*). He was looking at a thin slice of cork. The tiny walled boxes looked like little rooms, and “cell” comes from a Latin word for a small room.
2. (a) 10 × 40 = 400×. (b) 0.02 × 400 = 8 millimeters.
3. 60 × 18 = 1,080 cells in one inch. No, they were dead; only the stiff cell walls were left.
4. A flat, uneven cell. Cell membrane: the thin outer edge that holds the cell together and controls what goes in and out. Cytoplasm: the jelly-like filling where much of the work is done. Nucleus: the dark round control center that holds the cell’s instructions.
5. 0.45 ÷ 9 = 0.05 millimeter (about 1/500 inch).
6. Change: stain or no stain. Control: the unstained slide (water only). Measure: how many cells out of 10 (or 20) show a clear nucleus. Keep the same (any two): the person, the scraping method, the amount of liquid, the magnification, the light.
7. A muscle cell (cell) → muscle tissue (tissue) → the stomach (organ) → the digestive system (organ system) → you (organism).
8. Epithelial: covers and lines (skin, lining of the cheek). Connective: supports and joins (bone, fat, tendon, blood). Muscle: pulls to make movement (arm muscle, heart muscle). Nervous: carries messages (brain, nerves).
9. (1) All living things are made of cells. (2) The cell is the basic unit of life. (3) Every cell comes from another cell. Scientists: Schleiden (plants, 1838), Schwann (animals, 1839) or Virchow (every cell from a cell, 1855).
10. 1 cm cube: 6 ÷ 1 = 6. 3 cm cube: 54 ÷ 27 = 2. Small cells have much more surface for their size, so food and oxygen coming in through the membrane can reach every part. A giant cell would have too little surface for all the material inside, and its middle would starve.

UNIT 2

Skeleton and Muscles

Stand up, wave, jump and sit down again. In those few seconds, your bones, joints and muscles all worked together without your thinking about it. In this unit you will study the frame God built for your body: the **skeleton** that holds you up and guards your organs, the **joints** where bones meet and move, and the **muscles** that pull on bones in partner pairs.

You will begin in 1543 with Andreas Vesalius, the young doctor who did his own dissecting, checked the old books against real bodies, and printed the most beautiful anatomy book of his age. You will count the 206 bones of an adult skeleton and turn a chicken bone to rubber with vinegar. You will see the first X-ray of a living hand, made by Wilhelm Röntgen in 1895, and test how much your thumb joint helps you. Finally you will stand with Dr. Tulp in Rembrandt's painting and with Giovanni Borelli, who showed that bones are levers, and you will build a model arm that bends and straightens.

In every lesson you will work like a real anatomist: look carefully, measure in centimeters, record in a table, change only one thing at a time, and let the evidence decide.

BEFORE YOU BEGIN

- Knows that the body is made of cells, tissues and organs (Unit 1)
- Can measure length in centimeters with a ruler or tape measure
- Can add, subtract and divide whole numbers and read a simple data table
- Can measure an angle with a protractor, or is ready to learn with a parent's help

MASTERY CHECKLIST

- I can tell how Vesalius corrected old mistakes about the body by careful observation, and name two of those mistakes.
- I can explain why an adult has 206 bones while a baby has more pieces, and name the five jobs of the skeleton.
- I can find and name at least ten major bones, using both common and scientific names.
- I can name the kinds of joints, give an example of each, and tell a ligament from a tendon.
- I can explain why muscles work in pairs and describe what the biceps and triceps do when I bend and straighten my arm.
- I can plan a fair test that changes one thing, keeps everything else the same, and uses a control.

OPTIONAL BOOKS AND RESOURCES

- **Historical Anatomies on the Web, U.S. National Library of Medicine** (https://www.nlm.nih.gov/exhibition/historicalanatomies/home.html): Free. Page through pictures from famous old anatomy books, including Vesalius's *Fabrica* (Lessons

2.1 and 2.2). Some plates show dissected bodies, so a parent should preview and choose the skeleton pages.

- **KidsHealth: Your Bones** (https://kidshealth.org/en/kids/bones.html): Free. A clear article for children on what bones are made of, bone marrow, joints and how broken bones heal (Lessons 2.2 and 2.3).
- **KidsHealth: Your Muscles** (https://kidshealth.org/en/kids/muscles.html): Free. A short article for children on skeletal, smooth and cardiac muscle and how muscles work in pairs (Lesson 2.4).

2.1 Vesalius and the Fabrica (1543) ★

OBJECTIVES

- Tell the story of Andreas Vesalius and his great book *De humani corporis fabrica*, printed in 1543.
- Explain why Vesalius trusted careful looking at the human body more than old books, and name two mistakes he corrected.
- Test a claim about the body by measuring, recording and comparing, the way an anatomist does.

Warm-up. Close your eyes and use only your fingers to find five bones on your own body: your kneecap, your collarbone, the bump on the outside of your wrist, your lower jaw and one rib. For each one, say whether it feels long, flat, round or curved. Then open your eyes and sketch one of them from memory. Vesalius trained himself to know bones so well that he could name them by touch.

Video. Coming soon. Andreas Vesalius and the Fabrica woodcuts for kids: search museum and library channels (U.S. National Library of Medicine, Smithsonian, university rare-book libraries), history-of-science channels and Homeschool Pop (Alternate) style biographies; preview for dissection images.

KEY TERMS

anatomy
The study of the parts of a living body and how they are put together.

anatomist
A scientist who studies the structure of the body, often by careful dissection and drawing.

dissection
Carefully cutting apart a dead plant or animal body to see and study its parts.

skeleton
The frame of bones that holds up the body, protects soft organs and lets it move.

woodcut
A picture carved into a block of wood, inked and pressed onto paper so it can be printed many times.

CORE IDEAS

The story. In the summer of 1543, in the city of Basel in Switzerland, a printer named Johannes Oporinus finished one of the most beautiful science books ever made. It was called *De humani corporis fabrica*, Latin for “On the Fabric of the Human Body.” Its author was Andreas Vesalius, a young doctor from Brussels who taught anatomy at the University of Padua in Italy. The book had hundreds of pages and more than two hundred woodcut

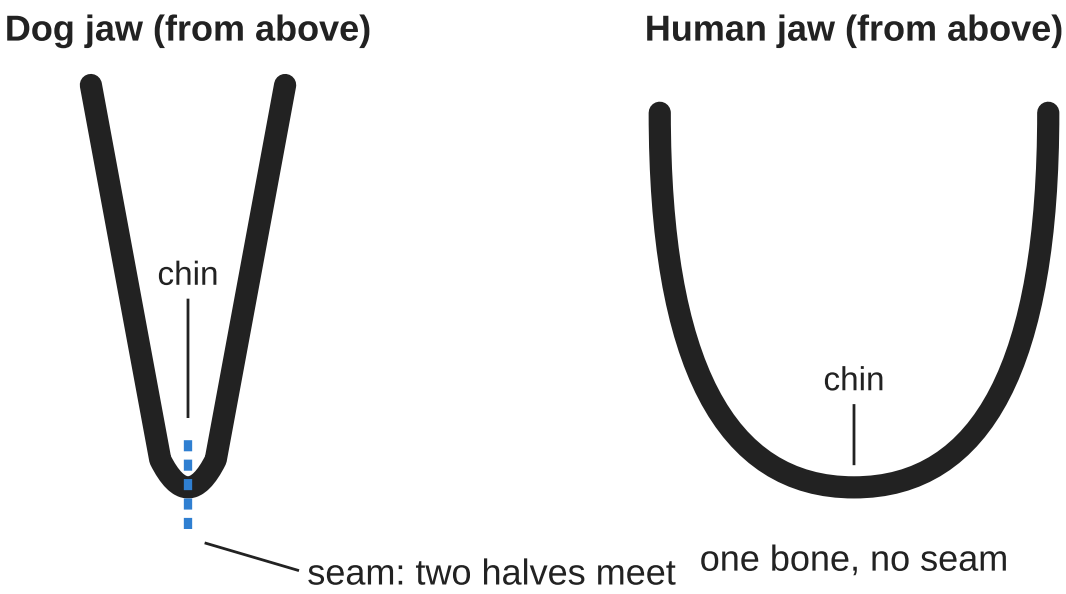
pictures of bones, muscles and organs, drawn so clearly that students could learn from them almost as well as from a real body. Vesalius dedicated it to the Emperor Charles V, and the carved wooden blocks for the pictures were carried over the Alps from Italy to Basel to be printed.

How they figured it out. For about thirteen hundred years, doctors in Europe had learned anatomy from the writings of Galen, a brilliant Greek doctor who lived in the Roman Empire. Galen had done many careful studies, but the laws of Rome did not allow him to dissect human bodies, so he mostly studied apes, pigs, dogs and oxen. In Vesalius's day, a professor often sat in a high chair reading Galen aloud while a helper did the cutting. Vesalius did the cutting himself. As a student in Paris he had studied old bones from a cemetery until he could name them by touch. At Padua he compared Galen's words with what was really in front of him, and he found that Galen was sometimes describing an animal, not a person. Galen said the lower jaw was made of two bones, as it is in a dog; Vesalius showed that the adult human jaw is one bone. Galen said the breastbone had seven parts; Vesalius found three.

The big idea. Vesalius respected Galen and called him a great teacher, but he had learned a scientist's rule: **when a book and careful observation disagree, look again, and trust what you can show.** Anatomy is the study of how the body is built. Its first tool is the eye, then the hand, then the pencil. Vesalius wanted his readers to check everything for themselves. His pictures show the **skeleton** standing and even posing in a landscape, so students could see how the bones fit together in a living person. The book begins with bones, because the skeleton is the frame that everything else hangs on. That is where this unit begins too.

Try it and see. You can work like Vesalius without a dissecting table. An old saying claims that your foot is as long as your forearm from the inside of your elbow to your wrist, and another says that your arm span (fingertip to fingertip, arms straight out) is the same as your height. Do not just believe them, and do not just doubt them. Measure several people, write the numbers in a table and decide what the evidence shows. That is exactly what Vesalius did with Galen.

God's handiwork. Vesalius lived when many scientists believed that studying God's works was a way of honoring Him. The Bible says, "The works of the LORD are great, sought out of all them that have pleasure therein" (Psalm 111:2). The human body is not a guess or a rough sketch. Every bone has a shape that fits its job, and the closer anyone looks, the more there is to see. Looking carefully is a way of giving thanks.



Galen's mistake. Many animals he studied, like dogs, have a lower jaw made of two halves joined at the chin. An adult human lower jaw is one bone.

PICTURE STUDY



Portrait of Andreas Vesalius, from the Fabrica, Unknown artist of the workshop of Titian (often credited to Jan Steven van Calcar), for Andreas Vesalius, 1543 · Woodcut printed in a book · Printed in Basel; copies are kept in many libraries, including the U.S. National Library of Medicine

This is the portrait of Vesalius that historians trust most to show what he really looked like, and he put it at the front of his own book. Instead of posing with fine clothes or a pile of books, he chose to be shown at work, holding the arm and hand of a body he is studying. (Parents may wish to preview: the arm is opened to show its muscles.)

The picture was carved in wood by a skilled artist in Venice, probably from Titian's workshop. Words around the picture give Vesalius's age as 28. He wanted readers to know that the book was made by someone who had seen these things with his own eyes.

Look closely

- Find Vesalius's hands. What is he doing with them?
- Look at the arm on the table. Can you see the long cords running down toward the fingers?
- Find the pen and inkwell. Why might a scientist need writing tools beside his work?
- Look at his face. Does he seem proud, curious, calm or busy?

Talk about it

1. Why do you think Vesalius chose to be pictured working instead of reading a book?
2. What would you hold in your hands if you were drawn as a scientist at work?

EXPERIMENT: CHECK THE OLD SAYING: AN ANATOMIST'S MEASURING TEST

Vesalius tested Galen's words against real bodies. You will test two old sayings about the body against real people: "Your foot is as long as your forearm" and "Your arm span equals your height."

Question: Are these sayings true for the people in my family? Prediction: write yes, no or close for each one before you begin. What we change: the person being measured. What we keep the same: the same tape measure, shoes off, standing against the same wall, measuring the same way each time. What we measure: foot length, forearm length, height and arm span, in centimeters.

You will need

- Cloth or paper tape measure marked in centimeters (or a meterstick)
- A wall, a pencil and a small sticky note
- Lab notebook and pencil
- At least four people of different sizes (family members, friends or a younger brother or sister)

Steps

1. Rule a table in your notebook with five columns: Name, Foot (cm), Forearm (cm), Height (cm), Arm span (cm).
2. Foot: the person stands barefoot with a heel against the wall. Measure from the wall to the tip of the longest toe.
3. Forearm: the person bends the arm and rests it flat on a table. Measure from the inside crease of the elbow to the crease of the wrist.
4. Height: the person stands straight against the wall, barefoot. Lay a book flat on the head, mark the wall with a sticky note and measure from the floor to the mark.

5. Arm span: the person stands with arms straight out against the wall. Mark the tip of each middle finger and measure between the marks.
6. Measure each thing twice. If the two numbers differ by more than 1 cm, measure a third time and use the two that agree.
7. Fill in the table for every person. Then add two more columns: Foot minus forearm, and Arm span minus height.
8. Write your conclusion: For my family, the foot saying was (true, close or false) and the arm span saying was (true, close or false). Give your numbers as evidence.

Tips

- Measure to the nearest half centimeter. A tape that slips or a person who slouches is the biggest source of error.
- “Close” is a fine scientific answer. Real bodies vary, and a scientist reports what was found, not what was hoped.
- To change centimeters to inches, divide by 2.54.

Check your work

- I measured at least four people and recorded every number.
- I measured each thing twice and kept the same method each time.
- My conclusion uses my numbers as evidence.

NATURE NOTEBOOK

1. Draw your own hand from life, slowly, the way Vesalius’s artists drew. Then gently press each finger and mark with dots where you think each bone begins and ends.
2. Make a two-column chart titled “Galen Said / Vesalius Saw.” Fill in the jaw and the breastbone.
3. Copy the title *De humani corporis fabrica* in your best lettering and write its meaning underneath. Add a small border of drawn bones.

> **From history.** The carved wooden blocks used to print the *Fabrica* pictures had a long life. After Vesalius, they were used for later printings and passed from owner to owner for nearly four hundred years. In 1934 they were used one last time to print a fine new edition of the pictures. Sadly, the blocks were destroyed when the library in Munich, Germany, where they were kept was bombed in 1944, during World War II. Only the printed pages remain.

WORKED EXAMPLES

Example 1. Galen was born in about AD 129. Vesalius's *Fabrica* was printed in 1543. About how many years after Galen's birth was the *Fabrica* printed?

1. Both dates are AD, so subtract the earlier year from the later year.
2. 1543 − 129 = 1414.
3. Galen's birth year is known only roughly, so round the answer.

Answer: About 1,400 years. For well over a thousand years, Galen's books were the main guide to anatomy in Europe.

Example 2. Lucy measures her height as 142 cm and her arm span as 144 cm. How much longer is her arm span? Is the saying "arm span equals height" true, close or false for Lucy? What is her height in inches?

1. Difference: 144 cm − 142 cm = 2 cm.
2. Compare the difference to the whole: 2 cm out of 142 cm is very small, less than 2 parts in 100.
3. Change height to inches: 142 ÷ 2.54 = 55.9, so about 56 inches.

Answer: Her arm span is 2 cm (about 0.8 in) longer, so the saying is close for Lucy. Her height is about 56 in.

PRACTICE

1. EASY What does the title *De humani corporis fabrica* mean in English, and in what year was it printed?
2. EASY Who was Galen, and why did he mostly dissect animals instead of people?
3. MEDIUM Name two of Galen's mistakes that Vesalius corrected, and say what Vesalius actually found.
4. MEDIUM A family measured foot length and forearm length (elbow crease to wrist crease).
   Name: Forearm / Foot
   Dad: 28 cm / 26 cm
   Mom: 25 cm / 24 cm
   Ben: 21 cm / 21 cm
   Ruth: 19 cm / 20 cm
   (a) For whom are the two exactly equal? (b) Whose numbers differ the most, and by how much? (c) Is the saying "your foot is as long as your forearm" true, close or false for this family?
5. MEDIUM William Harvey published his great book about the heart and blood in 1628. How many years was that after the *Fabrica*?

6. HARD You want to test whether arm span equals height. Name what changes from one test to the next, what you measure, and three things you must keep the same so the test is fair.
7. HARD In two or three sentences, explain why it mattered that Vesalius did the dissecting himself instead of only reading Galen aloud.
8. CHALLENGE A woodcut skeleton in a book is 20 cm tall and stands for a man 170 cm tall. In the picture, the thighbone is 5 cm long. How long was the real thighbone, in centimeters and in inches?

COMMON MISTAKES

- Thinking Vesalius proved that Galen knew nothing. Galen was a careful scientist who was right about a great deal; his mistakes came mostly from studying animals instead of people.
- Thinking that an old or famous book must be right, or must be wrong. A scientist checks claims against careful observation.
- Thinking a human body is built just like a dog's or an ape's. Animals share many similar parts, but each kind has its own design, and you must study the real thing.

> **Make it a game · Galen or Vesalius?.** A parent reads a statement, such as "The human lower jaw is two bones" or "The adult human jaw is one bone." If it is Galen's old mistake, stand up and say "Look again!" If it is what Vesalius saw, touch that bone on your body and say "Show me!" Then add your own true or false body statements from this lesson and take turns. Score a point for each correct answer and a bonus point for naming the bone correctly.

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

Vesalius sought out the works of God in the human body with patient, careful looking. Science done well is a way of taking pleasure in what God has made.

Practice answers

1. "On the Fabric (structure) of the Human Body." It was printed in 1543.
2. Galen was a famous Greek doctor who lived in the Roman Empire. Roman law did not allow human dissection, so he studied apes, pigs, dogs and oxen.
3. Galen said the lower jaw had two bones; Vesalius found the adult human jaw is one bone. Galen said the breastbone had seven parts; Vesalius found three.
4. (a) Ben. (b) Dad, by 2 cm. (c) Close: everyone is within 2 cm, and one person is exactly equal.
5. 1628 − 1543 = 85 years.
6. What changes: the person measured. What you measure: each person's height and arm span. Keep the same (any three): the same tape measure, shoes off, standing against the same wall, arms held straight and level, measuring middle fingertip to middle fingertip, measuring twice each time.

7. Because he looked with his own eyes, he could compare the old book with the real human body and see where they disagreed. Reading alone would only repeat old mistakes; observation let him correct them and draw what was really there.
8. Scale: 170 ÷ 20 = 8.5, so the real body is 8.5 times bigger. Thighbone: 5 × 8.5 = 42.5 cm. In inches: 42.5 ÷ 2.54 ≈ 16.7 in (about 17 in).

2.2 206 Bones

OBJECTIVES

- Explain that an adult skeleton has 206 bones, that a baby has more bony pieces, and why the number goes down as a child grows.
- Name and find at least ten major bones and describe five jobs of the skeleton.
- Run a fair test with a control to show that bone is made of hard minerals and a softer, bendy material.

Warm-up. Lay one hand flat on the table and press gently along each finger with your other hand. Count how many separate bones you can feel in one finger, then in your thumb. Write your guesses. (Answer: three in each finger and two in the thumb.) Now guess: how many bones are in your whole hand, including the palm and wrist? Keep your guess for later.

Video. Coming soon. The human skeleton and how bones grow for kids: search SciShow Kids, Homeschool Pop (Alternate), Science Max, Smithsonian and children's hospital channels for videos on bone structure, bone marrow and the chicken-bone-in-vinegar experiment.

KEY TERMS

bone
A hard, living body part made of minerals such as calcium and a tough, bendy material called collagen.

compact bone
The smooth, dense, heavy outer layer of a bone.

spongy bone
The lighter inner layer of bone, built like a honeycomb of tiny struts, found especially at the ends of long bones.

bone marrow
The soft tissue inside many bones. Red marrow makes new blood cells.

fuse
To grow together into one piece, as several baby bones do to form one adult bone.

CORE IDEAS

The story. While the *Fabrica* was being printed in Basel in 1543, Andreas Vesalius did not sit idle. He prepared the skeleton of a man of that city, cleaning each bone and joining them together in their proper places with wire so that students could study a whole human frame. He gave it to the University of Basel. That very skeleton is still kept at the university's Anatomical Museum today, and it is often called the oldest anatomical skeleton in any

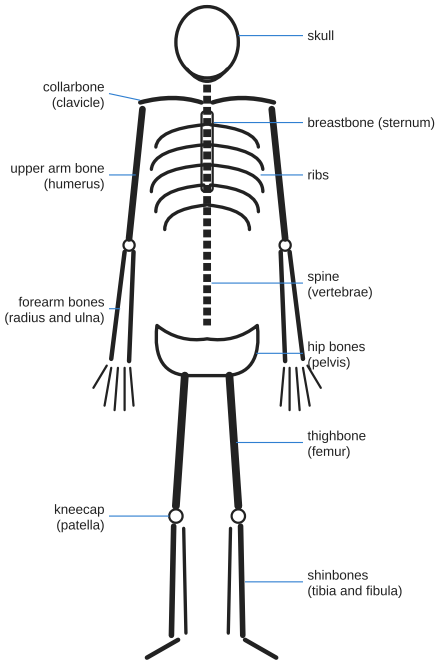
museum. Vesalius knew that a real skeleton, standing in front of you, teaches what no book can.

How they figured it out. If you count the bones of an adult skeleton like Vesalius's, you get **206**. Anatomists count each separate bone once, from the big thighbone to the three tiny bones inside each ear. A newborn baby has more pieces, about 270 to 300, many of them still partly made of soft cartilage. As a child grows, some pieces **fuse**, or grow together. The bones of the skull knit together. Five bones at the bottom of the spine join into one, called the sacrum. Three bones on each side of the hip join into one hip bone. That is why the count goes down as you grow up, even though your body gets bigger.

The big idea. Your skeleton has five great jobs. It **supports** you, like the frame of a house. It **protects** soft organs: the skull guards the brain, and the 24 ribs (12 pairs, the same in men and women) guard the heart and lungs. It lets you **move**, because muscles pull on bones. It **makes blood**: red marrow inside bones makes millions of new blood cells every second. And it **stores minerals** such as calcium for the rest of the body. A bone is not a dry stick. It is alive, with blood vessels and bone cells, and it can heal when it breaks. On the outside is smooth, heavy **compact bone**; inside is light **spongy bone**, built like a honeycomb, and in the middle is **marrow**.

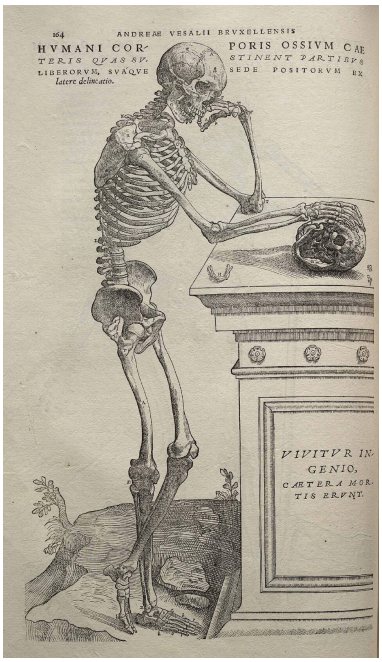
Try it and see. Your hands and feet hold more than half of all your bones: 27 in each hand and 26 in each foot. Your longest bone is the thighbone, or femur, about one quarter of your height. Your smallest is the stirrup bone, or stapes, deep in your ear, about 3 millimeters (about 1/8 inch) long. To see what bone is made of, soak a clean chicken bone in vinegar for several days. The vinegar slowly dissolves the hard calcium minerals and leaves the bendy collagen behind, so the bone becomes rubbery. Keep a second bone in plain water as a control so you know the vinegar made the difference.

God's handiwork. Engineers who design bridges and airplanes want parts that are strong but light. Bone does both. Its hard minerals keep it from bending, its collagen keeps it from snapping, and its spongy inside saves weight where strength is needed least. Solomon wrote that we do not know "how the bones do grow in the womb of her that is with child" (Ecclesiastes 11:5). We know much more now, and it is still a wonder.



Major bones of the human skeleton. The common name comes first and the scientific name is in parentheses.

PICTURE STUDY



Skeleton Leaning on a Tomb, from the Fabrica, Unknown artist of the workshop of Titian (often credited to Jan Steven van Calcar), for Andreas Vesalius, 1543 · Woodcut printed in a book · Printed in Basel; copies are kept in many libraries, including the U.S. National Library of Medicine

Book One of the *Fabrica* is about bones, and it shows the whole skeleton in three large pictures. In this one, the skeleton leans on a stone tomb as if it were thinking, with one hand on a skull. Behind it are hills and buildings.

Why would an anatomy book pose a skeleton like a person? Vesalius wanted students to see how bones sit in a living, standing body, not in a heap on a table. The thoughtful pose also reminded readers of something every person in his day knew: life on earth is short, so use it well.

Look closely

- Find the skull, the ribs and the spine. Can you see how the ribs curve around from the spine?
- Find the long thighbone and the kneecap. Compare the thighbone's length to the whole skeleton.
- Look at the hands and feet. Why did the artist have to be so patient to draw them?
- Look at the landscape. Why do you think the artist put the skeleton outdoors instead of on a plain page?

Talk about it

1. What does this picture teach that a list of 206 bone names cannot?
2. If you were drawing a skeleton for a science book, how would you pose it, and why?

> **Safety first.** Use only cooked chicken bones that an adult has cleaned of meat. Wash your hands with soap after touching the bones. Keep the jars covered and away from small children and pets, do not drink the vinegar, and throw the bones away in the trash when the test is done.

EXPERIMENT: THE RUBBER BONE: A FAIR TEST WITH A CONTROL

Bone is made of hard minerals and a tough, bendy material called collagen. You will find out what happens when the minerals are taken away.

Question: What happens to a bone soaked in vinegar? Prediction: write what you think will happen. What we change: the liquid (vinegar or plain water). What we keep the same: the kind and size of bone, the amount of liquid, the kind of jar, the place and the number of days. What we measure: how far the bone bends before it stops (none, a little, a lot), how it looks and feels, and its length.

You will need

- 2 cooked chicken leg bones (drumsticks or wing bones), cleaned of meat, about the same size
- 2 clean glass jars with lids
- White vinegar (enough to cover one bone) and tap water
- Masking tape and a marker for labels
- Ruler marked in centimeters
- Lab notebook and pencil

Steps

1. Label one jar “Vinegar” and one jar “Water (control).” Write the date on both.
2. Measure each bone’s length in centimeters and record it. Gently try to bend each one and write what you feel. Draw each bone.
3. Put one bone in each jar. Cover the first with vinegar and the second with the same amount of water. Close the lids.
4. Every day, look at the jars without opening them. Write what you see. Tiny bubbles on the vinegar bone are a clue: the vinegar is reacting with the minerals.
5. After 2 days, ask an adult to pour off the old vinegar and add fresh vinegar. Change the water in the control jar too, so both are treated the same.
6. After 4 to 7 days, take out both bones, rinse them, and dry them with a paper towel.
7. Try to bend each bone again. Measure each length. Record and draw what you find.
8. Write your conclusion: What did the vinegar remove? What was left? Why did you need the water jar?

Tips

- Thin wing bones turn rubbery faster than thick leg bones.
- The control bone in water should still be hard. If it is, you know the vinegar, not just soaking, made the change.
- Your body keeps bones hard by building in calcium from foods such as milk, cheese, yogurt and leafy greens.

Check your work

- I changed only one thing, the liquid, and kept everything else the same.
- I recorded observations every day with the date.
- I can explain what the vinegar took away and why the control matters.

NATURE NOTEBOOK

1. Draw the outline of your body on a large sheet of paper (a parent can trace you). Draw in and label at least ten bones using the figure in this lesson.
2. Draw the inside of a long bone as if it were cut in half the long way: label compact bone, spongy bone and marrow.
3. Make a daily log for your vinegar test with the date, a sketch of each bone and one sentence of observation.

> **From history.** In the *Fabrica*, Vesalius stated plainly that men and women have the same number of ribs. Many people in his day believed that men had one fewer, because of the story of Eve being made from Adam’s rib (Genesis 2:21–22). Vesalius counted real skeletons and reported what he found, and he was right. The Bible tells what God did for Adam; it does not say that every man after him would be missing a rib.

WORKED EXAMPLES

Example 1. The bones along the center of the body are the skull (22), the ear bones (6), the hyoid bone in the throat (1), the spine (26), the ribs (24) and the breastbone (1). How many is that? How many bones are left for the shoulders, arms, hips and legs?

(Use the map or drawing "Find the skull, spine, ribs and breastbone in the center of the body." shown earlier in this lesson.)

1. Add the center bones: 22 + 6 + 1 + 26 + 24 + 1.
2. 22 + 6 = 28; 28 + 1 = 29; 29 + 26 = 55; 55 + 24 = 79; 79 + 1 = 80.
3. Subtract from the total: 206 − 80 = 126.

Answer: 80 bones are in the center of the body, and 126 bones are in the shoulders, arms, hips and legs.

Example 2. Each hand has 27 bones and each foot has 26 bones. How many bones are in both hands and both feet together? Is that more or less than half of 206?

1. Both hands: 27 × 2 = 54.
2. Both feet: 26 × 2 = 52.
3. Together: 54 + 52 = 106.
4. Half of 206 is 206 ÷ 2 = 103. Compare: 106 is more than 103.

Answer: 106 bones, which is more than half of all 206 bones in the body.

PRACTICE

1. EASY How many bones are in an adult skeleton? About how many bony pieces does a newborn baby have, and why is the number different?
2. EASY List the five jobs of the skeleton.
3. MEDIUM Each hand has 8 wrist bones, 5 palm bones and 14 finger bones. Show that this adds up to 27.
4. MEDIUM Read the table of bones by body region.
   Region: Bones
   Skull: 22
   Ear bones and hyoid: 7
   Spine: 26
   Ribs and breastbone: 25
   Shoulders, arms and hands: 64
   Hips, legs and feet: 62
   (a) Which region has the most bones? (b) How many more bones are in the spine than in the skull? (c) Add all the regions. What total do you get?

5. MEDIUM The thighbone (femur) is about one quarter of a person's height. About how long is the femur of a man 180 cm tall? Give the answer in centimeters and inches.
6. HARD In the rubber-bone test, what is the one thing you change, what is the control, and name three things you keep the same?
7. HARD Your friend says, "Bones are dead, like rocks." Write two or three sentences giving evidence that bones are alive.
8. CHALLENGE The stirrup bone (stapes) is about 3 mm long and a man's femur is about 450 mm long. About how many stirrup bones laid end to end would equal one femur?

COMMON MISTAKES

- Thinking bones are dead and dry. Living bones have blood vessels and cells, grow, heal and make blood.
- Thinking men have one fewer rib than women because of Adam's rib. Men and women both have 24 ribs (12 pairs). Genesis tells of one rib taken from Adam, not of a change in all his sons.
- Thinking babies have fewer bones because they are small. A newborn has more bony pieces than an adult; many fuse as the child grows.

> **Make it a game · Bone Says.** Play like Simon Says, but use bone names. The caller says, "Bone says touch your femur!" or "Bone says tap your clavicle!" Players touch the right bone. If the caller leaves off "Bone says," anyone who moves is out for a round. Start with common names (thighbone, collarbone), then switch to scientific names (femur, clavicle, sternum, patella, humerus, tibia). The last player standing becomes the next caller.

> **Scripture.** "As thou knowest not what is the way of the spirit, nor how the bones do grow in the womb of her that is with child: even so thou knowest not the works of God who maketh all." (Ecclesiastes 11:5, KJV)

Most of your 206 bones began as soft cartilage before you were born and grew in the dark, hidden from every eye but God's. Science helps us understand a little of how; it should also make us humble.

Practice answers

1. 206. A newborn has about 270 to 300 pieces. As a child grows, some of them fuse (grow together) into single bones, such as the skull bones, the sacrum and the hip bones.
2. Support the body, protect organs, help the body move, make blood cells (in red marrow) and store minerals such as calcium.
3. 8 + 5 + 14 = 27.
4. (a) Shoulders, arms and hands, with 64. (b) 26 − 22 = 4 more. (c) 22 + 7 + 26 + 25 + 64 + 62 = 206.
5. 180 ÷ 4 = 45 cm. 45 ÷ 2.54 ≈ 17.7 in, about 18 in.
6. Change: the liquid (vinegar or water). Control: the bone soaked in plain water. Keep the same (any three): kind and size of bone, amount of liquid, kind of jar, place, number of days, how often the liquid is changed.

7. Bones have blood vessels and living bone cells. They grow as you grow and can heal when they break. Red marrow inside bones makes new blood cells all the time.
8. 450 ÷ 3 = 150 stirrup bones.

2.3 Joints

OBJECTIVES

- Name and give examples of hinge, ball-and-socket, pivot, gliding and fixed joints, and tell what each one lets the body do.
- Explain how cartilage, joint fluid and ligaments keep joints smooth and strong, and tell ligaments from tendons.
- Design and run a fair test of how the thumb joint helps the hand, and measure joint movement in degrees.

Warm-up. Stand up and move your body without bending your knees or elbows at all. Try to walk, sit down, pick up a pencil and scratch your nose. Then try it with your knees and elbows free. Make a quick list of the places on your body that bend, twist or turn. Each place is a joint.

Video. Coming soon. Types of joints in the human body for kids (hinge, ball-and-socket, pivot) and Wilhelm Röntgen's discovery of X-rays: search SciShow Kids, Homeschool Pop (Alternate), Science Max, Smithsonian and children's hospital or physical-therapy education channels.

KEY TERMS

joint
A place where two or more bones meet.

cartilage
A smooth, firm, rubbery tissue that covers the ends of bones in a joint so they glide without rubbing.

ligament
A strong band of tissue that holds one bone to another bone at a joint.

tendon
A tough cord that attaches a muscle to a bone.

X-ray
An invisible kind of light that passes through soft parts of the body more easily than through bone, so it can make pictures of bones.

CORE IDEAS

The story. On November 8, 1895, in his laboratory in Würzburg, Germany, the physicist Wilhelm Conrad Röntgen noticed something strange. A special glass tube he was testing was covered in black cardboard, yet a coated screen lying nearby began to glow. Some unknown rays were passing right through the cardboard. He called them **X-rays**, because "X" stands for something unknown. For weeks he tested them on paper, wood and metal. Then, on

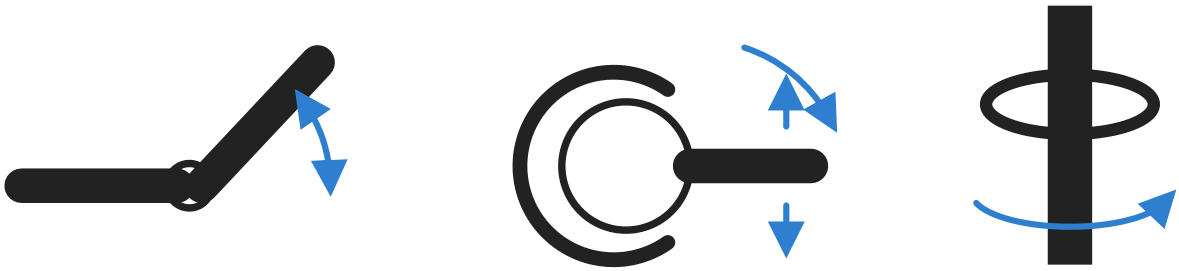
December 22, 1895, he asked his wife, Anna Bertha, to hold her hand still in the path of the rays over a photographic plate for several minutes. When the plate was developed, it showed the bones of her living hand, with her wedding ring floating around one finger. For the first time, people could see the skeleton of a living person.

How they figured it out. Look closely at an X-ray of a hand and you notice something surprising: the finger bones do not seem to touch. There is a small gap at every knuckle. The bones are not really floating apart. The ends of each bone are capped with **cartilage**, a smooth, rubbery tissue that X-rays pass through easily, so it does not show. Anatomists who had opened joints long before knew what was there: cartilage on each bone end, a thin bag around the joint filled with slippery joint fluid, a little like egg white, and strong bands called **ligaments** holding bone to bone. The X-ray pictures matched what dissection had shown.

The big idea. A **joint** is a place where bones meet, and each kind is built for its job. A **hinge joint** swings back and forth in one direction, like a door: your elbow, knee and finger joints. A **ball-and-socket joint** has a round end that turns in a cup, so it can swing in a circle: your shoulder and hip. A **pivot joint** lets one bone turn around another: the top two bones of your neck let you shake your head “no.” **Gliding joints** let small, flat bones slide a little against each other, as in your wrist and ankle. A **saddle joint** at the base of your thumb lets it swing across your palm to touch each finger. Some joints hardly move at all: the bones of your skull meet in wavy **fixed joints** called sutures, locked together to guard your brain. Remember: ligaments join bone to bone; **tendons** join muscle to bone.

Try it and see. Your thumb’s special joint is one reason human hands can button a shirt, hold a pencil and thread a needle. You can test how much it helps. Tape your thumb gently against the side of your hand and time yourself doing simple jobs, then do the same jobs with your thumb free. You can also measure how far a joint bends with a protractor: a straight elbow makes a straight angle of 180 degrees, and as you bend it the angle between your upper arm and forearm gets smaller.

God’s handiwork. Your knees carry your weight every time you climb stairs, jump or run, often thousands of times a day, and in a healthy knee the cartilage stays smooth and slick through many years of use. In the prophet Ezekiel’s vision, the dry bones came together, “bone to his bone” (Ezekiel 37:7). A skeleton only works when every bone meets the right partner in the right kind of joint.



Hinge joint
elbow, knee, fingers

Ball-and-socket joint
shoulder, hip

Pivot joint
top of the neck

Three kinds of moving joints. A hinge swings one way, a ball-and-socket swings in many directions, and a pivot turns.

PICTURE STUDY



Hand mit Ringen (Hand with Rings): the first X-ray picture of a human hand, Wilhelm Conrad Röntgen, December 22, 1895 · X-ray photograph on a glass photographic plate · Made in Würzburg, Germany; copies are kept in many museums and archives

This is not a painting or a drawing, but it may be the most famous picture in the history of medicine. Röntgen made it a few weeks after he discovered X-rays. The hand belonged to his wife, Anna Bertha. She had to hold still for several minutes while the rays passed through her hand onto a glass plate.

Röntgen mailed copies of this picture to other scientists at the start of 1896, and within weeks newspapers around the world printed it. Doctors quickly began using X-rays to find

broken bones and set them correctly.

Look closely

- Count the bones in one finger. Then count the bones in the thumb.
- Find the gaps at the knuckles. What is really filling those spaces?
- Find the cluster of small bones at the wrist. What kind of joints do they make?
- Find the ring. Why does it look so dark and sharp compared with the skin?

Talk about it

1. Why was this picture so exciting to doctors in 1896?
2. What could you learn from an X-ray that you could never learn by looking at the outside of a hand?

EXPERIMENT: THE THUMB TEST: HOW MUCH DOES ONE JOINT HELP?

The saddle joint at the base of your thumb lets your thumb press against each fingertip. You will find out how much harder everyday jobs become without it.

Question: Does taping the thumb make simple tasks take longer? Prediction: write how much longer you think it will take. What we change: thumb free or thumb taped. What we keep the same: the same person, the same hand, the same tasks, the same objects and the same timer. What we measure: the time in seconds for each task.

You will need

- Masking tape or a soft cloth strip
- A shirt or sweater with at least 4 buttons
- 10 coins in a pile
- A pencil and paper
- A stopwatch or a phone timer (a partner can run it)
- Lab notebook

Steps

1. Make a table with four rows (Button 4 buttons, Pick up 10 coins one at a time, Write your full name, Tie a shoe) and two columns (Thumb free, Thumb taped).
2. With your thumb free, do each task while your partner times you. Record the time to the nearest second.
3. Have your partner tape your thumb gently against the side of your writing hand, so you can still move your fingers. It should not be tight or hurt.
4. Do the same tasks in the same order with your thumb taped. Record each time.
5. Remove the tape. Do the whole test a second time on another day, or let a family member be the test person, to see whether the results repeat.
6. For each task, subtract to find how many seconds longer it took with the thumb taped.

7. Write your conclusion: Which task needed the thumb the most? Use your numbers as evidence.

Tips

- Take the tape off right away if your hand feels numb or tingly.
- Doing a task the second time is often faster just from practice. A fair scientist notices this. You can make the test fairer by doing the taped round first on your second day.
- Try a bonus test with your wrist held straight by a ruler and soft tape. Which joint did you miss more?

Check your work

- I changed only one thing: thumb free or thumb taped.
- I timed each task and recorded every number.
- I can name the kind of joint at the base of my thumb and explain what it lets my hand do.

NATURE NOTEBOOK

1. Trace your hand on paper. Inside the outline, draw the finger bones and mark each joint with a small circle. Label one hinge joint and the saddle joint at the base of your thumb.
2. Make a three-column chart: Joint type, Where in my body, What motion. Fill in at least five rows.
3. Find three hinges, pivots or ball-and-socket parts around your house (a door, a swivel chair, a desk lamp, a computer mouse ball, a toy). Draw each one beside the body joint it is like.

> **From history.** In 1901, Wilhelm Röntgen received the very first Nobel Prize in Physics for discovering X-rays. He chose not to take out a patent on his discovery, because he wanted X-rays to be used freely to help people everywhere. Within a few months of his announcement, doctors in many countries were using X-ray pictures to find broken bones, set them straight and locate objects such as swallowed pins.

WORKED EXAMPLES

Example 1. With his arm straight, Sam’s elbow makes a straight angle of 180°. When he bends it as far as he can, a protractor shows 35° between his upper arm and forearm. How many degrees did his elbow bend?

1. The joint started at 180° and ended at 35°.
2. The amount it bent is the difference: $180° - 35° = 145°$.

Answer: Sam’s elbow bent 145°.

Example 2. Abby buttoned 4 buttons in 20 seconds with her thumb free and in 55 seconds with her thumb taped. How many seconds longer did it take with the thumb taped? How many times as long is that?

1. Difference: 55 s − 20 s = 35 s longer.
2. Times as long: 55 ÷ 20 = 2.75.

Answer: 35 seconds longer, which is 2.75 times as long (almost three times). Abby's thumb joint made a big difference for buttoning.

PRACTICE

1. EASY Name the kind of joint: (a) elbow, (b) shoulder, (c) the bones of the skull, (d) the top of the neck that lets you shake your head "no."
2. EASY What is the difference between a ligament and a tendon?
3. MEDIUM In Röntgen's X-ray of a hand, the finger bones seem to have gaps between them at each knuckle. Explain why.
4. MEDIUM One student measured how far some of her joints could bend from straight.
   Joint: Degrees of bend
   Elbow: 145°
   Knee: 135°
   Wrist (bending forward): 80°
   Middle finger knuckle: 100°
   (a) Which joint bent the most? (b) How many more degrees did the elbow bend than the knee? (c) Which joint bent the least?
5. MEDIUM You can swing your arm in a full circle at the shoulder but not at the elbow. Explain why, using the names of the joints.
6. HARD Design a fair test to find out whether taping the thumb slows down picking up coins. Name the variable you change, the control, what you measure and two things you keep the same.
7. HARD A baby's skull has soft spots where the bones have not yet joined. In two or three sentences, explain why that is helpful, and what happens to the soft spots later.
8. CHALLENGE Each finger has 3 bones, and the thumb has 2. (a) How many finger bones are in both hands? (b) The joints between finger bones are hinge joints. A finger with 3 bones has 2 joints between them; a thumb with 2 bones has 1. How many of these joints are in one hand?

COMMON MISTAKES

- Thinking ligaments and tendons are the same thing. Ligaments join bone to bone; tendons join muscle to bone.
- Thinking bones rub directly on each other in a joint. Healthy joints have smooth cartilage and slippery fluid between the bone ends.

- Thinking all joints move. The joints of the skull are fixed, and the joints between the bones of the spine move only a little each.

> **Make it a game · Joint Charades.** Write these on slips of paper: hinge, ball-and-socket, pivot, gliding, saddle, fixed. One player draws a slip and acts out a motion using only that kind of joint (for a hinge, nod a knee or bend an elbow; for a pivot, turn the head; for a saddle, touch the thumb to each fingertip; for fixed, stand perfectly still and point to the skull). The others guess the joint type and name a joint in the body that moves that way. A correct guess with a correct body example earns two points.

> **Scripture.** “So I prophesied as I was commanded: and as I prophesied, there was a noise, and behold a shaking, and the bones came together, bone to his bone.” (Ezekiel 37:7, KJV)

In Ezekiel’s vision, God brings dry bones back together, each one meeting its proper partner. A real skeleton works the same way: every bone fits its neighbor in exactly the kind of joint it needs.

Practice answers

1. (a) Hinge. (b) Ball-and-socket. (c) Fixed joints (sutures). (d) Pivot.
2. A ligament holds bone to bone. A tendon attaches muscle to bone.
3. The ends of the bones are covered with cartilage, and the joint has fluid inside. X-rays pass easily through cartilage and soft tissue, so those parts do not show, and the space looks empty.
4. (a) The elbow (145°). (b) 145° − 135° = 10° more. (c) The wrist (80°).
5. The shoulder is a ball-and-socket joint: a round ball turns in a cup, so it can move in many directions. The elbow is a hinge joint, which swings back and forth in only one direction.
6. Change: thumb taped or thumb free. Control: doing the task with the thumb free. Measure: the time in seconds to pick up the coins. Keep the same (any two): the same person, the same hand, the same number and kind of coins, the same table and the same timer.
7. The soft spots let the skull bones shift a little at birth and let the head and brain grow quickly in the first years. Later the bones grow together at fixed joints called sutures, making a strong, closed case to protect the brain.
8. (a) One hand: 4 × 3 + 2 = 14 bones, so both hands have 28. (b) 4 fingers × 2 joints = 8, plus 1 in the thumb = 9 hinge joints in one hand.

2.4 Muscles in Pairs

OBJECTIVES

- Explain that skeletal muscles can only pull, never push, and so they work in pairs such as the biceps and triceps.
- Name the three kinds of muscle (skeletal, smooth and cardiac) and tell where each is found.
- Build a model arm and test how the place a muscle attaches to a bone changes how far the bone moves, recording the results in a table.

Warm-up. Rest your left hand on the front of your right upper arm. Slowly bend your right elbow, then straighten it. What do you feel under your hand? Now move your left hand to the back of your upper arm and do it again. Which side got hard and thick when you bent your arm, and which side got hard when you straightened it?

Video. Coming soon. How muscles work in pairs (biceps and triceps, flexors and extensors) for kids: search SciShow Kids, Homeschool Pop (Alternate), Science Max, Smithsonian and children's hospital channels, plus model-arm build demonstrations with cardboard and string.

KEY TERMS

muscle
A body tissue that can contract (get shorter) to pull on bones or squeeze organs.

contract
To get shorter and thicker. A muscle pulls when it contracts.

muscle pair
Two muscles that pull a bone in opposite directions, such as the biceps (bends the elbow) and triceps (straightens it).

lever
A stiff bar that turns on a fixed point called a fulcrum. Bones act as levers, and joints act as fulcrums.

skeletal muscle
Muscle attached to bones by tendons; you can move it when you choose.

CORE IDEAS

The story. In January 1632, in Amsterdam, crowds paid to watch a public anatomy lesson given by Dr. Nicolaes Tulp of the city's Guild of Surgeons. A young painter named Rembrandt was asked to paint it. In his picture, Dr. Tulp lifts the muscles of the forearm with a small pair of tongs. With his other hand, he curls his own fingers. He is showing the surgeons a simple, wonderful fact: those forearm muscles pull on long tendons that run all the way to

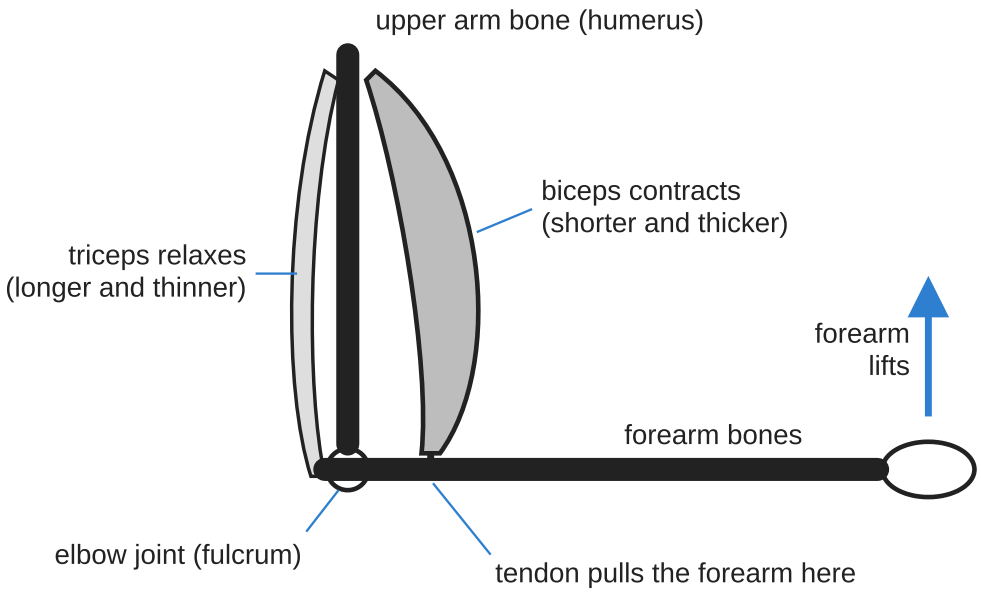
the fingers, and when the muscles shorten, the fingers bend. Most of the muscles that move your fingers are not in your fingers at all. They are in your forearm, working like puppeteers pulling strings.

How they figured it out. About fifty years later, an Italian mathematician and scientist, Giovanni Alfonso Borelli, looked at the body like an engineer. In his book *On the Movement of Animals*, printed in Rome in 1680 and 1681 after his death, he showed that bones act as **levers** and joints act as the turning points, called fulcrums. He measured and calculated how hard muscles must pull to lift loads. Because a muscle such as the biceps attaches close to the elbow, it must pull much harder than the weight in your hand. In return, a small shortening of the muscle swings your hand a long way, quickly. That trade is what lets you throw a ball fast.

The big idea. A skeletal **muscle** can do only one thing: **contract**, getting shorter and thicker, and pull. It can never push. So muscles work in **pairs** that pull in opposite directions. When the **biceps** on the front of your upper arm contracts, it bends your elbow, while the **triceps** on the back relaxes and lets itself be stretched. To straighten your arm, the triceps contracts and the biceps relaxes. In your thigh, the **hamstrings** on the back bend the knee and the **quadriceps** on the front straighten it. Your body has more than 600 skeletal muscles, all fastened to bones by tough **tendons**. The thickest is the Achilles tendon, which joins your calf muscles to your heel bone.

Try it and see. Not all muscles are attached to bones. There are three kinds. **Skeletal muscle** moves your bones when you choose. **Smooth muscle** lines your stomach, intestines and blood vessels and works without your thinking about it. **Cardiac muscle** is found only in the heart, and it squeezes all day and all night. Skeletal muscles do get tired. Squeeze a clothespin open and shut as many times as you can in 30 seconds, rest a moment, and do it again several times. Write each count in a table. The numbers usually drop: your muscle is showing **fatigue**.

God’s handiwork. Every motion you make, from a smile to a sprint, is muscles pulling in perfect teamwork, one partner tightening as the other lets go. Job said to God, “Thou hast clothed me with skin and flesh, and hast fenced me with bones and sinews” (Job 10:11). Sinews are tendons. Bones, joints, tendons and muscles were made to work together as one.



Bending the elbow. The biceps contracts and pulls the forearm up while the triceps relaxes. To straighten the arm, they switch jobs.

PICTURE STUDY



The Anatomy Lesson of Dr. Nicolaes Tulp, Rembrandt van Rijn, 1632 · Oil on canvas · Mauritshuis, The Hague, Netherlands

Parent preview: this painting shows a body on a dissecting table with the forearm opened. It is not gory, but parents may wish to look first and decide how to share it.

Rembrandt was still in his twenties when the Amsterdam surgeons asked him to paint their anatomy lesson, and this picture made him famous. Instead of lining the men up stiffly, as group portraits usually were, he shows them leaning in, looking, thinking. Dr. Tulp is teaching how the forearm muscles bend the fingers, and he shows it with his own hand at the same moment.

Look closely

- Find Dr. Tulp. He is the only man wearing a hat. What is he doing with each hand?
- Look at the forearm on the table. Can you see the long muscles and the cords running toward the fingers?
- Look at the faces of the other men. Where is each one looking? Do any of them look at you?
- Find the big open book at the bottom right corner. Why might it be in the picture?

Talk about it

1. What is Dr. Tulp teaching with his left hand? Try it yourself while feeling your forearm with your other hand.
2. Why do you think Rembrandt lit the body and the faces brightly and left the rest dark?

EXPERIMENT: THE MODEL ARM: WHERE SHOULD THE MUSCLE ATTACH?

You will build an arm out of cardboard, with strings for the biceps and triceps, and see for yourself that a muscle can pull but cannot push. Then you will test Borelli’s lever idea.

Question: Does the place where the “biceps” string attaches to the forearm change how far the hand lifts? Prediction: write which hole will lift the hand highest. What we change: the hole the string is tied to (2 cm, 4 cm or 8 cm from the elbow). What we keep the same: the same model, the same starting position and the same pull of 1 cm on the string. What we measure: how many centimeters the end of the forearm rises.

You will need

- 2 strips of stiff cardboard, about 30 cm by 4 cm (12 in by 1 1/2 in)
- 1 brass paper fastener (brad)
- 2 pieces of string, each about 50 cm (20 in) long
- 2 large paper clips or a hole punch
- Ruler marked in centimeters, a marker and masking tape
- A sharp pencil to poke holes (an adult can help)
- A cereal box or heavy book to stand the upper arm against
- Lab notebook

Steps

1. Upper arm: tape one strip upright against the side of the cereal box so it stands like an upper arm. Mark the bottom end “elbow.”

2. Forearm: on the second strip, poke a hole 3 cm from one end. Join it to the bottom of the upper arm strip with the brad, so the forearm swings up and down like a hinge. The short 3 cm tab sticking out behind the brad is the elbow point.
3. On the forearm, poke three small holes along the top edge, 2 cm, 4 cm and 8 cm from the brad. Mark the far end of the forearm with an “H” for hand.
4. Biceps: tie one string through the 4 cm hole. Run it up the front of the upper arm and through a paper clip taped at the top. Pull the string down at the top: the forearm should lift.
5. Triceps: tie the second string to the short tab behind the elbow and run it up the back of the upper arm through a second clip. Pull it: the forearm should straighten. Now try to push either string. What happens?
6. Test: with the forearm hanging straight down, mark the biceps string with the marker at the clip. Pull the string exactly 1 cm. Measure how high the H end rose from its starting point. Record it.
7. Retie the biceps string at the 2 cm hole and repeat the test, then at the 8 cm hole. Do each one twice and record both trials.
8. Make a table: Hole distance from elbow (cm), Rise of hand trial 1 (cm), trial 2 (cm). Write your conclusion: Which hole gave the biggest lift for the same pull? Which hole felt hardest to pull?

Tips

- Start every trial with the forearm in the same place, or the test is not fair.
- You should find that the hole closest to the elbow makes the hand move farthest but takes the hardest pull. Your real biceps attaches only a few centimeters from your elbow.
- A string that goes slack when pushed is just like a real muscle: it can only pull.

Check your work

- My model arm bends when I pull the biceps string and straightens when I pull the triceps string.
- I changed only the attachment hole and kept the pull the same.
- I can explain why muscles must work in pairs.

NATURE NOTEBOOK

1. Draw your arm bent and straight, side by side. Color the muscle that is contracting in each drawing and label biceps, triceps, tendon and elbow joint.
2. Draw your leg bent at the knee and then kicking straight. Label the hamstrings and quadriceps and write which one is contracting in each drawing.
3. Make a three-box chart for skeletal, smooth and cardiac muscle. In each box, draw where it is found and write one fact about it.

From history. The word *muscle* comes from the Latin *musculus*, which means “little mouse.” People long ago thought that a muscle moving under the skin, such as the biceps rising and falling, looked like a small mouse running underneath. Try it in a mirror and see whether you agree.

WORKED EXAMPLES

Example 1. Grace squeezed a clothespin as many times as she could in 30 seconds, rested 10 seconds, and repeated. Her counts were:

Round: Squeezes
1: 62
2: 55
3: 49
4: 44
5: 40

(a) How much did her count drop from round 1 to round 5? (b) What was her average count per round?

1. (a) Drop: 62 − 40 = 22 squeezes.
2. (b) Add all five rounds: 62 + 55 + 49 + 44 + 40 = 250.
3. Divide by the number of rounds: 250 ÷ 5 = 50.

Answer: (a) Her count dropped by 22 squeezes. (b) Her average was 50 squeezes per round. The steady drop shows muscle fatigue.

Example 2. Eli wrapped a cloth tape measure around the thickest part of his upper arm. With his arm hanging relaxed, it measured 21.5 cm. With his elbow bent and his biceps tightened, it measured 24.0 cm. How much thicker did his arm get, in centimeters and in inches?

(Use the map or drawing “A contracting biceps gets shorter and thicker, so the upper arm measures more ar” shown earlier in this lesson.)

1. Difference: 24.0 cm − 21.5 cm = 2.5 cm.
2. Change to inches: 2.5 ÷ 2.54 ≈ 0.98, about 1 inch.

Answer: His arm measured 2.5 cm (about 1 in) more around. When the biceps contracts, it gets shorter and thicker.

PRACTICE

1. EASY Can a skeletal muscle push? What is the only thing it can do?
2. EASY Name the partner muscle: (a) the biceps works with the ____. (b) The hamstrings work with the ____.

3. MEDIUM Name the three kinds of muscle and tell where each is found.
4. MEDIUM Noah did the clothespin test with each hand.
   Round: Right hand / Left hand
   1: 60 / 48
   2: 54 / 43
   3: 50 / 40
   4: 46 / 37
   5: 43 / 35
   (a) In round 1, how many more squeezes did the right hand make? (b) How much did each hand drop from round 1 to round 5? (c) Which hand do you think Noah writes with, and why?
5. MEDIUM What does a tendon do? Name the tendon at the back of your ankle and the two things it joins.
6. HARD You want to know whether resting for one minute between rounds helps your clothespin count stay higher. Name the variable you change, the control, what you measure and three things you keep the same.
7. HARD You pull your foot back and then kick a ball. In two or three sentences, explain what your thigh muscles do in each part of the kick.
8. CHALLENGE Your biceps attaches about 4 cm from your elbow, and your hand is about 32 cm from your elbow. Using Borelli’s lever idea, the hand moves about as many times farther than the attachment point as it is times farther from the elbow. If the attachment point moves 1 cm, about how far does the hand move? Why is this useful?

COMMON MISTAKES

- Thinking muscles can push. Every skeletal muscle only pulls, so straightening a joint needs a second muscle on the other side.
- Thinking the muscles that bend the fingers are in the fingers. They are mostly in the forearm, connected to the fingers by long tendons.
- Thinking all muscles are the kind you control. The heart’s cardiac muscle and the smooth muscle of the stomach work without your choosing.

Make it a game · Pull Partners. Players stand in a line. The caller names a motion: “Bend your elbow!”, “Straighten your knee!”, “Kick!”, “Lift your toes!” Each player does the motion and, within five seconds, calls out the muscle that is contracting (for example, biceps, quadriceps or hamstrings) and its partner that is relaxing. A correct pair earns a point. A bonus point goes to anyone who also names the joint that moved and its type.

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

Job saw his body as God’s handiwork, with bones and sinews (tendons) fitted together. Every time you bend an arm, muscles, tendons, joints and bones work as one design.

Practice answers

1. No. A muscle can only contract (get shorter) and pull.
2. (a) Triceps. (b) Quadriceps.
3. Skeletal muscle is attached to bones (arms, legs, face). Smooth muscle is in the walls of the stomach, intestines and blood vessels. Cardiac muscle is found only in the heart.
4. (a) 60 − 48 = 12 more. (b) Right: 60 − 43 = 17. Left: 48 − 35 = 13. (c) Probably his right hand, because it made more squeezes in every round; the hand used most is often stronger.
5. A tendon attaches a muscle to a bone. The Achilles tendon joins the calf muscles to the heel bone.
6. Change: resting one minute between rounds or not resting (or a short 10-second rest). Control: the rounds done without the long rest. Measure: the number of squeezes in each 30-second round. Keep the same (any three): the same hand, the same clothespin, 30-second rounds, the same number of rounds, the same person, the same time of day.
7. To pull the foot back, the hamstrings on the back of the thigh contract and bend the knee while the quadriceps relax. To kick, the quadriceps on the front contract and straighten the knee while the hamstrings relax and stretch.
8. 32 ÷ 4 = 8, so the hand moves about 8 cm (about 3 in). A short, quick muscle pull near the joint makes the hand move a long way fast, which helps us throw and reach, even though the muscle must pull hard.

Unit 2 review

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

1. (5 pts) Who was Andreas Vesalius, what book did he publish in 1543, and what did he do differently from professors who only read Galen aloud?
2. (5 pts) Why did Galen make some mistakes about the human body? Give one mistake and what Vesalius found instead.
3. (5 pts) How many bones does an adult have? Why does a newborn baby have more bony pieces than an adult?
4. (5 pts) Name the five jobs of the skeleton and give one example of a bone that protects an organ.
5. (5 pts) In the vinegar test, one chicken bone soaked in vinegar and one in plain water for five days. The vinegar bone became rubbery and the water bone stayed hard. What did the vinegar remove, and why was the water bone needed?
6. (5 pts) Name the type of joint and one place it is found: (a) swings back and forth in one direction, (b) a round end turning in a cup, (c) one bone turning around another, (d) does not move.
7. (5 pts) A straight knee makes a 180° angle. When fully bent, the angle between the thigh and the lower leg is 45°. How many degrees did the knee bend? What tissue covers the bone ends inside the knee so they do not rub?
8. (5 pts) What is the difference between a ligament and a tendon? What did Röntgen’s first X-ray of a hand, made in 1895, allow people to see for the first time?
9. (5 pts) Explain why muscles work in pairs, using the biceps and triceps as your example.
10. (5 pts) Mia squeezed a clothespin in four 30-second rounds and counted 52, 47, 43 and 38. (a) What was her average count? (b) What does the pattern show? (c) Name one thing she must keep the same to make the rounds a fair comparison.

Unit project: my moving skeleton and anatomist’s notebook

Build a life-size or half-size paper skeleton of yourself. Trace your body on a long sheet of paper, cut out the major bones from stiff paper, label each with its common and scientific name, and join them at the shoulders, elbows, hips and knees with brass paper fasteners so they move. Mark each joint with its type. Add cardboard-and-string biceps and triceps to one arm to show how a muscle pair bends and straightens the elbow.

Beside your skeleton, display your anatomist’s notebook: your Vesalius measuring table, your rubber-bone daily log, your thumb-test results and your model-arm lever table. Write one paragraph explaining what you learned about how bones, joints and muscles work together, and how working like Vesalius (looking, measuring and checking) helped you learn it.

- **Accuracy**: At least twelve bones are shaped, placed and labeled correctly, and every joint is marked with the correct type.

- **Working model**: The skeleton moves at its joints, and the muscle pair on the arm clearly shows that one muscle pulls to bend and the other pulls to straighten.
- **Records**: The notebook includes all four experiments with dated, complete tables, units in centimeters or seconds, and a conclusion for each test that names what was changed and what was kept the same.
- **Explanation and care**: The paragraph correctly explains how bones, joints and muscles work together, and the whole project is neat, careful and easy to read.

Answer key

1. Vesalius was a young doctor from Brussels who taught anatomy at Padua. He published *De humani corporis fabrica* (“On the Fabric of the Human Body”). He did the dissecting himself and compared the old books with what he actually saw in the human body.
2. Galen was not allowed to dissect humans, so he studied animals such as apes, pigs and dogs, and some of their parts differ from ours. Example: Galen said the lower jaw is two bones; Vesalius found the adult human jaw is one bone. (Or: Galen said the breastbone had seven parts; Vesalius found three.)
3. 206. A newborn has about 270 to 300 pieces, and as the child grows, some fuse together into single bones, such as the skull bones, the sacrum and the hip bones.
4. Support, protection, movement, making blood cells and storing minerals. Example: the skull protects the brain (or the ribs protect the heart and lungs).
5. The vinegar dissolved the hard calcium minerals, leaving the bendy collagen. The water bone was the control: it showed that soaking alone did not make the bone rubbery, so the vinegar caused the change.
6. (a) Hinge: elbow, knee or fingers. (b) Ball-and-socket: shoulder or hip. (c) Pivot: top of the neck. (d) Fixed joint (suture): the skull.
7. 180° − 45° = 135°. Cartilage covers the bone ends (with slippery joint fluid between them).
8. A ligament joins bone to bone; a tendon joins muscle to bone. Röntgen’s X-ray let people see the bones and joints inside a living person’s hand without cutting it open.
9. A muscle can only pull, never push. The biceps contracts to bend the elbow while the triceps relaxes; to straighten the arm, the triceps contracts and the biceps relaxes. One muscle is needed for each direction.
10. (a) 52 + 47 + 43 + 38 = 180; 180 ÷ 4 = 45 squeezes. (b) The counts drop each round, showing muscle fatigue. (c) Any one: the same hand, the same clothespin, the same 30-second time, the same rest between rounds.

UNIT 3

Heart and Blood

Put your hand on your chest and wait. There it is: a steady beat that began before you were born and has not stopped since. In this unit you will learn what that beat is doing. You will meet **William Harvey**, the English doctor who showed in 1628 that the blood travels in a great circle, pumped by the heart. You will count your own pulse the way Sir John Floyer did with his pulse-watch, look at blood through the eyes of Antoni van Leeuwenhoek and his tiny lenses, and stand beside James Blundell as he gave the first transfusions of human blood.

Along the way you will work like a real scientist: doing Harvey's arithmetic with a squeeze bottle, running a fair test on exercise and heart rate, measuring the layers of a model blood sample, and timing a gravity-fed "gravitator." You will read data tables and graphs, name the variable you change and the things you keep the same, and record everything in your lab notebook.

Long before anyone saw a red blood cell, Scripture said, "the life of the flesh is in the blood" (Leviticus 17:11). By the end of this unit you will be able to explain, with real science, why that is true, and you will have many reasons to say with the psalmist that we are "fearfully and wonderfully made."

BEFORE YOU BEGIN

- Can multiply and divide whole numbers (for example, 19 × 4 and 5,000,000 ÷ 5,000)
- Can read a clock or timer in seconds and measure with a metric ruler and measuring cup
- Knows that the body is made of cells, tissues and organs (Unit 1)
- Can read a simple bar graph and data table

MASTERY CHECKLIST

- I can tell how William Harvey showed that blood circulates and explain why Galen's idea could not be right.
- I can trace blood through the four chambers of the heart, to the lungs and to the body, and tell what arteries, veins, capillaries and valves do.
- I can find and count my pulse, turn a 15-second count into beats per minute, and explain why exercise raises heart rate.
- I can name the four parts of blood and the job of each.
- I can explain why blood must be matched by type before a transfusion and read a blood-type chart.
- I can plan a fair test that changes one variable, keeps other things the same and uses a control.

OPTIONAL BOOKS AND RESOURCES

- **KidsHealth: Your Heart and Circulatory System** (https://kidshealth.org/en/kids/heart.html): Free. A clear, child-friendly article on the heart, blood vessels and blood, written by doctors at Nemours Children's Health. Good for review after Lessons 3.1 and 3.3.
- **American Red Cross Blood Services** (https://www.redcrossblood.org/): Free. Parent-guided browsing for facts about blood types, how donation works and what happens to donated blood (Lesson 3.4). If a blood drive is held near you, a parent who donates can show the child the process.
- **Wellcome Collection (images of historic medicine)** (https://wellcomecollection.org/): Free. Search the online collection for "Harvey De motu cordis," "Leeuwenhoek microscope" and "Blundell transfusion" to see historic pictures from this unit. A parent should preview searches, since some medical images are graphic.

3.1 William Harvey and the Circulation of the Blood (1628) ★

OBJECTIVES

- Tell how William Harvey used careful experiments and simple arithmetic to show that blood travels in a circle, and explain why his idea replaced Galen's.
- Name the four chambers of the heart and trace the path of blood from the heart to the lungs, back to the heart, out to the body and home again.
- Explain the jobs of arteries, veins, capillaries and valves, and use multiplication to estimate how much blood the heart pumps.

Warm-up. Hold one hand down at your side for 30 seconds and look at the back of it. Do you see blue-looking lines under the skin? Now raise that hand high above your head for 30 seconds and look again. What happened to the lines? Write one sentence guessing why. (Those lines are veins, and you just watched gravity help them drain toward your heart.)

Video. Coming soon. William Harvey and the discovery of blood circulation, plus how the heart pumps (four chambers and valves), for children; search Homeschool Pop (Alternate), SciShow Kids, Science Max, TED-Ed history of medicine, and animated heart-anatomy clips from children's hospitals or the Smithsonian.

KEY TERMS

circulation
The trip blood makes around and around the body in a closed loop, pushed by the heart.

heart
A strong, hollow muscle about the size of your fist with four chambers. It squeezes to pump blood.

artery
A thick-walled blood vessel that carries blood away from the heart.

vein
A blood vessel that carries blood back toward the heart. Many veins have valves inside.

capillary
The tiniest blood vessel, so narrow that blood cells pass through in single file. Capillaries connect arteries to veins.

valve
A flap that lets blood flow only one way, like a door that opens in one direction.

CORE IDEAS

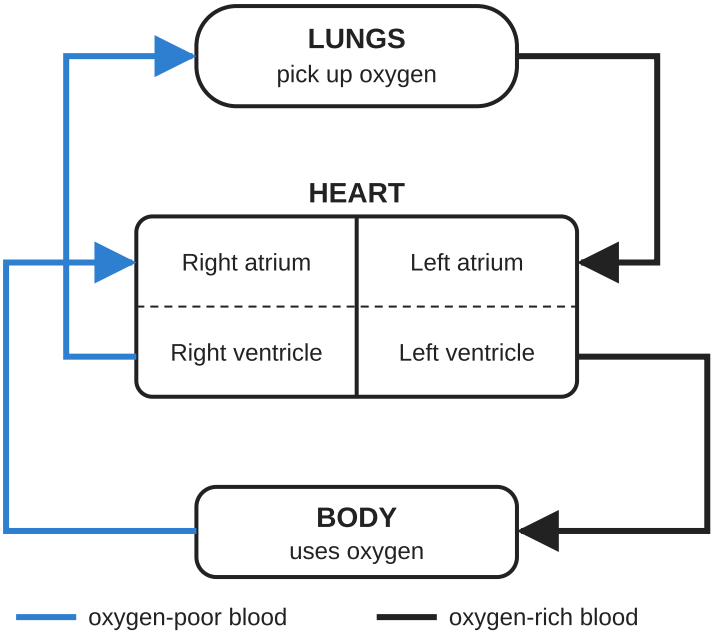
The story. In 1628 a small book of only 72 pages was printed in Frankfurt, Germany. Its Latin title meant *An Anatomical Study of the Motion of the Heart and of the Blood in Animals*. The author was William Harvey, an English doctor who cared for patients at St. Bartholomew's Hospital in London and served as physician to King James I and later King Charles I. For about 1,400 years, doctors had followed the teaching of Galen, a Greek physician of Roman times. Galen taught that the liver turned food into new blood, that the blood flowed out to the body and was used up there, like water soaking into a field. Harvey's little book said something startling: the same blood goes *around and around* in a circle.

How they figured it out. Harvey did not just think about the question; he looked and he measured. He watched the beating hearts of many kinds of animals, especially slow cold-blooded ones like frogs, snakes and eels, so he could see each squeeze clearly. He saw that when the heart squeezed, the arteries swelled. Then he did some arithmetic. Even if the heart pushed out only a small amount of blood with each beat, it beats thousands of times an hour. In half an hour it would push out more blood than the whole body holds, far more than a person could ever make from food. The blood could not be getting used up. It had to be coming back. Harvey had studied in Padua, Italy, under Fabricius, who had found small valves inside the veins. Harvey tied a band around a person's upper arm and pressed on the swollen veins below it. He showed that the valves let blood move only *toward* the heart, never away from it.

The big idea. Your heart is really two pumps side by side, with four rooms called chambers. Blood that has given away its oxygen comes back from the body into the **right atrium**, drops into the **right ventricle**, and is pumped to the lungs. In the lungs it picks up fresh oxygen and returns to the **left atrium**, then the **left ventricle**, the strongest chamber, which pumps it out to the whole body. **Arteries** carry blood away from the heart. **Veins** bring it back. In between are millions of **capillaries**, so thin that blood cells squeeze through them one at a time. Valves inside the heart and veins keep the blood moving one way, and their closing makes the "lub-dub" sound of your heartbeat. At rest, your blood makes a full trip around your body in about one minute.

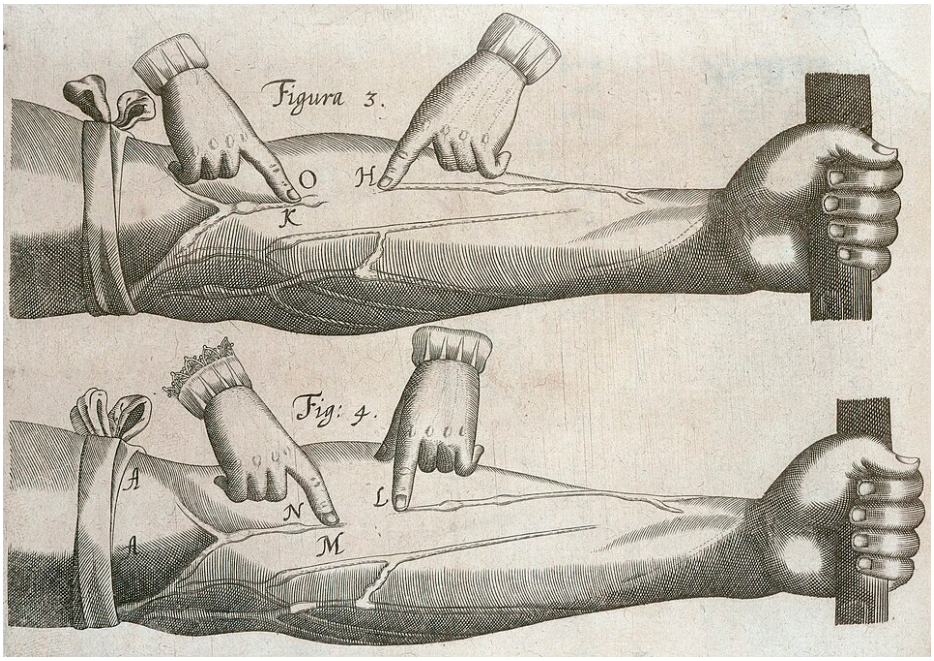
Try it and see. Harvey never saw capillaries; his lenses were not strong enough. He simply reasoned that tiny passages must join the arteries to the veins. In 1661, a few years after Harvey died, the Italian scientist Marcello Malpighi looked at a frog's lung through a microscope and saw them. Harvey's reasoning had been right. You can repeat a gentle form of Harvey's vein test on your own arm or the back of your hand in this lesson's project, and you can do his arithmetic with a squeeze bottle and a measuring cup.

God's handiwork. If all the blood vessels in a grown man's body were laid end to end, they would stretch about 100,000 kilometers (60,000 miles), more than twice around the earth. Your heart beats about 100,000 times a day without your ever reminding it, resting only in the short pause between one beat and the next. Harvey was a careful observer who believed nature was orderly and worth studying patiently. When we trace the path of the blood, we are reading the plan of the One who made us.



The two loops of circulation. The heart is drawn as if the person is facing you, so the heart's right side is on your left.

PICTURE STUDY



Figures of the Veins of the Arm, from De Motu Cordis, Engraving in William Harvey's book (based on drawings from his teacher Fabricius's book on the valves of the veins), 1628 · Engraving printed in a book · Printed copies of the 1628 book survive in many old libraries; scans of the figures are on Wikimedia Commons.

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

Harvey's book had only one page of pictures, but it may be one of the most important pages in the history of medicine. The figures show a forearm with a tight band tied around it, so the

veins swell and stand out. Along the veins are little knots marked with letters. Those knots are the valves.

The pictures were made to help a reader repeat Harvey's test on his own arm. They are not beautiful paintings; they are instructions. A good scientific drawing shows exactly what to look for, so anyone can check the claim.

Look closely

- Find the band tied around the arm. Which part of the arm is between the band and the hand?
- Find the small knots along the veins. What are they?
- Find a finger pressing on a vein. What do you think happens to the vein on one side of the finger?
- Notice the letters. Why would a scientist put letters on a drawing?

Talk about it

1. Why do you think Harvey wanted readers to try the experiment on their own arms instead of just believing him?
2. How is a scientific drawing different from a painting made to be beautiful?

> **Safety first.** Use only gentle finger pressure on veins, never a tight band, string or rubber band. Do the vein test with a parent present and stop if anything feels uncomfortable. Wipe up spilled water right away so no one slips.

EXPERIMENT: HARVEY'S ARITHMETIC: THE SQUEEZE-BOTTLE HEART

Harvey proved the blood must circle by doing simple arithmetic: a little blood per beat, times many beats, adds up to a huge amount. You will test his idea with a squeeze bottle as a model heart.

Question: How much water can a "heart" move in one minute? **Prediction:** Write your guess in milliliters before you start. **What we change:** the number of squeezes per minute. **What we keep the same:** the bottle, how hard you squeeze, and how full you keep the bottle. **What we measure:** the water collected.

You will need

- A soft plastic squeeze bottle with a cap that has a spout (such as a dish-soap or sports bottle, rinsed clean)
- A large bowl or dishpan of water
- A second large bowl to catch the water
- A measuring cup marked in milliliters (or cups)
- A clock or timer with a second hand
- Lab notebook and pencil

Steps

1. **Vein test first.** Let your arm hang down until the veins on the back of your hand or wrist show. Press one fingertip on a vein at the end nearest your fingers. With another finger, gently stroke along the vein *toward your heart*, away from the first finger. Lift the second finger. Does the vein stay flat for a moment? Then lift the first finger and watch it refill. Try stroking the other way and compare. Write what you see.
2. Fill the bottle with water. Squeeze it once, as hard as you comfortably can, into the empty catch bowl. Pour that into the measuring cup and record the milliliters. Do this three times and find the average. This is your “stroke volume.”
3. Predict how much one minute of squeezing will move if you squeeze 60 times. Multiply your stroke volume by 60 and write the prediction.
4. Now squeeze 60 times in one minute (about once a second) into the catch bowl, dipping to refill as you need. A partner can count and time. Measure the total water.
5. Repeat with 30 squeezes in one minute. Keep everything else the same.
6. Make a table: squeezes per minute, water moved (mL). Compare your measured numbers to your predictions.
7. A resting heart pushes about 70 milliliters (about 2.4 fluid ounces) per beat. Multiply 70 mL by your own resting pulse rate to estimate how much blood your heart moves in one minute.

Tips

- Your arm will get tired, so your squeezes may get weaker. That is a real result. Write it down. Your heart muscle is built never to tire that way.
- If you have no metric cup, measure in cups and remember 1 cup is about 240 mL.

Check your work

- I recorded my prediction before I measured.
- I kept the bottle and squeeze strength the same and changed only the number of squeezes.
- I can explain how Harvey’s arithmetic showed that the blood must come back to the heart.

NATURE NOTEBOOK

1. Draw the heart as a box with four rooms. Label right atrium, right ventricle, left atrium and left ventricle, and draw arrows to the lungs and to the body.
2. Draw what you saw in the vein test: a vein, your two fingers, and the empty stretch between them. Add a small sketch of a valve as a one-way door.
3. Make a two-column chart titled “Galen said / Harvey showed.” Write at least two lines in each column.

> **From history.** Harvey’s idea was not accepted at once. Some doctors mocked it, and his friend John Aubrey wrote that fewer patients came to Harvey for a while afterward. But

he kept answering his critics with experiments that anyone could repeat, and within his lifetime many of the best physicians in Europe agreed with him. During the English Civil War, Harvey stayed with King Charles I and is said to have looked after the king's sons during the Battle of Edgehill in 1642. He died in 1657, and the Royal College of Physicians in London still honors him with a yearly lecture, the Harveian Oration.

WORKED EXAMPLES

Example 1. A resting heart pushes out about 70 milliliters of blood with each beat and beats 70 times a minute. How much blood does it pump in one minute? The body of a grown man holds about 5 liters of blood. About how long does it take for all of it to go around once?

1. Blood per minute = blood per beat × beats per minute = 70 mL × 70 = 4,900 mL.
2. There are 1,000 mL in 1 liter, so 4,900 mL = 4.9 liters (about 5.2 quarts).
3. 4.9 liters is almost the same as the 5 liters in the whole body, so all the blood goes around about once each minute.

Answer: About 4,900 mL (4.9 L, about 5.2 quarts) per minute, so the whole supply circles about once a minute.

Example 2. Harvey's puzzle: Using the same heart (4.9 liters per minute), how much blood would the heart pump in one hour? How many times more is that than the 5 liters a man's body holds?

1. One hour has 60 minutes: 4.9 L × 60 = 294 liters.
2. Compare with the body's supply: 294 ÷ 5 is about 59.
3. No one could make 294 liters of new blood from food in an hour, or about 59 times the blood in the body. So, as Harvey reasoned, the same blood must be coming back to the heart again and again.

Answer: About 294 liters (about 78 gallons) in an hour, roughly 59 times the body's blood. The blood must circulate.

PRACTICE

1. EASY What do arteries do? What do veins do?
2. EASY Name the four chambers of the heart.
3. EASY What did Galen teach about blood, and what did Harvey show instead?
4. MEDIUM Put the steps in order, starting in the right atrium: left ventricle, lungs, right ventricle, body, left atrium.
5. MEDIUM A child's heart beats 90 times a minute. How many times does it beat in one hour? In one day (24 hours)?

6. MEDIUM Data table. A student squeezed a bottle heart and measured the water moved in one minute.
   Squeezes per minute: 20, 40, 60
   Water moved (mL): 600, 1,200, 1,700
   (a) How much water moved per squeeze at 20 squeezes per minute? (b) Which trial did not follow the pattern, and what is one likely reason?
7. HARD Experiment design. You want to test whether a bigger squeeze bottle moves more water per minute than a smaller one. What is the variable you change? Name two things you must keep the same. What do you measure?
8. CHALLENGE Harvey never saw a capillary, yet he was sure something must connect arteries to veins. Explain his reasoning in two or three sentences. Who finally saw capillaries?

COMMON MISTAKES

- Thinking blood in veins is blue. Blood is always red; blood low in oxygen is dark red. Veins only look bluish because of the way light passes through skin.
- Thinking arteries always carry oxygen-rich blood. Arteries carry blood *away* from the heart. The arteries going to the lungs carry oxygen-poor blood.
- Thinking the heart is on the far left of the chest. It sits near the middle, behind the breastbone, tipped a little to the left.

Make it a game · Blood Cell Relay. Set four chairs in a square and label them right atrium, right ventricle, left atrium and left ventricle. Put a pillow marked LUNGS on one side of the room and a pillow marked BODY on the other. You are a red blood cell holding a dark red paper (oxygen-poor). Run the correct path: from the right atrium to the right ventricle, to the LUNGS (swap your dark red paper for a bright red one), back to the left atrium, the left ventricle, out to the BODY (swap bright red for dark red), and home. A parent times you. Any wrong turn is a 5-second penalty. Try to beat your time while saying each place aloud.

Scripture. “I will praise thee; for I am fearfully and wonderfully made: marvellous are thy works; and that my soul knoweth right well.” (Psalm 139:14, KJV)

Harvey looked closely at something people had seen for thousands of years and found an order no one had noticed. The closer we look at the heart, the more there is to marvel at.

Practice answers

1. Arteries carry blood away from the heart. Veins carry blood back toward the heart.
2. Right atrium, right ventricle, left atrium, left ventricle.
3. Galen taught that the liver made new blood from food and the body used it up. Harvey showed that the same blood travels around the body in a circle, pumped by the heart.
4. Right atrium → right ventricle → lungs → left atrium → left ventricle → body → back to the right atrium.
5. 90 × 60 = 5,400 beats in an hour. 5,400 × 24 = 129,600 beats in a day.

6. (a) 600 ÷ 20 = 30 mL per squeeze. (b) The 60-squeeze trial: at 30 mL per squeeze it should have been about 1,800 mL, but it was 1,700 mL. Most likely the student’s hand got tired and the squeezes got weaker (or the bottle was not refilled fully).
7. Change: the size of the bottle. Keep the same: the number of squeezes per minute, the person squeezing (and how hard), the length of time, how full the bottles are kept. Measure: the milliliters of water moved in one minute (repeat each trial at least twice).
8. Harvey showed that blood leaves the heart in arteries and returns in veins, and that the amount pumped is far too great to be made new. So the blood must pass from the arteries into the veins somewhere in the body through passages too small to see. Marcello Malpighi saw capillaries in a frog’s lung with a microscope in 1661.

3.2 Take Your Pulse ★

OBJECTIVES

- Find the pulse at the wrist and neck, count it accurately, and turn a 15-second count into beats per minute.
- Explain what a pulse is and why the heart beats faster during exercise and slows down afterward.
- Plan and carry out a fair experiment on exercise and heart rate, record the data in a table, and draw a bar graph.

Warm-up. Sit very still and put two fingers (not your thumb) flat on the side of your neck, just beside your windpipe and under your jaw. Feel a soft, steady tap? Now try the thumb side of your wrist. Which place is easier for you? Tap the rhythm on the table so someone else can hear it.

Video. Coming soon. How to take your pulse and why heart rate rises with exercise, for children; search SciShow Kids, Homeschool Pop (Alternate), Science Max, children's hospital health channels, and the American Heart Association's kid-friendly heart-rate demonstrations.

KEY TERMS

pulse
The throb you feel in an artery each time the heart squeezes and pushes a wave of blood through it.

heart rate
How many times the heart beats in one minute, written in beats per minute (bpm).

resting heart rate
Your heart rate when you have been sitting or lying quietly for several minutes.

recovery
The return of the heart rate toward its resting rate after exercise stops.

variable
The one thing a scientist changes on purpose in an experiment to see what happens.

CORE IDEAS

The story. In 1707 an English doctor named Sir John Floyer, who lived in the cathedral town of Lichfield, published a book called *The Physician's Pulse-Watch*. For many centuries doctors had felt the pulse of their patients, but mostly they described it with words: strong or weak, quick or slow, hard or soft. Floyer wanted numbers. Most clocks and watches of his day were not good at timing short spans of seconds, so he had a special watch made to time his counting for one minute. With it he counted the pulse of healthy people and of sick

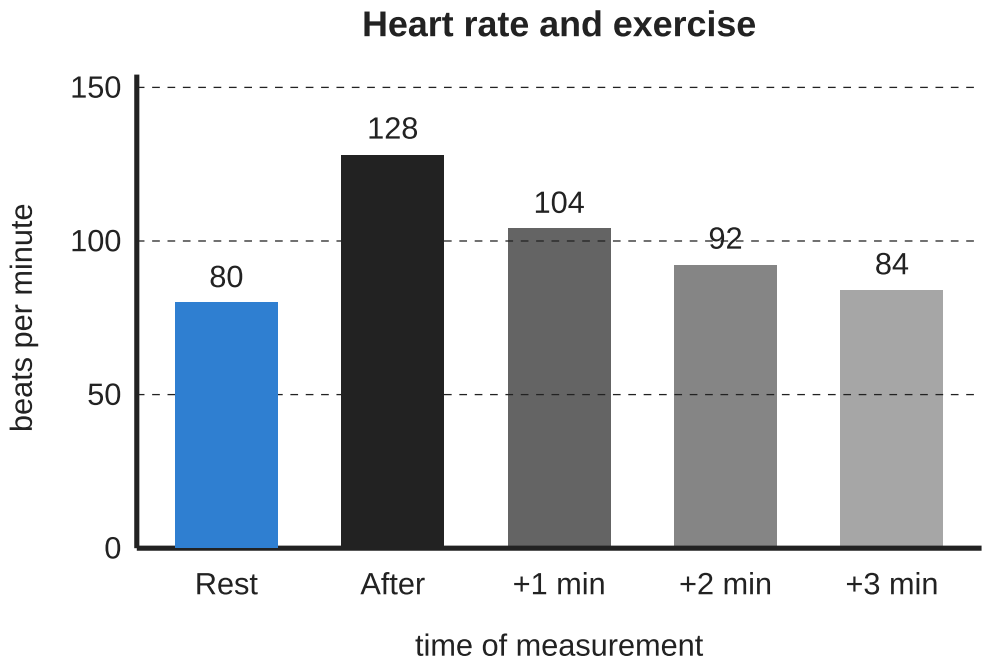
people, at rest and after work, and wrote the numbers down. Counting beats against a clock became one of the most useful things a doctor does, and it still is.

How they figured it out. Floyer was not the first to try. About a hundred years earlier, an Italian professor named Santorio Santorio of Padua had built a “pulsilogium,” a little swinging weight on a string. He made the string longer or shorter until the swings kept time with the patient’s pulse, then read the length on a scale. The idea came from the pendulum, which Galileo had studied. A pendulum of the same length always takes the same time for each swing, so it makes a steady clock. Today we use a clock or watch with a second hand, but the idea is the same: compare the beats to something steady.

The big idea. Your **pulse** is not blood rushing past your finger. It is a wave. Each time the left ventricle squeezes, it shoves blood into the big artery leaving the heart, and the stretchy artery walls bulge. That bulge travels along the arteries much faster than the blood itself flows, and you feel it wherever an artery runs close to the skin over something firm, such as the wrist bone or the side of the neck. So each pulse beat is one heartbeat. Your **heart rate** is the number of beats in one minute. For most children your age, the resting heart rate is somewhere around 70 to 100 beats per minute. For grown-ups it is usually 60 to 100, and very fit athletes may rest even lower.

Try it and see. When you run, jump or climb, your leg and arm muscles need much more oxygen and food. The blood carries both. So your brain sends signals that make the heart beat faster and harder, and you breathe faster too, to bring in more oxygen. When you stop, your heart rate drops back toward resting. This is called **recovery**. A strong, well-trained heart usually recovers faster, because it pumps more blood with each beat. In this lesson you will measure all of this yourself. To count quickly, count beats for 15 seconds and multiply by 4, since 15 seconds is one fourth of a minute.

God’s handiwork. No one has to remind your heart to speed up when you race a friend or slow down when you fall asleep. It adjusts itself, beat by beat, to what your body needs. Floyer and Santorio could count the pulse, but they could not make it. Every steady tap under your fingers is a reminder that our life is held in God’s hands.



One student's heart rate before and after one minute of jumping jacks. The bars climb, then step back down during recovery.

PICTURE STUDY



The Doctor's Visit, Frans van Mieris the Elder, 1667 · Oil on panel · J. Paul Getty Museum, Los Angeles

Frans van Mieris was a painter from Leiden in the Netherlands who was famous for small paintings so detailed that people looked at them with a magnifying glass. Doctors' visits were a favorite subject for Dutch painters of his time, and in many of these pictures the doctor is doing the same thing: holding the patient's wrist and feeling the pulse.

This was painted forty years before Floyer's pulse-watch. The doctor in the picture had no watch for counting. He had only his fingertips, his experience, and words like quick, slow, strong and weak.

Look closely

- Find the doctor's hand. Where exactly is he touching the patient?
- Look at the doctor's face. Is he looking at the patient, or does he seem to be listening and thinking?
- Find the other people in the room. How do they seem to feel?
- Look for small details the painter worked hard on: cloth, fur, metal, light on skin.

Talk about it

1. Why would a doctor of 1667 learn less from feeling a pulse than a doctor today who counts it against a clock?
2. If you were the doctor, what would you want to know about the pulse besides how fast it is?

> **Safety first.** Exercise only in a clear space, in good shoes or bare feet on a non-slippery floor. If you have asthma or any heart condition, ask a parent before doing the exercise part. Stop at once if you feel dizzy, faint or have chest pain, and sit down. Never press hard on both sides of the neck at the same time; use light pressure on one side only.

EXPERIMENT: EXERCISE AND HEART RATE: A FAIR TEST

Scientists answer questions by changing one thing and measuring what happens. You will test how exercise changes your heart rate and how quickly it recovers.

Question: How does one minute of jumping jacks change my heart rate, and how long does it take to come back down? **Prediction:** Write a number for your resting rate and your rate right after jumping. **What we change:** the activity (resting or jumping). **What we keep the same:** the person, the place you feel the pulse, the 15-second count, the length of exercise. **What we measure:** beats per minute. **Control:** your resting heart rate, measured before any exercise.

You will need

- A watch, clock or timer that shows seconds
- Lab notebook, pencil and ruler
- Graph paper or plain paper for a bar graph
- A partner (a parent or sibling) to time and record

Steps

1. Sit quietly for 3 minutes. Find your pulse at the wrist or neck with two fingers.

2. Count your pulse for 15 seconds while your partner times you. Multiply by 4. Do this three times and use the average as your resting heart rate.
3. Make a data table with two columns: Time and Heart rate (bpm). Rows: Rest, Right after, 1 minute after, 2 minutes after, 3 minutes after, 4 minutes after.
4. Do jumping jacks steadily for 1 minute.
5. Stop and at once sit down, find your pulse and count for 15 seconds. Multiply by 4 and record it as Right after.
6. Stay seated. At 1, 2, 3 and 4 minutes after stopping, count again for 15 seconds and record.
7. Draw a bar graph with the times along the bottom and beats per minute up the side. Write a title and label both axes.
8. If you have time, rest until you are back to normal and test a second person in your family the same way. Compare the two graphs.
9. Write a conclusion: Was your prediction right? How many minutes did it take to get within 10 beats of your resting rate?

Tips

- If you lose count, start the 15 seconds over. A careful count is better than a fast guess.
- Do not use your thumb to feel a pulse. Your thumb has its own pulse and can confuse you.
- Repeating the resting count three times shows you how much your numbers wobble even when nothing changes.

Check your work

- I can find my pulse and turn a 15-second count into beats per minute.
- I measured a resting heart rate as my control before exercising.
- My bar graph has a title, labeled axes and correct bars.

NATURE NOTEBOOK

1. Trace your hand and arm on a page. Mark with a red dot where you can feel a pulse on your wrist, and draw a small picture of your neck with a dot where you feel it there.
2. Draw Santorio’s pulsilogium: a weight swinging on a string next to a ruler. Write one sentence explaining how it worked.
3. Copy your exercise data table neatly and write one question your experiment made you wonder about.

> **From history.** In 1816 a French doctor, René Laennec, needed to listen to a patient’s heart. Putting his ear on the patient’s chest seemed improper, so he rolled a few sheets of paper into a tight tube, set one end on the chest and the other at his ear. To his surprise, the heart sounded louder and clearer than ever. He went on to make wooden tubes and named the instrument the *stethoscope*, from Greek words meaning “chest” and “to look at.” Doctors still listen to the “lub-dub” of the heart’s valves with stethoscopes today.

WORKED EXAMPLES

Example 1. Mia counts 19 pulse beats in 15 seconds. Her brother counts 38 beats in 30 seconds. What is each heart rate in beats per minute?

1. There are 60 seconds in a minute. 60 ÷ 15 = 4, so a 15-second count is multiplied by 4.
2. Mia: 19 × 4 = 76 beats per minute.
3. 60 ÷ 30 = 2, so a 30-second count is multiplied by 2.
4. Brother: 38 × 2 = 76 beats per minute.

Answer: Both are 76 beats per minute.

Example 2. Use the bar graph of one student's pulse (rest 80; right after 128; 1 minute after 104; 2 minutes after 92; 3 minutes after 84). (a) How much did the heart rate rise with exercise? (b) How much did it fall in the first minute of rest? (c) After 3 minutes, how far above resting was it?

(Use the map or drawing "Read each bar's height from the scale on the left." shown earlier in this lesson.)

1. (a) Rise: 128 − 80 = 48 beats per minute.
2. (b) First minute of recovery: 128 − 104 = 24 beats per minute.
3. (c) After 3 minutes: 84 − 80 = 4 beats per minute above resting.

Answer: (a) 48 bpm higher. (b) It fell 24 bpm in the first minute. (c) Only 4 bpm above resting after 3 minutes.

PRACTICE

1. EASY What is a pulse?
2. EASY Name two places on your body where you can easily feel a pulse. Why should you not use your thumb to feel it?
3. EASY You count 22 beats in 15 seconds. What is your heart rate in beats per minute?
4. MEDIUM Why does your heart beat faster when you run?
5. MEDIUM Data table. Three family members took their pulse before and right after climbing stairs for 1 minute.
   Dad: rest 64, after 112
   Mom: rest 72, after 116
   Sam (age 10): rest 84, after 140
   (a) Whose heart rate rose the most? By how much? (b) Who had the lowest resting rate?

6. MEDIUM Sir John Floyer and Santorio Santorio both worked on measuring the pulse. What did each one use to time it?
7. HARD Experiment design. Ben wants to know whether jumping rope or walking raises heart rate more. He jumps rope for 2 minutes and walks for 1 minute, and takes his pulse 5 minutes after walking. What is wrong with his test? How should he fix it, and what is his control?
8. CHALLENGE A grown-up's resting heart rate is 60 beats per minute and a child's is 90. How many more times does the child's heart beat in one hour? Why might a smaller heart need to beat more often?

COMMON MISTAKES

- Thinking the pulse is blood rushing under your finger. It is a pressure wave moving along the stretchy artery walls, which travels much faster than the blood itself.
- Forgetting to multiply. A count of 20 beats in 15 seconds is not a heart rate of 20; it is $20 \times 4 = 80$ beats per minute.
- Thinking a faster resting heart rate always means a healthier heart. In grown-ups, a fit heart often rests slower because it moves more blood with each beat.

> **Make it a game · Guess the Rate.** One player does an activity for 30 seconds: sitting still, walking around the room, hopping on one foot or doing jumping jacks. The other players guess that player's heart rate. Then the player counts a 15-second pulse and multiplies by 4. The closest guess wins a point. Take turns, and see who becomes the best "heart detective" after five rounds.

> **Scripture.** "For in him we live, and move, and have our being; as certain also of your own poets have said, For we are also his offspring." (Acts 17:28, KJV)

Paul told the people of Athens that our very life and movement depend on God. Every beat you counted today, at rest and while jumping, happened without your telling your heart what to do.

Practice answers

1. The throb felt in an artery each time the heart squeezes and sends a wave of pressure through the artery walls. Each pulse beat is one heartbeat.
2. The thumb side of the wrist and the side of the neck. The thumb has its own pulse, which can mix up your count.
3. $22 \times 4 = 88$ beats per minute.
4. Working muscles need more oxygen and food, which the blood carries. The heart beats faster (and harder) to send more blood to them each minute.
5. (a) Sam: $140 - 84 = 56$ bpm (Dad rose 48, Mom rose 44). (b) Dad, at 64 bpm.
6. Santorio used a pulsilogium, a swinging weight on a string whose length he matched to the pulse. Floyer had a special watch made to time his pulse counts for one minute.
7. He changed more than one thing: the time of exercise (2 minutes vs 1 minute) and when he measured (right after vs 5 minutes later). He should do each activity for the same time,

measure right after each one in the same way (15-second count × 4), and rest until he is back to his resting rate between tests. His control is his resting heart rate measured before exercise.

8. Child: 90 × 60 = 5,400. Adult: 60 × 60 = 3,600. The child’s heart beats 1,800 more times an hour. A smaller heart pushes out less blood with each beat, so it must beat more often to move enough blood for the body.

3.3 Blood Cells

OBJECTIVES

- Name the four parts of blood (plasma, red blood cells, white blood cells and platelets) and tell the job of each.
- Tell how Antoni van Leeuwenhoek’s tiny microscopes revealed red blood cells and capillaries, and explain why the shape and hemoglobin of red cells suit their work.
- Build a model of blood, measure the layers, and compare numbers of blood cells using simple division.

Warm-up. Look closely at a scrape or a healed scab from an old bump (or think of one you have had). How did the bleeding stop by itself? Write two guesses. Then fill a clear glass with water, stir in a spoonful of sand or dirt, and watch for one minute. What happens to the heavy bits? You will use that idea today.

Video. Coming soon. Parts of blood (red cells, white cells, platelets, plasma) and how a scab forms, for children; search SciShow Kids, Homeschool Pop (Alternate), Science Max, American Red Cross blood education clips, and real microscope footage of blood cells and capillary blood flow.

KEY TERMS

plasma
The pale yellow liquid part of blood, mostly water, that carries cells, food, salts and wastes. It is a little more than half of your blood.

red blood cell
A tiny, round, dented disk filled with hemoglobin that carries oxygen from the lungs to the body. Red cells are by far the most common blood cells.

hemoglobin
The iron-containing protein inside red blood cells that grabs oxygen in the lungs and lets it go in the body. It makes blood red.

white blood cell
A blood cell that defends the body against germs. Some swallow germs; others make antibodies that help destroy them.

platelet
A tiny piece of a cell that helps blood clot. Platelets stick together to plug a cut and start a scab.

bone marrow
The soft tissue inside many bones where new blood cells are made.

CORE IDEAS

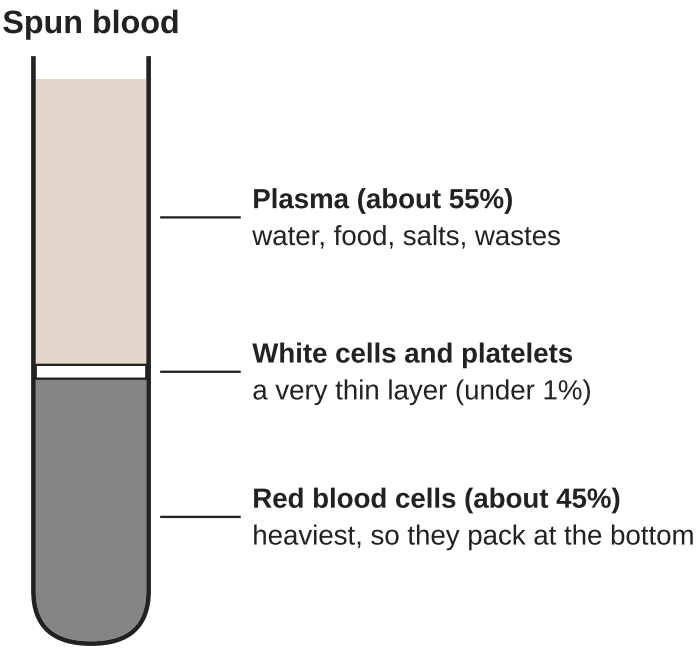
The story. In the Dutch town of Delft lived a cloth merchant named Antoni van Leeuwenhoek. He had no university training, but he had patience, sharp eyes and a gift for grinding and shaping tiny glass lenses. His microscopes were small brass or silver plates, about the size of a thumb, with one tiny lens set in a hole. Holding one close to his eye, he could see things magnified more than two hundred times. In the 1670s he began writing letters to the Royal Society in London describing what he saw, and among the many wonders he reported were the tiny reddish “globules” that make blood red. In human blood they were round; in the blood of fish and frogs, he noted, they were oval. Some years earlier, the Dutch naturalist Jan Swammerdam had also seen these particles in frog blood.

How they figured it out. Leeuwenhoek did not stop at a drop of blood on glass. He wanted to see blood *moving*. He placed a live tadpole and later a small eel in a water-filled glass tube and looked at its thin, clear tail. There he saw the red globules racing along in narrow channels, passing one by one from the tiny arteries into the tiny veins. These were the capillaries that William Harvey had reasoned must exist. With his own eyes Leeuwenhoek watched the blood circulate, just as Harvey had said, and he was delighted.

The big idea. Blood is a living tissue with four main parts. A little more than half of it is **plasma**, a pale yellow liquid that is mostly water and carries sugar from your food, salts, wastes and signals. Nearly all the rest is **red blood cells**. A single drop of blood holds about 250 million of them. Each one is a round disk with a dent on both sides, thin enough to bend through capillaries, and packed with **hemoglobin**, an iron-containing protein that grabs oxygen in the lungs and releases it in the body. Human red cells have no nucleus, which leaves more room for hemoglobin. A red cell lasts about 120 days, so the **bone marrow** must make about 2 million new ones every second. **White blood cells** are fewer and larger; some swallow germs whole, and others make antibodies that help destroy them. **Platelets** are tiny cell pieces. When you cut yourself, they pile up and stick at the cut, and threads form a net that traps red cells. The plug dries into a scab.

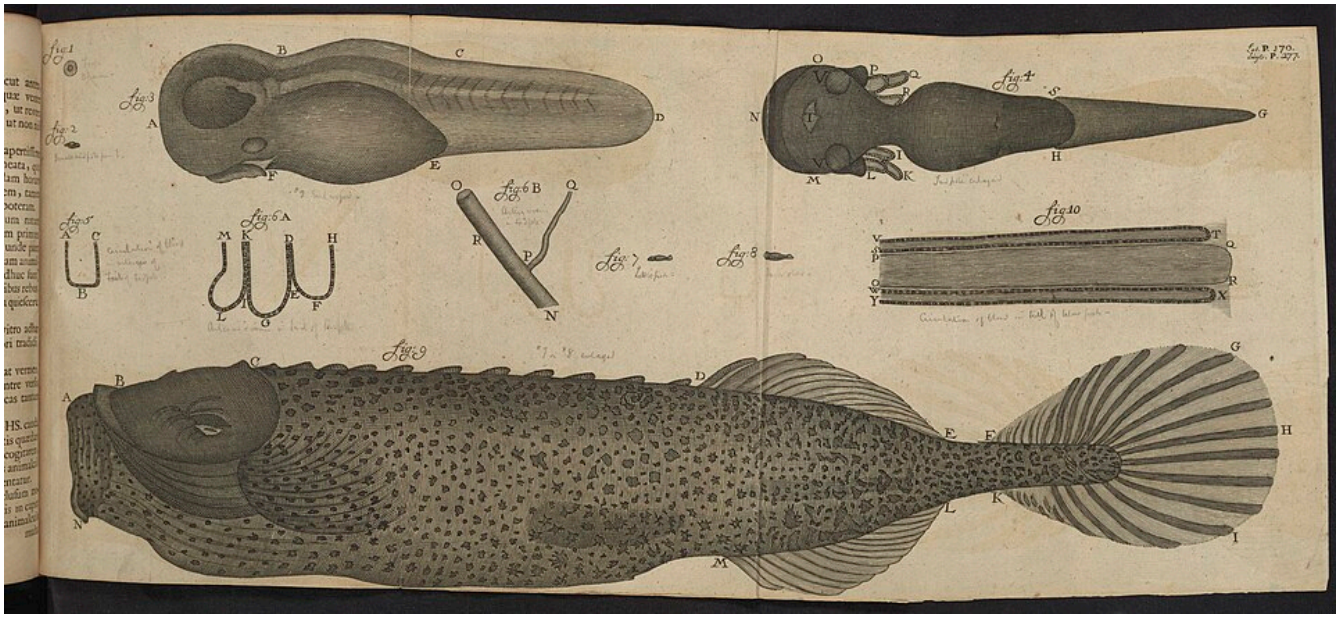
In the world today. When a doctor wants to check your blood, a nurse may take a small sample and a machine counts the cells. Another simple test spins a thin tube of blood very fast in a machine called a centrifuge. The heavy red cells pack at the bottom, a thin pale layer of white cells and platelets sits on them, and the yellow plasma rises to the top. The height of the red layer tells the doctor whether there are enough red cells. If there are too few, a person may have *anemia* and feel tired and pale, because not enough oxygen is being carried. Eating foods with iron, such as meat, eggs, beans and leafy greens, helps the body make hemoglobin.

God’s handiwork. Leeuwenhoek lived to be ninety and spent much of his life looking at a world no one had seen before. Each of us carries trillions of red cells, each one shaped just right to slip through the narrowest passages and to hold as much oxygen as possible. A merchant with a homemade lens showed that God’s workmanship is just as careful in the smallest things as in the largest.



Blood spun in a centrifuge separates into layers. The thin middle band holds the white cells and platelets.

PICTURE STUDY



Tadpoles, Frogs and Fish under the Microscope, from Leeuwenhoek's Letters, Drawn for Antoni van Leeuwenhoek and engraved for his published letters, 1695 · Engraving printed in a book · Science History Institute, Philadelphia (one printed copy)

Leeuwenhoek often had a hired artist draw what he showed through his tiny lenses, and engravers then cut the drawings into copper plates for printing. This page was printed in 1695 in a collection of his letters. It shows young frogs, tadpoles and small fish, and magnified views of the thin, clear parts of their tails, where he watched the blood moving.

Pictures like these let readers who had never looked through one of his lenses see what he had seen: blood cells passing from the smallest arteries into the smallest veins, just as William Harvey had reasoned they must.

Look closely

- Find the tadpoles and young frogs. How many different stages can you find?
- Find a magnified tail. Can you trace the lines that branch apart and join again?
- Look for the numbers beside the figures. How do they help a reader?
- Compare the whole animals with the magnified parts. How can you tell which drawings are magnified?

Talk about it

1. Why do you think Leeuwenhoek chose the thin, clear tail of a tadpole or fish to watch blood moving?
2. How does this page give evidence for Harvey’s idea that blood travels in a circle?

> **Safety first.** Never touch another person’s blood. If someone is bleeding, get a grown-up, who should wear gloves or use a clean cloth as a barrier. Do not prick your finger for this lesson; use the model, pictures, or a store-bought prepared slide of blood if you have a microscope. Keep dried lentils and beans away from small children, who could choke on them.

EXPERIMENT: A MODEL BLOOD TEST: HOW MUCH IS RED?

Doctors check for anemia by measuring what part of a blood sample is red cells. You will build two model “blood samples” and measure them the same way.

Question: If a blood sample has fewer red cells, how does the red layer change? **Prediction:** Write what percent of each jar you think will be red. **What we change:** the amount of “red cells” (dried red lentils). **What we keep the same:** the jars, the total height of the sample, the “plasma” (yellow water), the white cells and platelets. **What we measure:** the height of the red layer and the whole sample, in centimeters. **Control:** Jar A, the “healthy” model.

You will need

- Two identical clear, straight-sided jars or glasses
- Dried red lentils (red cells), about 1 cup (240 mL)
- Five dried white beans, such as navy beans (white cells)
- A pinch of sesame seeds or tiny cake sprinkles (platelets)
- Water with one drop of yellow food coloring (plasma)
- Measuring cup, ruler marked in centimeters, masking tape and marker
- Lab notebook and pencil

Steps

1. Put a strip of masking tape up the side of each jar. Mark a fill line about 12 centimeters (about 4¾ inches) from the bottom on both jars.
2. Jar A (healthy model): pour in lentils until they reach a little less than half the fill line. Add 3 white beans and a pinch of sesame seeds.
3. Jar B (anemia model): pour in only half as many lentils as Jar A. Add 2 white beans and the same pinch of sesame seeds.
4. Slowly pour yellow water into each jar up to the fill line. Stir each jar, then let both stand for 2 minutes.
5. Observe: Where did the lentils settle? Where are the sesame seeds? Draw both jars.
6. Measure the height of the red layer and the total height (to the fill line) in each jar. Record them in a table.
7. Calculate the percent red for each jar: red height ÷ total height × 100. Compare with real blood, which is roughly 40 to 45 percent red cells.
8. Write a conclusion: How would a doctor know from a spun tube that someone had too few red cells?

Tips

- Sight the layers at eye level, the way scientists read a measuring cup.
- Your model is much simpler than real blood. In real blood there are hundreds of red cells for every white cell, and everything is far too small to see without a microscope.
- If you have a microscope, look at a prepared slide of human blood and count how many white cells you find among the red ones in one view.

Check your work

- I changed only the amount of “red cells” and kept everything else the same.
- I measured both layers in centimeters and calculated a percent.
- I can name the four parts of blood and tell the job of each.

NATURE NOTEBOOK

1. Draw a red blood cell from the top (a circle) and from the side (a disk thinner in the middle). Next to it draw a white blood cell and a few platelets. Label each with its job.
2. Draw Leeuwenhoek’s tiny microscope from a picture: a small metal plate with a lens in it and a pin to hold the specimen.
3. Draw the four steps of a scab forming: cut, platelets pile up, net of threads traps red cells, dry scab.

> **From history.** For a long time, people thought there was only one kind of human blood. In 1901, an Austrian doctor named Karl Landsteiner mixed blood from different people in Vienna and found that some samples clumped together and others did not. He discovered the blood groups we now call A, B and O, and his co-workers soon found a fourth, AB.

> Because of his discovery, doctors learned to match blood before giving it to a patient, and Landsteiner received the Nobel Prize in 1930.

WORKED EXAMPLES

Example 1. A tiny speck of blood 1 millimeter on each side (1 cubic millimeter) holds about 5,000,000 red blood cells, 5,000 white blood cells and 250,000 platelets. (a) How many red cells are there for each white cell? (b) How many red cells for each platelet?

1. (a) Divide red cells by white cells: 5,000,000 ÷ 5,000 = 1,000.
2. (b) Divide red cells by platelets: 5,000,000 ÷ 250,000 = 20.
3. So red cells far outnumber everything else. That is why blood looks red.

Answer: (a) About 1,000 red cells for every white cell. (b) About 20 red cells for every platelet.

Example 2. A red blood cell is about 7.5 micrometers across, which is 0.0075 millimeter. About how many red cells lined up edge to edge would stretch across 1 millimeter? Across 1 centimeter (about the width of your fingernail)?

1. Divide the length by the size of one cell: 1 mm ÷ 0.0075 mm ≈ 133.
2. 1 centimeter = 10 millimeters, so 133 × 10 ≈ 1,330 (more exactly 10 ÷ 0.0075 ≈ 1,333).
3. A row of more than a thousand red cells could fit across a fingernail.

Answer: About 133 cells across 1 mm, and about 1,330 across 1 cm (about 0.4 inch).

PRACTICE

1. EASY Name the four parts of blood.
2. EASY Match each part to its job: (1) red blood cells, (2) white blood cells, (3) platelets, (4) plasma. Jobs: A. fight germs, B. carry oxygen, C. help blood clot, D. carry food, salts and wastes in a liquid.
3. EASY Where in the body are new blood cells made?
4. MEDIUM Give two ways the red blood cell is well suited to its job.
5. MEDIUM A red blood cell lives about 120 days. About how many times are your red blood cells replaced in one year (365 days)? Round to the nearest whole number.
6. MEDIUM Data table. Three model blood jars were measured.
   Jar A: red layer 5.4 cm, total 12 cm
   Jar B: red layer 2.7 cm, total 12 cm
   Jar C: red layer 6 cm, total 12 cm
   (a) What percent of each jar is red? (b) Which jar models anemia?

7. HARD Experiment design. Lily wants to know if a cut on the arm stops bleeding faster when you press on it. (She will use a model: a sponge “wound” with colored water and a paper towel, not real blood.) What is the variable she changes? What is her control? Name two things she must keep the same and one thing she measures.
8. CHALLENGE How did Leeuwenhoek’s observation of a tadpole’s or eel’s tail support William Harvey’s idea? Write two or three sentences.

COMMON MISTAKES

- Thinking blood is only a red liquid. More than half of blood is pale yellow plasma; the red color comes from the red cells floating in it.
- Thinking white blood cells are as common as red ones. There are hundreds of red cells for every white cell.
- Thinking a scab is dirt or dead skin. A scab is dried clotted blood: platelets, threads of protein and trapped red cells, which protect the cut while new skin grows under it.

> **Make it a game · Who Am I? Blood Edition.** Write each of these on a card: red blood cell, white blood cell, platelet, plasma, hemoglobin, bone marrow, capillary. One player draws a card and gives clues without saying the word, such as “I carry oxygen and I am shaped like a dented disk.” The others guess. A correct guess after one clue earns 3 points, after two clues 2 points, after three clues 1 point. Then switch.

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

Leeuwenhoek took pleasure in seeking out the small works of God, and the more closely he looked, the more he found. These words were later carved over the door of the famous Cavendish Laboratory in Cambridge.

Practice answers

1. Plasma, red blood cells, white blood cells and platelets.
2. 1-B, 2-A, 3-C, 4-D.
3. In the bone marrow, the soft tissue inside many bones.
4. Any two: it is a thin, flexible, dented disk that can bend through narrow capillaries; it is packed with hemoglobin, which holds oxygen; it has no nucleus, leaving more room for hemoglobin; its thin shape lets oxygen move in and out quickly.
5. 365 ÷ 120 ≈ 3.04, so about 3 times a year.
6. (a) A: 5.4 ÷ 12 × 100 = 45%. B: 2.7 ÷ 12 × 100 = 22.5%. C: 6 ÷ 12 × 100 = 50%. (b) Jar B, because it has far fewer red cells than normal blood (about 40 to 45 percent).
7. Variable: pressing on the “wound” or not pressing. Control: the trial with no pressure. Keep the same: the sponge, the amount of colored water, the size of the paper towel, how long she waits. Measure: how much colored water leaks out (for example, the size of the wet spot) or how long until it stops dripping.
8. Harvey reasoned that blood must pass from arteries to veins through tiny passages he could not see. Leeuwenhoek, using his microscope on the thin, clear tail, saw red blood cells moving

one by one through tiny channels from the small arteries into the small veins. This showed with his own eyes that the blood really does circulate, as Harvey had said.

3.4 "The Life of the Flesh Is in the Blood" (Leviticus 17:11)

OBJECTIVES

- Explain why the body cannot live without blood, and estimate how much blood a person has from body mass.
- Tell how James Blundell gave the first successful transfusions of human blood and how the discovery of blood types made transfusion safe.
- Read a blood-type chart to decide which donor blood a patient can receive, and test how height affects the flow of a gravity-fed tube.

> **Warm-up.** Fill a large measuring cup or jug with 5 liters (about 5¼ quarts) of water, using a 1-liter bottle or a quart jar five times. That is about how much blood is in a grown man's body. Now pour out a little less than 500 mL (1 pint) into a glass. That is how much one person gives when donating blood. Guess: how much do you think is in your own body?

> **Video.** Coming soon. How blood donation and blood types work, and the history of blood transfusion, for children; search the American Red Cross, SciShow Kids, Homeschool Pop (Alternate), Science Max, and children's hospital clips that show what happens to donated blood.

KEY TERMS

transfusion
Giving blood (or part of blood) from one person into the veins of another person who needs it.

donor
A healthy person who gives blood so that someone else can receive it.

recipient
The patient who receives the donated blood.

blood type
The group a person's blood belongs to (A, B, AB or O), set by markers on the red blood cells. Blood must be matched before a transfusion.

blood bank
A place where donated blood is tested, separated into parts, labeled and stored until a patient needs it.

CORE IDEAS

The story. In London in 1818, a doctor named James Blundell faced a terrible problem. He cared for mothers having babies, and sometimes after a birth a mother bled so heavily that

she died, with nothing anyone could do. Blundell reasoned that if a person was dying from losing blood, the answer was to put blood back. He first studied the question carefully with animals, and then, at Guy's Hospital, he gave a patient blood taken from another *person*, the first recorded transfusion of human blood into a human being. Over the next years he tried it on other patients who were bleeding to death. Not all of them lived, but some did. In 1829 he reported in the medical journal *The Lancet* that a young mother who had bled badly after childbirth recovered after receiving blood.

How they figured it out. Others had tried before. In 1667 a French doctor named Jean-Baptiste Denys put lamb's blood into the veins of a patient, but animal blood is not made for the human body, and later attempts went badly enough that the practice was stopped for well over a century. Blundell insisted that only human blood should be used for people. He even designed an instrument he called the "gravitator," a cup on a stand with a tube running down to the patient. Blood from the donor was collected in the cup and flowed down by gravity into the patient's vein, just as a hospital drip bag hangs high today. But one mystery remained: why did some transfusions help and others make patients very sick? The answer came in 1901, when Karl Landsteiner discovered the blood groups. Blood from a mismatched donor clumps, and that clumping is dangerous.

The big idea. Blood carries oxygen and food to every cell, carries wastes away, fights germs and seals cuts. If the body loses too much blood too fast, the cells, especially in the brain, quickly run short of oxygen. That is why losing a large amount of blood is an emergency. A person has roughly 70 to 80 milliliters of blood for every kilogram of body mass, so a grown man has about 5 liters (about 5¼ quarts) and a child your age has perhaps half that. Today blood is matched by **blood type** before it is given. Type O red cells can go to patients of any ABO type, which is why O donors are so valuable in emergencies. Type AB patients can receive red cells of any ABO type. (Doctors also check another marker called Rh, the "positive" or "negative" you may hear in a blood type, but the ABO groups come first.)

In the world today. Healthy grown-ups and older teenagers give blood at blood drives and donation centers. A donor gives a little under 500 milliliters (about 1 pint), a small part of the whole. The body replaces the lost plasma within about a day and the red cells within a few weeks. Each gift is tested, labeled by type, and separated into red cells, plasma and platelets in a blood bank, so one donation can help more than one patient: a child with a serious illness, a mother after a hard birth, or a person hurt in an accident.

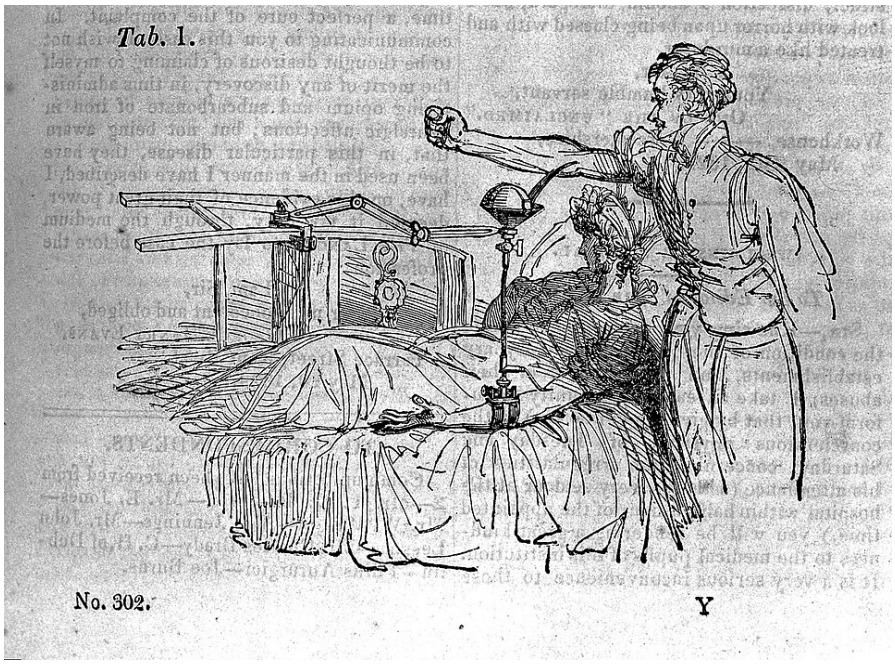
God's handiwork. Thousands of years before Harvey, God told Israel in the law given through Moses, "For the life of the flesh is in the blood" (Leviticus 17:11). For centuries afterward many doctors drained blood from sick people, believing it would let out disease. In 1799 George Washington's physicians took a large amount of his blood as he lay dying of a throat infection; they were doing what the best medicine of their time taught. Later science showed what Scripture had said plainly: the body's life is carried in its blood. The same verse points beyond the body, too. God gave the blood of the sacrifices to make atonement, and Christians believe those sacrifices pointed ahead to Jesus Christ, who gave His own blood for sinners.

Donor type	Patient (recipient) type: O	A	B	AB
O	YES	YES	YES	YES
A	no	YES	no	YES
B	no	no	YES	YES
AB	no	no	no	YES

YES = safe to give red cells (ABO only)

Which red cells can a patient safely receive? Read across from the donor's type (ABO groups only).

PICTURE STUDY



Blundell's Gravitator, Engraving from *The Lancet*, illustrating James Blundell's transfusion apparatus, 1829 · Engraving printed in a medical journal · Published in *The Lancet*, London; copies of the journal are kept in medical libraries

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

This plain drawing from a London medical journal shows James Blundell's "gravitator." Blood from the donor's arm was caught in a cup held high on a stand, and a tube carried it down into a vein in the patient's arm. Gravity did the pushing.

Blundell published drawings like this one so other doctors could build the same instrument and save lives. Like Harvey's figures, it is a picture made to teach, not to decorate.

Look closely

- Find the cup. Why is it held up high?
- Follow the tube with your finger from the cup to the patient. Where does it go in?
- Find the donor. Where is the blood coming from?
- Look for any part that could be raised or lowered. Why might that matter?

Talk about it

1. Why do you think Blundell used gravity instead of a pump?
2. Hospital drip bags still hang above patients today. What does that tell you about Blundell's idea?

> **Safety first.** This project uses only water. Never use a real needle or try to draw blood. Work over a sink, tub or outdoors, and wipe up spills right away. A grown-up should hold or tape the funnel stand if it is on a chair or shelf.

EXPERIMENT: BUILD A GRAVITATOR: DOES HEIGHT CHANGE THE FLOW?

Blundell let gravity carry blood from a cup down a tube into a patient. Hospital drip bags still hang high above the bed. You will build a water model and test how height affects flow.

Question: Does a higher cup make water flow through the tube faster? **Prediction:** Write which height will drain fastest. **What we change:** the height of the funnel above the bowl. **What we keep the same:** the funnel, the tube, the amount of water (250 mL, about 1 cup), the bowl. **What we measure:** the time, in seconds, for the water to drain.

You will need

- A kitchen funnel
- About 1 meter (about 3 feet) of clear plastic aquarium tubing that fits snugly on the funnel spout
- Measuring cup
- Water with a drop of red food coloring
- A bowl to catch the water, set on the floor or in the sink
- Stopwatch or timer, meter stick or tape measure
- Lab notebook and pencil; bathroom scale (for the blood-volume part)

Steps

1. Push one end of the tubing onto the funnel spout. Put the other end in the catch bowl.
2. Pinch the tube closed. Have a partner hold the funnel 20 centimeters (about 8 inches) above the bowl. Pour in 250 mL of red water.
3. Let go of the pinch and start the timer. Stop when the funnel is empty. Record the time.

4. Repeat at 50 centimeters (about 20 inches) and at 80 centimeters (about 31 inches). Do each height twice and average the times.
5. Make a table: Height (cm), Time trial 1, Time trial 2, Average time.
6. Write a conclusion: How did height change the flow? Why do nurses hang drip bags high?
7. **Blood-volume part.** Weigh yourself in kilograms (pounds ÷ 2.2). Multiply by 75 mL to estimate your blood volume. Fill jars or bottles with that much red water and set them beside the 5-liter grown-man amount from the warm-up.

Tips

- Keep the bottom end of the tube at the same place every time, so only the funnel height changes.
- If air bubbles stop the flow, squeeze the tube gently or start again.
- The 75 mL per kilogram rule gives an estimate, not an exact amount.

Check your work

- I changed only the funnel height and kept the water amount and tube the same.
- I repeated each height and averaged the times.
- I can explain why blood types must be matched before a transfusion.

NATURE NOTEBOOK

1. Draw your gravitator model and label the funnel, the tube, the height you measured and the bowl.
2. Copy the blood-type chart and circle your own family's blood types if your parents know them.
3. Copy Leviticus 17:11 in your best handwriting and draw a border of red blood cells around it.

> **From history.** Dr. Charles Drew, an American surgeon, studied how to store blood plasma, which keeps much longer than whole blood. In 1940, during World War II, he led the "Blood for Britain" project, which collected and shipped plasma from New York to help wounded soldiers and civilians in Britain. He then became the first director of the American Red Cross blood bank in 1941. His careful methods of collecting, testing and storing blood helped make modern blood banks possible.

WORKED EXAMPLES

Example 1. A child has a mass of 35 kilograms (about 77 pounds). If the body has about 75 milliliters of blood for each kilogram, about how much blood does the child have? Give the answer in milliliters, liters and quarts (1 liter ≈ 1.06 quarts).

1. Blood volume = 35 kg × 75 mL per kg = 2,625 mL.
2. 2,625 mL ÷ 1,000 = 2.625 liters, about 2.6 liters.
3. 2.6 × 1.06 ≈ 2.8 quarts.

Answer: About 2,625 mL, about 2.6 liters (about 2.8 quarts).

Example 2. A grown man has about 5,000 mL of blood. He donates 470 mL (about 1 pint). What percent of his blood did he give? How much is left?

1. Percent given = 470 ÷ 5,000 × 100 = 9.4%.
2. Blood left = 5,000 − 470 = 4,530 mL.
3. Less than one tenth of his blood was given, and his body will replace the plasma within about a day and the red cells within a few weeks.

Answer: About 9.4 percent (less than one tenth); about 4,530 mL is left.

PRACTICE

1. EASY What is a transfusion? What is the difference between a donor and a recipient?
2. EASY Who gave the first recorded transfusion of human blood to a human patient, and in what city?
3. EASY Name the four ABO blood types.
4. MEDIUM Why did some early transfusions help patients and others make them very sick? Who discovered the reason?
5. MEDIUM Data chart. Use the blood-type chart. (a) A patient with type B blood needs red cells. Which donor types can be used? (b) A donor has type A blood. Which patients can receive it? (c) Which donor type can give to every ABO type?
   (Use the map or drawing "Read across from the donor's type." shown earlier in this lesson.)
6. MEDIUM A child has a mass of 40 kilograms (about 88 pounds). Using 75 mL of blood per kilogram, estimate the child's blood volume in liters.
7. HARD Experiment design. In the gravitator test, Noah wants to know whether a wider tube lets water flow faster. What variable does he change? Name three things he must keep the same. What does he measure, and why should he repeat each trial?
8. CHALLENGE Leviticus 17:11 says, "the life of the flesh is in the blood." Using what you learned in this unit, give two scientific reasons the body cannot live without blood.

COMMON MISTAKES

- Thinking any person's blood can be given to any other person. Blood must be matched by type, or the red cells can clump.
- Thinking that giving blood leaves a healthy donor with much less blood for months. A donor gives less than one tenth of his blood, and the body replaces the plasma in about a day and the red cells in a few weeks.
- Thinking the old practice of bleeding sick people helped them. For most illnesses it made patients weaker. Doctors of the past did it because they sincerely believed it worked; careful study later showed otherwise.

Make it a game · Blood Bank Match-Up. Make 8 donor cards (two each of O, A, B and AB) and 8 patient cards (two each of the same types). Shuffle the patient cards and lay them face down. Turn one over; the first player to name a safe donor type and lay that card beside it wins the pair. A wrong match costs a card. When the donor cards run out, count your pairs. Bonus point: say why type O donors are so valuable.

Scripture. "For the life of the flesh is in the blood: and I have given it to you upon the altar to make an atonement for your souls: for it is the blood that maketh an atonement for the soul." (Leviticus 17:11, KJV)

This verse was written long before anyone knew about red cells or oxygen, and it is true of the body exactly as stated. It also teaches that life is precious and belongs to God, and it points to the greater gift of the blood of Christ (Hebrews 9:22).

Practice answers

1. A transfusion is giving blood from one person into the veins of another. The donor gives the blood; the recipient receives it.
2. James Blundell, in London (at Guy's Hospital), in 1818.
3. A, B, AB and O.
4. Blood was not matched by type. When a patient received blood of the wrong group, it clumped, which is dangerous. Karl Landsteiner discovered the blood groups in 1901.
5. (a) Type B or type O. (b) Patients with type A or type AB. (c) Type O.
6. 40 × 75 = 3,000 mL = 3 liters (about 3.2 quarts).
7. Change: the width of the tube. Keep the same: the funnel height, the length of the tube, the amount of water, the same funnel and bowl. Measure: the time in seconds for the water to drain. He repeats each trial (and averages) because single measurements can be off from small mistakes in timing or pouring.
8. Any two: red cells carry oxygen from the lungs to every cell, and without oxygen the cells (especially brain cells) quickly die; plasma carries food and carries away wastes; white cells defend against germs; platelets seal cuts so the body does not keep bleeding. Losing a large amount of blood quickly is deadly because the cells are starved of oxygen.

Unit 3 review

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

1. (5 pts) What did Galen teach about blood? What did William Harvey show in 1628 instead?
2. (5 pts) A heart pumps 60 mL of blood per beat and beats 80 times a minute. How much blood does it pump in one minute? Give the answer in mL and liters.
3. (5 pts) Trace the path of blood beginning in the right atrium and ending back in the right atrium. Name each chamber and where the blood goes after the right ventricle and after the left ventricle.
4. (5 pts) What is the job of the valves in the veins? How did Harvey use them as evidence?
5. (5 pts) You count 21 beats in 15 seconds. What is your heart rate in beats per minute? What is a pulse?
6. (5 pts) A student's heart rate was 78 at rest, 132 right after exercise, 108 one minute later and 90 two minutes later. (a) How much did it rise with exercise? (b) Why does the heart beat faster during exercise?
7. (5 pts) You want to test whether five minutes of bike riding raises heart rate more than five minutes of walking. Name the variable you change, two things you keep the same, and your control.
8. (5 pts) Name the four parts of blood and give the job of each.
9. (5 pts) What did Antoni van Leeuwenhoek see in a tadpole's or eel's tail, and why was it important?
10. (5 pts) (a) Who gave the first recorded transfusion of human blood to a human, and when? (b) A patient has type A blood. Which ABO donor types can give red cells to this patient? (c) Give one scientific reason that "the life of the flesh is in the blood."

Unit project: my heart and blood lab book

Make a lab book about your own heart and blood. Include a large labeled drawing of the heart's four chambers with arrows showing the two loops to the lungs and the body; your squeeze-bottle data table; your exercise-and-pulse table with a neat bar graph; your model blood-test jars drawn and measured; and your gravitator table. Finish with a one-page report titled "The Life Is in the Blood" that tells the stories of Harvey, Leeuwenhoek and Blundell in your own words and explains, with real science, why the body cannot live without blood.

- **Accuracy**: Heart chambers, vessels and the parts of blood are labeled correctly, and the path of blood is shown in the right order.
- **Data and graphs**: Tables are complete with units; calculations (beats per minute, percents, volumes) are correct; the bar graph has a title, labeled axes and correct bars.
- **Fair testing**: Each experiment names the question, prediction, the variable changed, what was kept the same, the control (where used) and a clear conclusion.

- **Explanation and care**: The report tells the three scientists' stories accurately, explains why blood is necessary for life, and the lab book is neat, dated and easy to read.

Answer key

1. Galen taught that the liver made new blood from food and that the body used it up. Harvey showed that the same blood circulates around and around the body in a closed loop, pumped by the heart.
2. 60 × 80 = 4,800 mL = 4.8 liters (about 5.1 quarts) per minute.
3. Right atrium → right ventricle → lungs (picks up oxygen) → left atrium → left ventricle → body (gives up oxygen) → back to the right atrium.
4. Valves let blood flow only toward the heart. Harvey pressed on veins in the arm and showed that blood could move only toward the heart, not away from it, so blood in the veins must be returning to the heart.
5. 21 × 4 = 84 beats per minute. A pulse is the throb of an artery each time the heart squeezes and sends a wave of pressure through it; each pulse beat is one heartbeat.
6. (a) 132 − 78 = 54 beats per minute. (b) Working muscles need more oxygen and food, so the heart beats faster to send more blood to them.
7. Change: the kind of exercise (biking or walking). Keep the same: the person, the length of exercise, when and how the pulse is measured (right after, 15-second count × 4), resting fully between tests. Control: the resting heart rate measured before exercise.
8. Plasma: the liquid that carries food, salts and wastes. Red blood cells: carry oxygen using hemoglobin. White blood cells: fight germs. Platelets: help blood clot and seal cuts.
9. Through his microscope he saw red blood cells moving one by one through tiny capillaries from the small arteries into the small veins. It showed with the eye what Harvey had reasoned: blood really does circulate from arteries to veins.
10. (a) James Blundell, in London, in 1818. (b) Type A or type O. (c) For example: red blood cells carry oxygen to every cell, and without oxygen the cells (especially in the brain) quickly die.

UNIT 4

Lungs

In the last unit you followed the blood around its great circle through the body. But blood would be no use without the lungs, where it picks up the oxygen every cell needs and drops off the carbon dioxide every cell makes. In this unit you will discover how two soft, spongy organs with no muscles of their own fill and empty more than 20,000 times a day, how much air they can hold, how they speed up when you run, and how they keep themselves clean.

You will build John Mayow's bellows idea in a plastic bottle, measure your breath with a water-jug spirometer like John Hutchinson's, count your breaths before and after exercise like Roger Bannister in the Oxford laboratory, and catch the specks in the air on sticky cards while learning how Richard Doll and Austin Bradford Hill proved that smoking causes lung cancer. In every lesson you will work like a real scientist: predict, change one thing, keep the rest the same, measure and record.

Through it all we remember that the first breath of man came from God, who "breathed into his nostrils the breath of life" (Genesis 2:7), and that "every thing that hath breath" is called to praise Him (Psalm 150:6).

BEFORE YOU BEGIN

- Knows that the heart pumps blood through the body and can take a pulse (Unit 3)
- Can multiply and divide whole numbers and find the average of three numbers
- Can measure length with a ruler in centimeters and read a simple bar graph
- Knows that air is a real substance that takes up space

MASTERY CHECKLIST

- I can trace the path of air from the nose to the alveoli and name each part.
- I can explain how the diaphragm and air pressure move air in and out of the lungs, and I can build a bottle lung model to show it.
- I can define tidal volume, vital capacity and residual volume and measure my vital capacity with a homemade spirometer.
- I can measure my breathing rate before and after exercise and explain the change using oxygen, carbon dioxide and cellular respiration.
- I can explain how mucus and cilia clean the airways and how smoke harms the lungs, and tell how Doll and Hill discovered it.
- I can design a fair experiment, naming what I change, what I keep the same, what I measure and my control.

OPTIONAL BOOKS AND RESOURCES

- **KidsHealth: Your Lungs & Respiratory System** (https://kidshealth.org/en/kids/lungs.html): Free. A clear, kid-friendly article on how the

lungs, diaphragm and airways work, from the Nemours children’s health system. Good for reading aloud with Lessons 4.1 and 4.2.

- **National Heart, Lung, and Blood Institute: How the Lungs Work** (https://www.nhlbi.nih.gov/health/lungs): Free. Plain explanations and diagrams from the U.S. National Institutes of Health on breathing, the airways, the alveoli and how the body controls breathing. Best for a parent to preview and share pictures.

4.1 Model Lung in a Bottle ★

OBJECTIVES

- Trace the path air takes from the nose to the tiny air sacs of the lungs and name each part.
- Explain how the diaphragm and rib muscles change the size of the chest so that air is pushed in and out by air pressure.
- Build and test a bottle model of a lung, measure how the balloon “lung” changes, and tell how the model is like and unlike a real chest.

Warm-up. Wrap a cloth tape measure (or a piece of string) around your chest just under your arms. Breathe out all the way and read the number. Now take the biggest breath you can and read it again. Then lay one hand flat on your belly just below your ribs and breathe slowly. Which way does your hand move when you breathe in? Write down both chest measurements and what your hand did.

Video. Coming soon. How the diaphragm and lungs work, with a homemade bottle-and-balloon lung model; search SciShow Kids, Homeschool Pop, Science Max, KidsHealth and TED-Ed for a breathing and respiratory system demonstration.

KEY TERMS

lungs
Two soft, spongy organs in the chest that take oxygen from the air into the blood and give off carbon dioxide. The right lung has three lobes (sections) and the left lung has two, leaving room for the heart.

diaphragm
A dome-shaped sheet of muscle under the lungs. When it tightens it flattens and moves down, making the chest larger so air flows in.

trachea
The windpipe: a tube held open by rings of cartilage that carries air from the throat down toward the lungs.

bronchi
The two large branches of the windpipe, one going to each lung. They divide again and again into smaller tubes called bronchioles.

alveoli
Tiny, thin-walled air sacs at the ends of the smallest airways, wrapped in blood vessels. Oxygen passes into the blood here.

air pressure
The push of air on everything around it. Air always flows from a place of higher pressure to a place of lower pressure.

CORE IDEAS

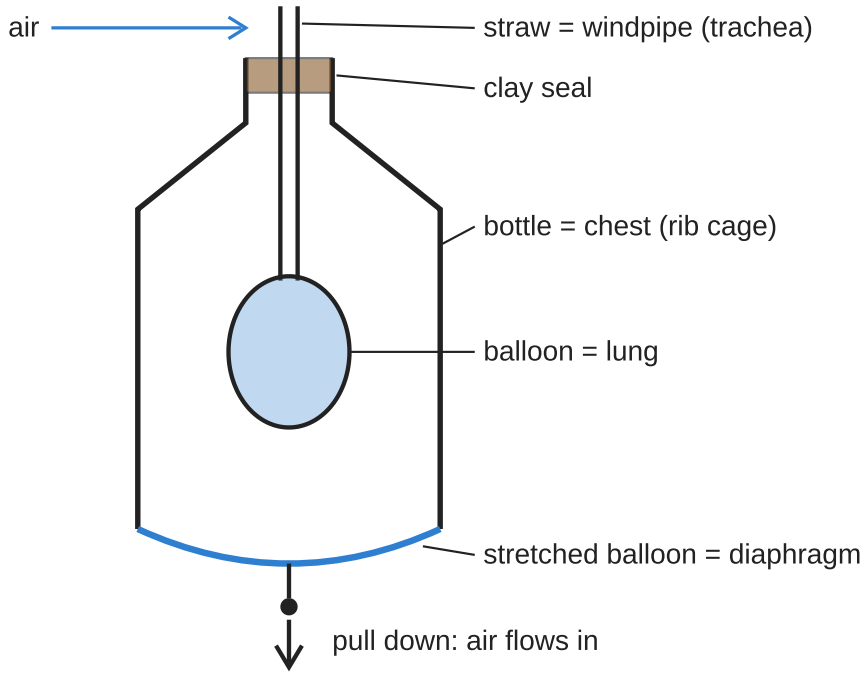
The story. In the 1660s a young doctor named John Mayow was studying at Oxford, England, and puzzling over a simple question: how do the lungs fill with air? Doctors who cut open a chest could see that the lungs have no muscles of their own. They are soft and spongy, like a wet sponge. So what makes them swell with every breath? In 1668 Mayow published a small book on breathing, and in it and in his later writings he gave an answer that still stands today.

How they figured it out. Mayow compared the chest to a blacksmith's bellows. When the handles of a bellows are pulled apart, the space inside grows larger and air rushes in through the nozzle. He described a model: a bellows with a thin bladder tied inside it, with the bladder's neck opening to the outside air. When the bellows was opened, the bladder swelled up with air, even though no one blew into it. That, said Mayow, is what the lungs do. The chest grows larger because of the muscles between the ribs and the sheet of muscle under the lungs called the **diaphragm**, and the lungs simply follow. Mayow also kept mice and candles in closed jars and saw that they used up only part of the air. About a hundred years later other scientists named that part *oxygen*.

The big idea. Air travels a branching path. It enters through the nose or mouth, goes down the **trachea** (windpipe), and splits into two **bronchi**, one for each lung. These divide again and again into thinner and thinner tubes until they end in clusters of tiny air sacs called **alveoli**. When you breathe in, your diaphragm tightens and flattens downward and the muscles between your ribs lift the ribs up and out. The space inside your chest gets bigger, so the **air pressure** inside your lungs drops a little below the pressure of the air outside. Air always flows from higher pressure to lower pressure, so the outside air is pushed in. When you breathe out, the diaphragm relaxes and domes back up, the ribs settle, the space gets smaller, and air is pushed out.

Try it and see. You can build Mayow's idea with a plastic bottle. The bottle is the chest. A balloon inside it is a lung. A straw through the bottle's mouth is the windpipe. A second balloon stretched across the cut-off bottom is the diaphragm. When you pull the bottom balloon down, the space inside the bottle grows, and the lung balloon puffs up. Push it up and the lung balloon shrinks. No one is blowing, yet air moves in and out. Like every model, this one is simpler than the real thing: a real chest has two lungs, ribs that move, and a thin, slippery lining that keeps the lungs pressed against the chest wall.

God's handiwork. If you breathe about 15 times a minute, you breathe more than 20,000 times a day, and you do it even while you sleep, without thinking once. Yet you can also take charge of your breathing whenever you wish: to sing, to speak, to blow out birthday candles or to dive under water. Scripture tells us that when the Lord formed the first man from the dust of the ground, He "breathed into his nostrils the breath of life." Every breath you take is a small reminder of that first one.



The bottle lung. Pulling the "diaphragm" down makes the space inside the bottle larger, so outside air flows in through the straw and fills the balloon "lung."

PICTURE STUDY



An Experiment on a Bird in the Air Pump, Joseph Wright of Derby, 1768 · Oil on canvas · The National Gallery, London

In the 1700s, traveling lecturers carried scientific instruments from town to town and showed families how nature works. One favorite was the air pump, which could pull the air out of a glass globe. Joseph Wright, an English painter from the town of Derby, loved to paint

science by candlelight. In this picture the lecturer has pumped air out of a globe holding a white cockatoo. Without air the bird cannot breathe.

Wright does not tell us how the story ends. The lecturer's hand rests on the top of the globe, where he could let the air back in. The painting asks the same question John Mayow asked: what is in the air that every living creature needs?

Look closely

- Find the bird inside the glass globe. What is happening to it?
- Find the lecturer's hand at the top of the globe. What might he be about to do?
- Look at each face around the table. Who is curious, who is frightened and who is not paying attention at all?
- Find the window and the boy beside it. What do you see in the sky?

Talk about it

1. Why does the bird need the air that is being pumped out of the globe?
2. Why do you think the painter chose to light the whole scene with a single candle?
3. Which person in the painting would you most like to be, and why?

> **Safety first.** An adult should cut the plastic bottle; cut edges can be sharp, so cover them with tape. Some people are allergic to latex balloons; use latex-free balloons if needed. Keep balloon pieces away from small children, who can choke on them.

EXPERIMENT: THE BOTTLE LUNG EXPERIMENT

You will build a working model of one lung and use it to answer a question: **What happens to the "lung" when the "diaphragm" is pulled down, and does pulling it farther make the lung fill more?** Before you start, write your prediction in your lab notebook.

What we change: how far the diaphragm is pulled down (0, 1, 2 and 3 centimeters). What we keep the same: the bottle, the balloons, the seal and the person pulling. What we measure: how wide the lung balloon gets.

You will need

- A clear plastic bottle, 500 mL to 1 liter (about 17 to 34 fluid ounces), with its label removed
- Two balloons (about 23 cm or 9 inches, the same kind)
- A plastic drinking straw
- Modeling clay or play dough (a piece about the size of a walnut)
- A rubber band and some tape
- Scissors (for an adult to use)
- A ruler marked in centimeters, and a lab notebook and pencil

Steps

1. Have an adult cut the bottom off the bottle about one third of the way up from the bottom. Cover the cut edge with tape.
2. Slide the neck of one balloon over one end of the straw and tape it so no air can leak. This balloon is the lung and the straw is the windpipe.
3. Push the balloon end of the straw into the bottle through its mouth, so the balloon hangs inside. Wrap clay around the straw at the bottle's mouth to seal it tightly. Air should be able to move only through the straw.
4. Tie a knot in the neck of the second balloon. Cut off the top part of this balloon (the round end opposite the knot) and stretch the rest over the open bottom of the bottle, with the knot hanging in the middle. Hold it with a rubber band and tape. This is the diaphragm.
5. Draw a table in your notebook with two columns: *Diaphragm pulled down (cm)* and *Width of lung balloon (cm)*.
6. With the diaphragm resting flat, hold the ruler against the bottle and measure how wide the lung balloon is. Record it beside 0 cm.
7. Have a helper hold the ruler beside the knot. Pull the knot down 1 cm, hold it there, and measure the lung balloon. Repeat for 2 cm and 3 cm. Record each width.
8. Now push the diaphragm up into the bottle. Watch the lung balloon and write what happens.
9. Finally, poke a small hole through the clay seal with a pencil and pull the diaphragm again. Write what happens now, and why.

Tips

- If the lung balloon barely moves, check the clay seal. Even a tiny leak lets air sneak in around the straw instead of through it.
- A smaller balloon works better as the lung than a large one, because it is easier for the air pressure to stretch it.
- Make a two-lung model by taping two balloons to the arms of a Y-shaped connector or two straws joined with tape.

Check your work

- I can name what each part of my model stands for.
- I can explain why the lung balloon fills when the diaphragm is pulled down, using the words *space* and *air pressure*.
- I can tell one way my model is like a real chest and one way it is different.

NATURE NOTEBOOK

1. Draw your bottle lung and label the straw (windpipe), lung balloon (lung), bottle (chest) and stretched balloon (diaphragm). Draw arrows to show which way air moves when the diaphragm is pulled down.
2. Draw the path of air from your nose to the alveoli as a branching tree, and label nose, trachea, bronchi, bronchioles and alveoli.

3. Record your chest measurements from the warm-up. Write: “Breathing out, my chest measured ___ cm. Breathing in, it measured ___ cm. It grew by ___ cm.”

> **From history.** John Mayow died young, in 1679, and for many years his ideas were mostly forgotten. In the 1770s Joseph Priestley in England and Antoine Lavoisier in France studied the part of the air that keeps candles burning and animals alive. Lavoisier gave it the name *oxygen* and showed that breathing and burning are alike: both use oxygen and both give off carbon dioxide. Looking back, scientists saw how close Mayow had come a century earlier.

WORKED EXAMPLES

Example 1. A child at rest breathes about 15 times each minute. About how many breaths is that in one hour? In one whole day?

1. There are 60 minutes in an hour: $15 \times 60 = 900$ breaths in one hour.
2. There are 24 hours in a day: $900 \times 24 = 21{,}600$ breaths in one day.
3. Check by rounding: about 1,000 breaths an hour times about 20 hours is 20,000, so an answer a little over 20,000 makes sense.

Answer: About 900 breaths an hour and about 21,600 breaths a day.

Example 2. One quiet breath for a grown-up holds about 500 mL of air (about 17 fluid ounces). The air we breathe in is about 21% oxygen. The air we breathe out is about 16% oxygen. About how much oxygen does one breath bring in, how much goes back out, and how much does the body keep?

1. Oxygen breathed in: 21% of 500 mL $= 0.21 \times 500 = 105$ mL.
2. Oxygen breathed out: 16% of 500 mL $= 0.16 \times 500 = 80$ mL.
3. Oxygen kept by the body: $105 \text{ mL} - 80 \text{ mL} = 25$ mL.
4. Notice that the air we breathe out still has plenty of oxygen in it. The body takes only a small part of the oxygen from each breath.

Answer: About 105 mL in, 80 mL out, so the body keeps about 25 mL of oxygen from each quiet breath.

PRACTICE

1. EASY What is the name of the dome-shaped muscle under your lungs that helps you breathe?
2. EASY Put these in the order air passes through them when you breathe in: bronchi, alveoli, nose, trachea, bronchioles.

3. EASY In the bottle lung model, what does each part stand for: the bottle, the straw, the balloon inside, and the balloon stretched across the bottom?
4. MEDIUM A child breathes 18 times a minute while reading. How many breaths is that in 30 minutes? In one hour?
5. MEDIUM Read this table from a student's bottle lung test.
   Diaphragm pulled down 0 cm: lung balloon 2.0 cm wide
   1 cm: 3.0 cm wide
   2 cm: 4.0 cm wide
   3 cm: 4.8 cm wide
   (a) How much wider was the balloon at 3 cm than at 0 cm? (b) Describe the pattern in one sentence.
6. MEDIUM Explain in two or three sentences why air flows into your lungs when your diaphragm moves down. Use the words *space* and *air pressure*.
7. HARD Design an experiment to test this question: "Does a bigger bottle make the lung balloon fill more?" Name what you will change, what you will keep the same, and what you will measure. How will you make your results trustworthy?
8. CHALLENGE In the project, a hole was poked through the clay seal. Why did the lung balloon stop filling? What does this tell you about why a real chest must be sealed?

COMMON MISTAKES

- Thinking the lungs are muscles that pull air in by themselves. The lungs have no muscles to move themselves; the diaphragm and rib muscles change the size of the chest, and air pressure does the rest.
- Thinking the air we breathe out has no oxygen left in it. Breathed-out air is still about 16% oxygen; the body keeps only a small part of the oxygen in each breath.
- Thinking the lungs are two hollow balloons. Real lungs are spongy, filled with branching tubes and hundreds of millions of tiny air sacs.

> **Make it a game · Diaphragm Says.** Play like "Simon Says." The caller says "Diaphragm says breathe in," and players must flatten their hands and move them down (the diaphragm tightening) while lifting their shoulders slightly (the ribs rising). "Diaphragm says breathe out" means hands dome upward. If the caller leaves off "Diaphragm says," anyone who moves is out for one round. Between rounds, the caller asks a quick question, such as "Name the tubes after the trachea," for a bonus point.

> **Scripture.** "And the LORD God formed man of the dust of the ground, and breathed into his nostrils the breath of life; and man became a living soul." (Genesis 2:7, KJV)

The first breath of the first man came from God Himself. Our lungs are made to keep that gift going thousands of times a day, so we can live, work, speak and sing His praise.

Practice answers

1. The diaphragm.

2. Nose, trachea, bronchi, bronchioles, alveoli.
3. The bottle is the chest (rib cage), the straw is the windpipe (trachea), the balloon inside is a lung, and the stretched balloon is the diaphragm.
4. 18 × 30 = 540 breaths in 30 minutes; 18 × 60 = 1,080 breaths in one hour.
5. (a) 4.8 − 2.0 = 2.8 cm wider. (b) The farther the diaphragm was pulled down, the wider the lung balloon became (though it grew a little less between 2 cm and 3 cm).
6. When the diaphragm moves down, the space inside the chest gets bigger. This makes the air pressure inside the lungs a little lower than the air pressure outside. Air flows from higher pressure to lower pressure, so outside air is pushed in through the nose or mouth into the lungs.
7. Change: the size of the bottle (for example a 500 mL bottle and a 2-liter bottle). Keep the same: the same kind and size of lung balloon, the same kind of diaphragm balloon, a tight clay seal, and the same pull distance (for example 2 cm). Measure: the width of the lung balloon with a ruler. Do at least three trials with each bottle and average them.
8. When the diaphragm was pulled down, outside air leaked in through the hole and filled the space inside the bottle, so the pressure around the balloon did not drop and the balloon did not fill. A real chest must be sealed so that when it grows larger, air can enter only through the windpipe into the lungs. If air gets into the space around a lung (for example from an injury), the lung cannot fill and may collapse.

4.2 Lung Capacity

OBJECTIVES

- Tell how John Hutchinson invented the spirometer and what he discovered about vital capacity.
- Define tidal volume, vital capacity and residual volume, and compare typical amounts in liters.
- Build a water-jug spirometer, measure vital capacity in three trials, and find the average.

Warm-up. Blow up a balloon with one normal, quiet breath out and pinch it closed. Then blow up a second balloon of the same kind with the biggest breath out you can manage. Hold them side by side. About how many quiet breaths would it take to make the small balloon as big as the large one? Write your guess.

Video. Coming soon. Lung capacity, vital capacity and how a spirometer works, including a homemade water-bottle spirometer; search SciShow Kids, Homeschool Pop, Science Max, KidsHealth, and lung health organizations' education channels.

KEY TERMS

spirometer
An instrument that measures how much air a person breathes out. The name comes from the Latin word *spirare*, "to breathe."

tidal volume
The amount of air moved in or out in one quiet, ordinary breath. For a grown-up it is about half a liter.

vital capacity
The most air a person can breathe out after taking the deepest breath possible.

residual volume
The air that always stays in the lungs, even after you breathe out as hard as you can. It keeps the tiny air sacs from collapsing.

liter
A metric unit of volume equal to 1,000 milliliters (mL), a little more than one U.S. quart.

CORE IDEAS

The story. In London in the 1840s, a surgeon named John Hutchinson wanted a simple way to tell how strong and healthy a person's lungs were. Doctors could listen to the chest and tap on it, but they could not measure it. So Hutchinson built a machine. He turned a large metal bell upside down in a tank of water. When a person blew through a tube into the bell, the air pushed the bell up, and a scale on the side showed exactly how much air had gone in.

He called his invention a **spirometer**, a “breath measurer.” In 1846 he reported his results to a society of London doctors.

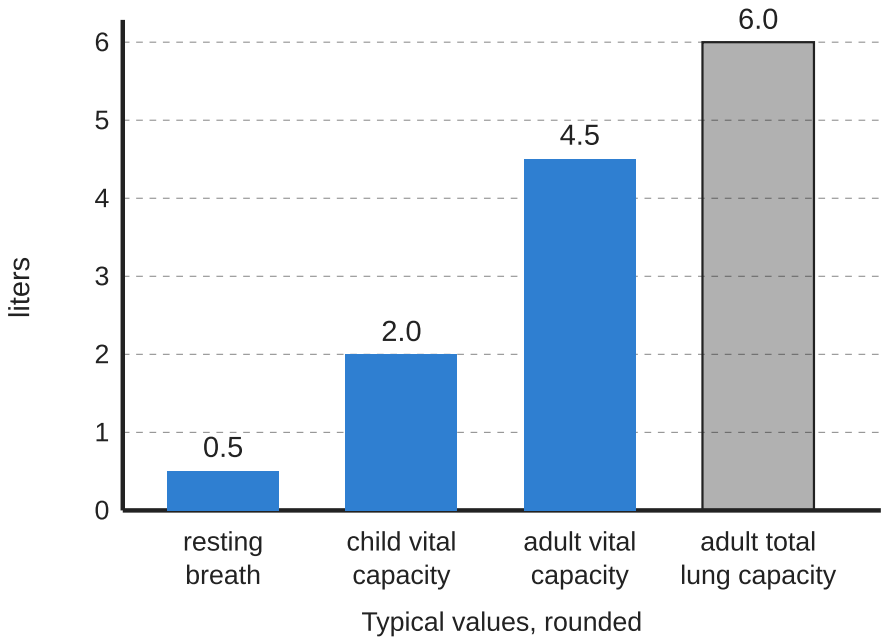
How they figured it out. Hutchinson did not measure just a few people. He measured more than a thousand: sailors, soldiers, policemen, gentlemen and workmen of many trades. For each person he asked them to take the deepest breath they could and then blow out as much as they could into the spirometer. He named this amount the **vital capacity**, from the Latin word for life. When he arranged his measurements in tables, a pattern jumped out: taller people had larger vital capacities. He also found that people with certain lung diseases blew out much less air than healthy people of the same height, so his spirometer could help a doctor spot a problem.

The big idea. Your lungs never use all their room at once. In a quiet breath, a grown-up moves only about half a liter of air (about a pint). That is the **tidal volume**, because it goes in and out like a small tide. With the biggest breath possible, a grown-up can blow out about 4 to 5 liters. A child your age can usually blow out about 2 liters (about 2 quarts), and the number grows as you grow taller. Even after the hardest breath out, about 1 to 1.5 liters of air stays inside a grown-up’s lungs. This **residual volume** keeps the tiny air sacs from collapsing like wet plastic bags. Vital capacity depends mostly on height, age and health, not on how good or strong a person is.

Try it and see. You can build Hutchinson’s idea in your kitchen. Fill a large jug with water, turn it upside down in a tub of water, and blow through a tube up into it. Your breath pushes the water out, and the lines you marked on the jug show how much air you blew. This is the same method Hutchinson used: let air take the place of water, and read the amount.

In the world today. Doctors still use spirometers. A patient takes a deep breath and blows as hard and fast as possible into a tube attached to a small machine, which measures both how much air comes out and how fast. Many children with asthma use a simple version called a peak flow meter to check their breathing at home. Singers, swimmers and people who play the trumpet or flute train to control their breath carefully, even though their lungs are about the same size as anyone else’s.

God’s handiwork. Notice how much extra room is built into your lungs. At rest you use only a small part of what they can hold. The rest stands ready for the day you need to sprint across a field, swim underwater, call loudly to a friend or sing a long note. Elihu said in the book of Job, “the breath of the Almighty hath given me life.” Our breath is measured and cared for by the One who gave it.



Typical lung volumes, rounded. A quiet breath uses only a small part of the lungs' room. Real values vary with height, age and health.

PICTURE STUDY



Soap Bubbles, Jean-Baptiste-Siméon Chardin, about 1733–34 · Oil on canvas · The Metropolitan Museum of Art, New York (Chardin painted other versions, now in the National Gallery of Art, Washington, and the Los Angeles County Museum of Art)

Jean-Baptiste-Siméon Chardin was a French painter who loved quiet, everyday moments: a boy with a top, a girl saying grace, a cook in a kitchen. Here a young man leans out of a

window and blows a soap bubble through a straw, while a little child peeks over the edge to watch.

Blowing a big bubble takes careful breath control. Blow too hard and the bubble bursts; blow too softly and it never grows. Chardin caught the very moment when the bubble is large, round and still growing.

Look closely

- Find the bubble. What can you see reflected or shining in it?
- Look at the young man's cheeks and lips. Is he blowing hard or gently?
- Find the small child. What is the child looking at?
- Find the glass of soapy water. Where is it?

Talk about it

1. Why do you think Chardin painted something as small and quick as a soap bubble?
2. If the young man took a deeper breath, could he blow a bigger bubble? What might stop him?
3. What everyday moment from your own home would make a good painting?

> **Safety first.** Work in a sink, bathtub or outdoors and wipe up spills at once so no one slips. Each person needs a clean tube of their own; never share a mouthpiece. Breathe normally between trials. If you feel dizzy or lightheaded, stop, sit down and breathe quietly until it passes.

EXPERIMENT: KITCHEN SPIROMETER

You will build a water-jug spirometer like John Hutchinson's and use it to answer a question: **Do taller people in my family have larger vital capacities?** Write your prediction first.

What we change: the person being measured. What we keep the same: the jug, the tube, the method of counting, and three trials per person. What we measure: the volume of air blown out, and each person's height.

You will need

- A clean, clear 1-gallon (about 3.8-liter) plastic jug with a cap
- A measuring cup that holds 250 mL (about 1 cup)
- A waterproof marker
- A dishpan, large bowl, sink or bathtub with water at least 15 cm (6 inches) deep
- About 60 cm (2 feet) of clean flexible plastic tubing for each person (aquarium tubing works), or several bendy straws taped together end to end
- A tape measure, a towel, a lab notebook and pencil

Steps

1. Mark the jug: pour in 250 mL of water at a time and draw a line at the water level each time, labeling 250, 500, 750 and so on until the jug is full (a 1-gallon jug holds about 3,750 mL). (The lines will read upside down once the jug is flipped, so write the numbers upside down, or turn the jug and label again.)
2. Fill the jug to the top with water and screw on the cap.
3. Turn the jug upside down and set the capped mouth under the water in the tub. Remove the cap under water. A helper holds the jug steady. The jug should still be full of water.
4. Slide one end of the tube up into the jug's mouth.
5. The person being tested takes the deepest breath possible and blows out through the tube in one long breath, as much as they can. Bubbles will push water out of the jug.
6. Read the line at the water level. That is the vital capacity in milliliters. Record it.
7. Refill the jug and repeat for a total of three trials. Find the average by adding the three numbers and dividing by 3.
8. Measure each person's height. Make a table: *Name*, *Height (cm)*, *Trial 1*, *Trial 2*, *Trial 3*, *Average (mL)*.
9. Bonus: measure your tidal volume by blowing out one normal, quiet breath into the jug.
10. Write a sentence answering the question, and tell whether your prediction was right.

Tips

- A grown-up may blow out more air than the jug holds and empty it. Mark that as "more than 3,750 mL," or use two jugs one after the other.
- Pinch your nose or wear a swimmer's nose clip so no air escapes through your nose.
- Your first trial is often smaller because you are still learning how to do it. That is one reason we do three trials.

Check your work

- I can explain what vital capacity is and how my spirometer measures it.
- I can find the average of three trials.
- I can describe the pattern between height and vital capacity in my family's data.

NATURE NOTEBOOK

1. Draw your jug spirometer in the tub, with arrows showing the air going in and the water going out. Label the tube, the jug, the marked lines and the water.
2. Draw two balloons side by side from the warm-up, one labeled "tidal volume" and one labeled "vital capacity," and write your guess of how many small ones fit in the big one.
3. Copy your family's data table into your notebook and make a bar graph of each person's average vital capacity, tallest person first.

> **From history.** The name *vital capacity* that Hutchinson chose is still used by doctors today. Life insurance companies of his day were interested in his spirometer, since it could help show whether a person's lungs were healthy. A few years after his great

> report, Hutchinson left England for Australia and later the Pacific island of Fiji, where he died in 1861. His spirometer, a bell floating in water, was the ancestor of the electronic breathing tests used in hospitals now.

WORKED EXAMPLES

Example 1. A jug spirometer is marked every 250 mL. After one big breath out, the water level is at the 9th line. What is the vital capacity in milliliters and in liters? About how many quarts is that? If the three trials were 2.25 L, 2.00 L and 2.25 L, what is the average?

1. Each line is 250 mL, so 9 lines = 9 × 250 = 2,250 mL.
2. There are 1,000 mL in a liter, so 2,250 mL = 2.25 L.
3. One liter is about 1.06 U.S. quarts, so 2.25 × 1.06 ≈ 2.4 quarts.
4. Average of three trials: (2.25 + 2.00 + 2.25) ÷ 3 = 6.50 ÷ 3 ≈ 2.17 L.

Answer: 2,250 mL, or 2.25 L (about 2.4 quarts). The average of the three trials is about 2.17 L, or about 2.2 L.

Example 2. Use the bar graph of typical lung volumes. (a) About how many times larger is an adult's vital capacity than a child's? (b) How many quiet breaths of 0.5 L would it take to equal a child's vital capacity? (c) An adult's lungs hold about 6 L in all. How much air is left inside after the adult blows out a full vital capacity?

(Use the map or drawing "Typical lung volumes, rounded." shown earlier in this lesson.)

1. Read the graph: adult vital capacity 4.5 L; child vital capacity 2.0 L; resting breath 0.5 L; adult total lung capacity 6.0 L.
2. (a) 4.5 ÷ 2.0 = 2.25, so a little more than twice as large.
3. (b) 2.0 ÷ 0.5 = 4 quiet breaths.
4. (c) 6.0 − 4.5 = 1.5 L stays in the lungs. This is the residual volume.

Answer: (a) About 2.25 times. (b) 4 quiet breaths. (c) About 1.5 L remains (the residual volume).

PRACTICE

1. EASY What is vital capacity?
2. EASY What instrument did John Hutchinson invent to measure the air a person breathes out?
3. EASY Change 3 liters to milliliters. Change 1,500 mL to liters.
4. MEDIUM A jug is marked every 250 mL. After a big breath out, the water is at the 7th line. What is the vital capacity in mL and in liters?

5. MEDIUM Read this family's data table (average vital capacity).
   Ruth, 140 cm tall: 2.0 L
   Sam, 152 cm tall: 2.4 L
   Mother, 165 cm tall: 3.4 L
   Father, 180 cm tall: 4.6 L
   (a) Who had the largest vital capacity? (b) How much more did Father blow out than Ruth? (c) What pattern do you see, and which scientist found the same pattern?
6. MEDIUM Why can no one blow all the air out of their lungs? What is the leftover air called?
7. HARD A student wonders, "Can I blow out more air when I stand up straight than when I sit slouched over?" Design an experiment. Name what you change, what you keep the same, what you measure, and how many trials you will do.
8. CHALLENGE A student's three trials were 1.9 L, 2.1 L and 2.3 L. Find the average. Why do scientists repeat a measurement several times instead of trusting just one?

COMMON MISTAKES

- Thinking you fill your lungs all the way with every breath. A quiet breath uses only a small part of the lungs' room, about half a liter for a grown-up out of about 6 liters.
- Thinking the lungs can be emptied completely. About 1 to 1.5 liters always stays inside an adult's lungs as residual volume.
- Thinking a bigger vital capacity always means a healthier or stronger person. Vital capacity depends mostly on height and age; a tall person and a short person can both have perfectly healthy lungs.

> **Make it a game · Ping-Pong Breath Race.** Lay a strip of tape on a smooth table as a starting line and another 1 meter (about 3 feet) away as a finish line. Each player blows a ping-pong ball (or a cotton ball) from start to finish using as few breaths as possible, counting each breath out. Fewest breaths wins the round. Then race again with a rule: only quiet tidal breaths allowed. Talk about which round needed more breaths and why.

> **Scripture.** "The Spirit of God hath made me, and the breath of the Almighty hath given me life." (Job 33:4, KJV)

Hutchinson measured the breath in liters, but the Bible reminds us where breath comes from. Every liter we breathe is a gift from the One who made us.

Practice answers

1. The most air a person can breathe out after taking the deepest breath possible.
2. The spirometer.
3. 3 L = 3,000 mL. 1,500 mL = 1.5 L.
4. 7 × 250 = 1,750 mL = 1.75 L.
5. (a) Father. (b) 4.6 − 2.0 = 2.6 L more. (c) The taller the person, the larger the vital capacity. John Hutchinson found the same pattern when he measured more than a thousand people.

6. Some air always stays in the lungs to keep the tiny air sacs (alveoli) and small airways from collapsing; the chest and lungs cannot squeeze down to nothing. This leftover air is the residual volume.
7. Change: posture (standing straight versus sitting slouched). Keep the same: the same person, the same jug spirometer and tube, the same way of breathing (deepest breath in, then blow out completely), rest between trials, and the same time of day. Measure: the vital capacity in mL. Do at least three trials in each posture and compare the averages.
8. (1.9 + 2.1 + 2.3) ÷ 3 = 6.3 ÷ 3 = 2.1 L. Single measurements can be off because of small mistakes, leaks or not trying the same each time; averaging several trials gives a more trustworthy result and shows how much the numbers vary.

4.3 Exercise and Breath

OBJECTIVES

- Tell the story of Roger Bannister's four-minute mile and what he and other scientists learned about breathing during hard exercise.
- Explain why exercise makes us breathe faster and deeper, using the words oxygen, carbon dioxide and cellular respiration.
- Measure breathing rate before and after exercise, make a bar graph, and find the recovery time.

Warm-up. Sit still for one minute while a helper watches your chest or belly and counts your breaths. Then do 20 jumping jacks and count again right away. Write both numbers. Did anything else change besides how fast you breathed? Feel your neck or wrist for your pulse, as you learned in Lesson 3.2.

Video. Coming soon. What happens to breathing and heart rate during exercise, and footage of Roger Bannister's 1954 four-minute mile; search SciShow Kids, Homeschool Pop, Science Max, KidsHealth, and historic newsreel archives such as British Pathé.

KEY TERMS

breathing rate
The number of breaths a person takes in one minute.

oxygen
A gas that makes up about 21% of the air. Every cell in the body needs it to release energy from food.

carbon dioxide
A waste gas made by the body's cells as they use food for energy. The blood carries it to the lungs, and we breathe it out.

cellular respiration
The work inside each cell that uses oxygen to release energy from food (sugar), giving off carbon dioxide and water.

recovery time
How long it takes for breathing rate and pulse to return to their resting numbers after exercise.

CORE IDEAS

The story. On the windy evening of May 6, 1954, at the Iffley Road running track in Oxford, England, a 25-year-old medical student named Roger Bannister lined up for a one-mile race. Runners had tried for years to run a mile in under four minutes, and many people thought it could not be done. Two friends, Chris Brasher and Chris Chataway, set the pace for him. On

the last lap Bannister pulled ahead and threw himself across the finish line. The time was 3 minutes 59.4 seconds, the first mile ever officially run in under four minutes. Right after the finish he nearly collapsed, gasping for air, his heart and lungs working as hard as they could.

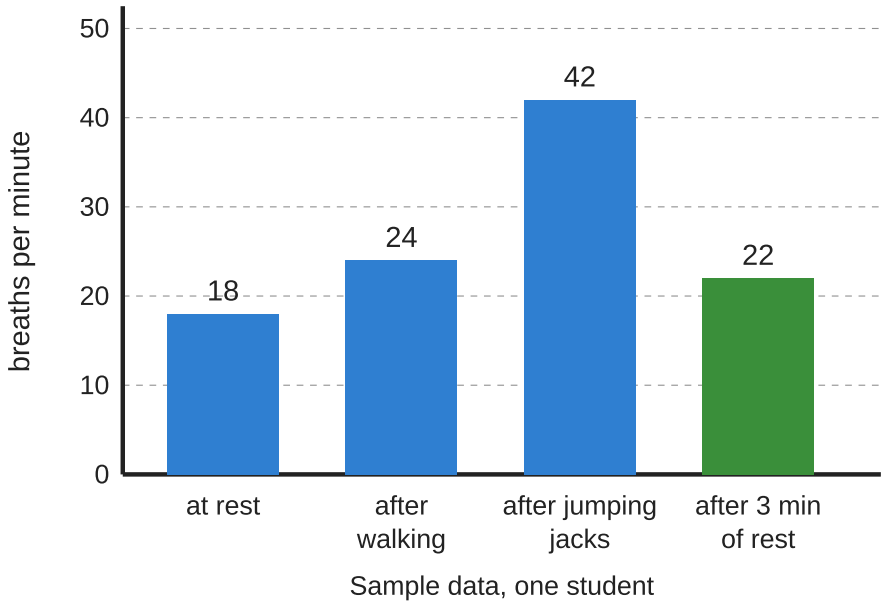
How they figured it out. Bannister was not only a runner. He was training to be a doctor, and he wanted to understand what his body was doing. In the physiology laboratory at Oxford, he ran on a treadmill while scientists measured the air he breathed in and out. He helped study how runners performed when they breathed air with extra oxygen added. Experiments like these showed that during hard exercise the body needs far more oxygen than at rest and must get rid of far more carbon dioxide, and that the lungs, heart and blood all speed up together to make that happen.

The big idea. Your muscles run on food, but they can release the energy in food only with the help of oxygen. Inside each cell, sugar from your food combines with oxygen, releasing energy and giving off carbon dioxide and water. This is called **cellular respiration**. Breathing is the job of the lungs; cellular respiration is the job of every cell. When you run, your leg muscles do much more work, so they use more oxygen and make more carbon dioxide. A part of your brain near the top of the spinal cord senses the rising carbon dioxide in your blood and sends signals to your diaphragm and rib muscles: breathe faster and deeper! At the same time your heart beats faster to carry oxygen-rich blood to the muscles, which is why your pulse and your **breathing rate** rise together.

Try it and see. At rest, children your age usually take somewhere around 15 to 25 breaths a minute, and grown-ups about 12 to 20. A resting grown-up moves about 6 liters (about 6 quarts) of air each minute. During very hard exercise, a trained athlete can move more than 100 liters a minute, by breathing both much faster and much deeper. You can see a small piece of this at home: count your breaths at rest, after walking and after jumping jacks, and then keep counting each minute as you rest, to find your **recovery time**.

In the world today. Coaches use breathing and pulse to see how fit an athlete is. Regular exercise makes the heart stronger and the breathing muscles more efficient, and a fit person usually recovers faster after a hard run. High in the mountains, the air is thinner, so each breath holds fewer oxygen molecules, even though oxygen is still about 21% of the air. That is why visitors to a mountain town breathe harder on a hike than they would at home near sea level.

God’s handiwork. No one has to tell the lungs to work harder when you start to run. The brain, lungs, heart and muscles talk to one another and adjust in a few seconds, and then settle back down when you rest. Isaiah wrote that those who wait upon the Lord “shall run, and not be weary.” A body that can speed up and slow down so wisely is itself a reason to give thanks.



Sample data from one student. Breathing rate rose with harder exercise and began to fall again during rest.

PICTURE STUDY



The Biglin Brothers Racing, Thomas Eakins, 1872 · Oil on canvas · National Gallery of Art, Washington, D.C.

Thomas Eakins was an American painter from Philadelphia who studied anatomy so carefully that he took classes alongside medical students. He loved rowing and often painted the rowers on Philadelphia's Schuylkill River. John and Barney Biglin were famous professional rowers of his day, and here Eakins shows them racing in a two-man boat.

Eakins wanted to paint the human body at work exactly as it is. Look at how the two brothers move together, their arms, backs and legs all pulling at once. To keep up that pace, their lungs and hearts must be working hard.

Look closely

- Find the two oars. Are the brothers pulling at the same moment?
- Look at the rowers' arms and shoulders. Which muscles do you think are working hardest?
- Find the front of another boat at the edge of the painting. Why might Eakins have shown only part of it?
- Look at the water. Is it rough or calm?

Talk about it

1. If you could count the Biglin brothers' breaths during the race, would the number be higher or lower than when they sat resting on the shore? Why?
2. Eakins studied anatomy to paint better. How might knowing about muscles and bones help an artist?
3. Why do you think rowers try to breathe in rhythm with their strokes?

> **Safety first.** Exercise in a clear space with good shoes on a non-slippery floor. Stop at once and rest if you feel dizzy, faint, have chest pain, or cannot catch your breath. A child with asthma or another health condition should follow the doctor's plan and keep any inhaler nearby. Drink water when you are done.

EXPERIMENT: BREATHS BEFORE AND AFTER

You will answer the question: **How does exercise change my breathing rate, and how long does it take to return to normal?** Write your prediction first.

What we change: the activity (resting, walking, jumping jacks). What we keep the same: the same person, the same counting method, and the same length of time for each activity (2 minutes). What we measure: breaths per minute, and pulse if you like.

You will need

- A clock, watch or timer that shows seconds
- A helper to count breaths
- A clear space indoors or a flat yard
- Lab notebook, pencil, ruler and colored pencils for a bar graph

Steps

1. Sit quietly for 3 minutes. Your helper watches your belly or chest rise and counts breaths for 30 seconds. Multiply by 2 to get breaths per minute. Record it as your resting rate.

2. Walk at a steady pace for 2 minutes. Right away, sit down and have your helper count your breaths for 30 seconds. Multiply by 2 and record.
3. Rest until your breathing is back near your resting rate.
4. Do jumping jacks (or run in place) for 2 minutes. Sit down and count breaths for 30 seconds right away. Multiply by 2 and record.
5. Stay seated. At 1, 2, 3, 4 and 5 minutes after stopping, count again for 30 seconds and record each rate.
6. Your recovery time is the number of minutes until your rate is back within 2 breaths of your resting rate.
7. If you finished Lesson 3.2, also take your pulse after each activity and record it in another column.
8. Make a bar graph with one bar for each activity. Then write two sentences explaining what you found.

Tips

- It is hard to count your own breaths honestly, because thinking about breathing changes it. That is why a helper counts.
- Count one breath for each full rise and fall of the belly, not two.
- Do the whole experiment twice on different days and compare. Are your numbers similar?

Check your work

- I can measure breathing rate in breaths per minute.
- I can make a bar graph of my results and find my recovery time.
- I can explain why I breathed faster after exercise, using the words oxygen and carbon dioxide.

NATURE NOTEBOOK

1. Draw a runner and add arrows: oxygen going in at the mouth, traveling in the blood to the leg muscles, and carbon dioxide traveling back to the lungs and out.
2. Copy your data table and bar graph from the project. Title it with the date and your name like a real lab report.
3. Write the cellular respiration “recipe” in words in a box: sugar + oxygen → energy + carbon dioxide + water. Draw a small cell around the box.

> **From history.** Bannister’s record lasted only 46 days. On June 21, 1954, the Australian runner John Landy ran a mile in 3 minutes 58.0 seconds in Turku, Finland. Later that summer the two men raced each other in Vancouver, Canada, and both broke four minutes, with Bannister winning. Bannister soon retired from running to finish his medical training and became a neurologist, a doctor who cares for people with illnesses of the brain and nerves.

WORKED EXAMPLES

Example 1. A helper counted 7 breaths in 15 seconds right after a student ran in place. What is the student's breathing rate in breaths per minute? If the student's resting rate was 18 breaths per minute, how much did it go up?

1. One minute is 60 seconds, and 60 ÷ 15 = 4, so there are four 15-second periods in a minute.
2. Breaths per minute = 7 × 4 = 28.
3. Increase = 28 − 18 = 10 breaths per minute.

Answer: 28 breaths per minute, which is 10 more than the resting rate.

Example 2. Use the bar graph of one student's breathing. (a) How many more breaths per minute did the student take after jumping jacks than at rest? (b) About how many times the resting rate is that? (c) After 3 minutes of rest, had the student fully recovered?

(Use the map or drawing "Sample data from one student." shown earlier in this lesson.)

1. Read the graph: rest 18, walking 24, jumping jacks 42, after 3 minutes of rest 22.
2. (a) 42 − 18 = 24 more breaths per minute.
3. (b) 42 ÷ 18 ≈ 2.3, so a little more than twice the resting rate.
4. (c) 22 − 18 = 4. The rate is still 4 breaths above resting, more than 2 above, so the student had not fully recovered yet.

Answer: (a) 24 more breaths per minute. (b) About 2.3 times the resting rate. (c) Not yet; the rate was still 4 above resting.

PRACTICE

1. EASY During exercise, which gas do your muscles need more of, and which waste gas do they make more of?
2. EASY A helper counts 10 breaths in 30 seconds. What is the breathing rate in breaths per minute?
3. EASY What is the difference between breathing and cellular respiration?
4. MEDIUM Use the bar graph of one student's breathing (rest 18, walking 24, jumping jacks 42, after 3 minutes of rest 22). How many more breaths per minute did the student take after jumping jacks than after walking?
5. MEDIUM Read this recovery table for a student whose resting rate is 18 breaths per minute.
   0 minutes after stopping: 40
   1 minute: 32
   2 minutes: 26

3 minutes: 22
4 minutes: 19
5 minutes: 18
(a) By how much did the rate drop in the first minute? (b) What is the recovery time, if "recovered" means within 2 breaths of resting?

6. MEDIUM Explain in two or three sentences why you start breathing faster when you begin to run. Mention the brain.
7. HARD Design an experiment to test: "Does running in place raise my breathing rate more than jumping jacks do?" Name what you change, what you keep the same, what you measure, and what you use as a comparison (control).
8. CHALLENGE A resting grown-up takes 12 breaths a minute of 0.5 L each. During hard exercise the same person takes 40 breaths a minute of 2.5 L each. How many liters of air per minute is each? About how many times as much air moves during exercise?

COMMON MISTAKES

- Thinking breathing and cellular respiration are the same thing. Breathing moves air in the lungs; cellular respiration uses oxygen inside every cell to release energy.
- Thinking we breathe faster only because we are "running out of oxygen." The strongest signal the brain senses is rising carbon dioxide in the blood.
- Thinking exercise makes the lungs themselves grow bigger. Training mainly makes the heart, breathing muscles and leg muscles stronger and better at using oxygen; the lungs stay about the same size.

> **Make it a game · Pace and Breathe Relay.** Set up four stations: walk around the yard, hop on one foot, jumping jacks, and sit still. Each player spends 1 minute at a station; then a partner counts their breaths for 15 seconds and multiplies by 4. Before each count, the player guesses the number. A guess within 4 breaths earns a point. After all stations, players rank the activities from easiest to hardest by breathing rate.

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

Even the fastest runner gasps for breath at the finish line. Isaiah points to a strength that does not run out: the strength God gives to those who trust Him.

Practice answers

1. They need more oxygen and make more carbon dioxide.
2. 10 × 2 = 20 breaths per minute.
3. Breathing is moving air in and out of the lungs. Cellular respiration happens inside every cell, where oxygen is used to release energy from food, giving off carbon dioxide and water.
4. 42 − 24 = 18 more breaths per minute.

5. (a) 40 − 32 = 8 breaths per minute. (b) 4 minutes, because at 4 minutes the rate was 19, which is within 2 of 18 (at 3 minutes it was 22, still 4 above).
6. Running muscles use more oxygen and make more carbon dioxide in cellular respiration. The extra carbon dioxide builds up in the blood, and a part of the brain near the top of the spinal cord senses it. The brain then signals the diaphragm and rib muscles to breathe faster and deeper, bringing in more oxygen and getting rid of carbon dioxide.
7. Change: the kind of exercise (running in place versus jumping jacks). Keep the same: the same person, the same exercise time (for example 2 minutes), full rest back to resting rate before each test, the same counting method and helper. Measure: breaths per minute right after each exercise. Comparison (control): the resting breathing rate measured first. Repeat each exercise at least twice and compare averages.
8. Resting: 12 × 0.5 = 6 L per minute. Exercise: 40 × 2.5 = 100 L per minute. 100 ÷ 6 ≈ 17, so about 17 times as much air.

4.4 Smoke and the Lungs

OBJECTIVES

- Tell how Richard Doll and Austin Bradford Hill used careful comparisons to show that cigarette smoking causes lung cancer.
- Describe how mucus and cilia keep the airways clean, and explain how smoke harms the airways, the air sacs and the blood.
- Run a sticky-card experiment with a control to compare the particles in the air in different places.

Warm-up. Shine a flashlight across a dark room, or look at a sunbeam coming through a window. Watch the tiny specks floating in the light. Every one of them is something you could breathe in. Where do you think they come from? Write three guesses, then think: what keeps all those specks from piling up inside your lungs?

Video. Coming soon. How cilia and mucus clean the airways and what smoking does to the lungs, explained for children; search SciShow Kids, Homeschool Pop, KidsHealth, lung health organizations' education channels, and microscope footage of beating cilia.

KEY TERMS

mucus
A sticky, slippery liquid that lines the nose and airways and traps dust, smoke particles and germs.

cilia
Tiny hairlike parts on the cells lining the airways. They beat back and forth together, sweeping mucus up and out of the lungs toward the throat.

tar
A sticky brown substance in tobacco smoke that coats the airways and lungs. It contains chemicals that can cause cancer.

nicotine
A drug in tobacco (and in most e-cigarettes) that is addictive, meaning the body comes to crave it so that it is very hard to stop using.

carbon monoxide
A poisonous gas in smoke that takes the place of oxygen on red blood cells, so the blood carries less oxygen.

emphysema
A lung disease, often caused by smoking, in which the walls of the alveoli break down, leaving fewer, larger air sacs and making it hard to breathe.

CORE IDEAS

The story. In the early 1900s, doctors in Britain noticed something alarming. Lung cancer, once a rare disease, was becoming far more common. Some people blamed dust from the new tarred roads, others blamed car exhaust or coal smoke. In 1948 two London scientists, a young doctor named Richard Doll and a careful statistician named Austin Bradford Hill, set out to find the real cause. With trained interviewers, they questioned patients in London hospitals, some who had lung cancer and some who were in the hospital for other illnesses, and asked each one the same long list of questions about where they lived, what work they did and what habits they had, including smoking.

How they figured it out. When Doll and Hill compared the two groups, one difference stood out. Nearly all of the lung cancer patients had been smokers, and the people who smoked the most had the highest risk. They published their report in 1950. Doll, who had been a smoker himself, gave it up. Then, in 1951, they wrote to the doctors of Britain and asked about their smoking, and tens of thousands answered. Doll and Hill followed these doctors for years and years. Smokers died of lung cancer far more often than nonsmokers, and those who quit lowered their risk. In 1964 the Surgeon General of the United States, Dr. Luther Terry, issued a report agreeing that cigarette smoking causes lung cancer.

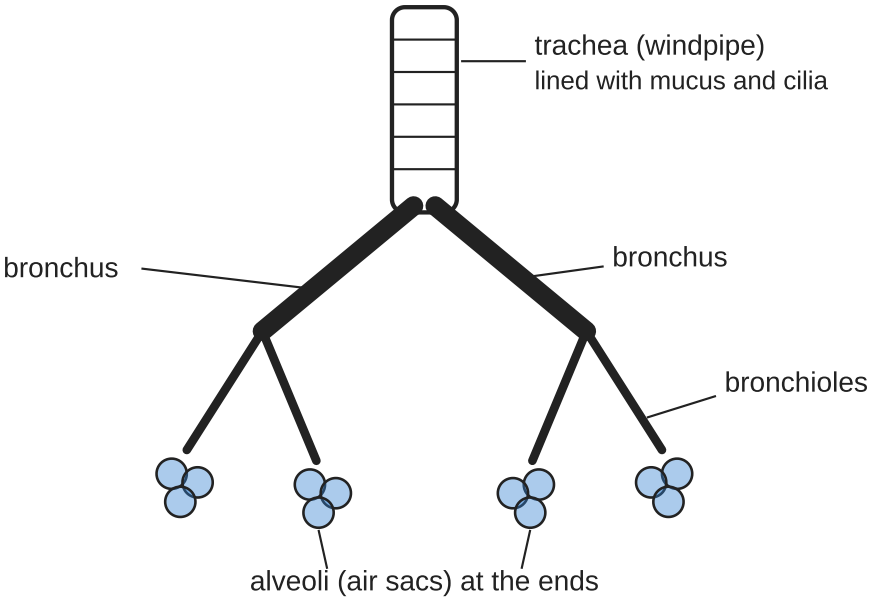
The big idea. Your airways have a wonderful cleaning system. Hairs in the nose catch large specks. The airways are lined with sticky **mucus** that traps dust and germs, and underneath it millions of **cilia** beat together like oars, sweeping the mucus up toward the throat, where it is swallowed or coughed out. Tobacco smoke attacks this system. Sticky **tar** coats the airways and slows or stops the cilia, so mucus builds up and smokers cough to clear it. Over years, smoke can break down the thin walls of the alveoli, causing **emphysema**: fewer, larger sacs with less surface for oxygen to pass into the blood. **Carbon monoxide** in smoke takes oxygen's place on red blood cells. Chemicals in tar can damage cells so that they grow out of control, which is cancer. And **nicotine** makes it very hard to stop. E-cigarettes, or vapes, also carry nicotine and other chemicals deep into the lungs; what comes out is not just water vapor.

Try it and see. You can catch the specks in the air the way your airways do. A card smeared with petroleum jelly works like mucus: whatever floats by sticks to it. Set cards in different places for two days and count the specks under a magnifying glass. A card sealed in a plastic bag is your control, to show that the specks really came from the air.

In the world today. Far fewer people smoke now than in Doll and Hill's day, and when a smoker quits, the lungs begin to recover: the cilia start working again, the cough often eases, and the risk of disease drops year by year. Other kinds of smoke and dust matter too. Wise people stand upwind of a campfire, open a window when cooking smoke fills the kitchen, and wear a dust mask when sanding wood or sweeping a dusty barn.

God's handiwork. The Bible says our bodies are "the temple of the Holy Ghost" and that we "are not your own." Caring for the lungs God gave us is not about fear. It is a way of

thanking Him for a body that cleans itself every moment of every day, and of keeping it strong for the work He gives us to do.



The airway tree. Mucus and cilia line the trachea, bronchi and bronchioles and sweep trapped particles back up toward the throat.

PICTURE STUDY



Breaker Boys in the Ewen Breaker, South Pittston, Pennsylvania, Lewis Wickes Hine, January 1911 · Photograph (gelatin silver print) · Library of Congress, Washington, D.C. (National Child Labor Committee Collection)

A coal breaker was a tall building where coal from the mines was crushed and sorted. Boys, some younger than you, sat bent over chutes all day picking out slate and rock by hand. They were called breaker boys. Lewis Hine, a teacher turned photographer, traveled across America taking pictures of children at work so that people would see what was happening and pass laws to protect them.

Hine wrote in his notes that the coal dust in this breaker was so thick at times that it hid the view, and that it reached deep into the boys' lungs. Pictures like this one helped win stronger laws, and in the years that followed, Pennsylvania and other states did more to keep young children out of the mines and breakers.

Look closely

- Look at the air in the photograph. Can you see the dust?
- Count how many boys you can see. How old do you think they are?
- Find the long chutes the coal slides down. What are the boys doing with their hands?
- Find where the light is coming from. How does the dust change the way the light looks?

Talk about it

1. What would the boys' mucus and cilia have to do all day in a room like this?
2. How did Hine use photographs to help children? Why can a picture sometimes persuade people better than words?
3. What kinds of dust or smoke should you protect your lungs from today?

> **Safety first.** Never light, handle or experiment with cigarettes, vapes or any smoke. This lesson uses only sticky cards. Place outdoor cards with an adult and keep them well away from roads and traffic. Wash your hands after handling petroleum jelly and dusty cards.

EXPERIMENT: DUST DETECTIVE: THE STICKY-CARD AIR TEST

You will answer the question: **Which place in or around my home has the most particles floating in the air?** Write your prediction first.

What we change: the place where each card sits. What we keep the same: the size of the card, the amount of petroleum jelly, the height of the card, and the time (48 hours). What we measure: the number of specks in a small square. Our control: a card sealed in a clean zip bag.

You will need

- Five white index cards
- Petroleum jelly and a craft stick or spoon to spread it
- A ruler, a pencil and tape
- A magnifying glass
- A clean zip-top plastic bag

- Lab notebook and pencil

Steps

1. On each card, draw three squares, each 2 cm by 2 cm (a little under 1 inch on a side). Label the cards with places, such as *bedroom*, *kitchen*, *porch*, *garage* and *control*.
2. Spread a thin, even layer of petroleum jelly over the squares on each card.
3. Seal the control card inside the zip bag right away.
4. Tape each other card, sticky side up, in its place, all about the same height (for example on a shelf about 1 meter, or 3 feet, high). Keep the control bag in the kitchen.
5. Leave all cards for 48 hours without touching the sticky side.
6. Collect the cards. Using the magnifying glass, count the specks in each of the three squares on each card.
7. Find the average for each card: add the three counts and divide by 3.
8. Make a data table and a bar graph. Write which place had the most particles, and whether the control card stayed nearly clean.

Tips

- Count the same way on every card. Decide ahead of time whether you will count a speck that is only partly inside a square.
- If some cards are so covered you cannot count, count just one square and say so in your notes.
- Compare a dry, still day with a windy day as a second experiment.

Check your work

- I can explain how my sticky card is like the mucus in my airways.
- I can tell why I used a control card.
- I can find averages and make a bar graph of my results.

NATURE NOTEBOOK

1. Draw the airway tree from the trachea to the alveoli. Add a zoomed-in circle showing cilia under a layer of mucus with a few dust specks caught in it, and an arrow showing which way the cilia sweep.
2. Tape your best sticky card into your notebook (or draw what you saw under the magnifying glass) and write the place, date and average count beside it.
3. Draw two alveoli clusters side by side: healthy (many small round sacs) and emphysema (a few large sacs). Write one sentence explaining why the healthy lung passes more oxygen to the blood.

> **From history.** Richard Doll and his colleague Richard Peto kept following the British doctors for fifty years. In 2004 they reported that, on average, the doctors who kept smoking died about ten years earlier than those who never smoked, and that those who stopped smoking by about age 30 avoided almost all of the extra risk. Austin Bradford Hill

also became famous for a list of questions scientists still use to decide whether one thing truly causes another. Both men were knighted for their work.

WORKED EXAMPLES

Example 1. A student's sticky cards had these counts in their three squares. Bedroom: 11, 13, 12. Porch: 38, 44, 38. Control (sealed bag): 1, 0, 2. Find the average for each card. How many times more specks did the porch card catch than the bedroom card? What does the control card tell us?

1. Bedroom average: (11 + 13 + 12) ÷ 3 = 36 ÷ 3 = 12 specks.
2. Porch average: (38 + 44 + 38) ÷ 3 = 120 ÷ 3 = 40 specks.
3. Control average: (1 + 0 + 2) ÷ 3 = 3 ÷ 3 = 1 speck.
4. Porch compared with bedroom: 40 ÷ 12 ≈ 3.3 times as many.
5. The control card stayed almost clean, so the specks on the other cards really came from the air, not from the jelly or our handling.

Answer: Bedroom 12, porch 40, control 1. The porch card caught about 3.3 times as many specks as the bedroom card. The nearly clean control shows the specks came from the air.

Example 2. Suppose mucus in a grown-up's windpipe is swept upward about 1 cm each minute, and the windpipe is about 12 cm (about 4.7 inches) long. How long would it take a trapped speck to travel the length of the windpipe? If smoke slowed the cilia so the mucus moved only 0.25 cm each minute, how long would it take?

1. Time = distance ÷ speed.
2. Healthy: 12 cm ÷ 1 cm per minute = 12 minutes.
3. Slowed: 12 cm ÷ 0.25 cm per minute = 48 minutes.
4. 48 ÷ 12 = 4, so the slowed cilia take 4 times as long, and mucus has time to pile up.

Answer: About 12 minutes normally, but about 48 minutes (4 times as long) if the cilia are slowed to 0.25 cm per minute.

PRACTICE

1. EASY What do cilia do?
2. EASY Which gas in smoke takes the place of oxygen on red blood cells?
3. EASY In their 1950 study, which two groups of hospital patients did Doll and Hill compare?
4. MEDIUM Mucus moves up a windpipe 12 cm long at 0.5 cm per minute. How many minutes does it take to travel the whole windpipe?

5. MEDIUM Read this sticky-card table (specks in three squares).
   Garage: 30, 26, 34
   Living room: 10, 14, 12
   Control (sealed bag): 0, 1, 0
   (a) Find the average for the garage and the living room. (b) How many times as many specks did the garage card catch? (c) Why was the control card important?
6. MEDIUM Explain why people who smoke often have a cough.
7. HARD A family wonders whether a fan with an air filter taped to the back cleans the air in a room. Design a sticky-card experiment. Name what you change, what you keep the same, what you measure, and what your control is.
8. CHALLENGE Showing that lung cancer patients were more often smokers was only the first step. Name two other things Doll and Hill found that made scientists sure that smoking causes lung cancer, and explain why each one matters.

COMMON MISTAKES

- Thinking smoke harms only the lungs. Carbon monoxide and other chemicals in smoke also harm the blood, the heart and the blood vessels.
- Thinking vapes give off only harmless water vapor. Most contain nicotine, which is addictive, along with other chemicals carried deep into the lungs.
- Thinking there is no point in quitting once someone has smoked for years. The cilia begin to work again and the risk of disease drops year by year after a person stops.

> **Make it a game · Cilia Relay.** Players sit in a line on the floor and become the cilia of the windpipe. A parent drops crumpled paper “dust” balls at the far end (the lungs). Players pass each ball hand to hand, using only gentle sweeping motions, up to the front (the throat) and into a basket. Time how long it takes to clear ten balls. Then play the “smoke round”: every other player must keep their hands in their lap, as if their cilia were stopped by tar. Compare the times.

> **Scripture.** “What? know ye not that your body is the temple of the Holy Ghost which is in you, which ye have of God, and ye are not your own?” (1 Corinthians 6:19, KJV)

Paul reminds Christians that the body is a gift held in trust from God. Choosing not to fill our lungs with smoke is one simple way of caring for that gift.

Practice answers

1. Cilia are tiny hairlike parts on the cells lining the airways. They beat together to sweep mucus, with the dust and germs trapped in it, up and out of the lungs toward the throat.
2. Carbon monoxide.
3. Patients who had lung cancer and patients who were in the hospital for other illnesses.
4. 12 ÷ 0.5 = 24 minutes.
5. (a) Garage: 90 ÷ 3 = 30. Living room: 36 ÷ 3 = 12. (b) 30 ÷ 12 = 2.5 times as many. (c) The control shows that almost no specks come from the jelly or the card itself, so the specks on the other cards came from the air.

6. Tar in smoke coats the airways and slows or stops the cilia, so they cannot sweep mucus out. Mucus and trapped particles build up in the airways, and the body coughs to try to clear them.
7. Change: whether the filter fan is running (two similar rooms, or the same room on two different weeks). Keep the same: card size, amount of jelly, height and spot of the card, time (for example 48 hours), and the same doors and windows open or closed. Measure: average specks in three squares per card. Control: a card in the same room with the fan off (and a sealed card to check the jelly). Repeat the test more than once.
8. (1) The more people smoked, the higher their risk: if smoking causes the disease, more smoking should mean more disease. (2) When they followed thousands of doctors forward in time, the smokers later developed lung cancer far more often than nonsmokers, showing the smoking came first. (3) People who quit lowered their risk, which is what we would expect if smoking is the cause. Any two of these, explained.

Unit 4 review

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

1. (5 pts) Put these parts in the order air passes through them when you breathe in: alveoli, trachea, nose, bronchioles, bronchi. In which part does oxygen pass into the blood?
2. (5 pts) Explain how the diaphragm makes air flow into the lungs. Use the words *space* and *air pressure*.
3. (5 pts) In the bottle lung model, what do the bottle, the straw, the inside balloon and the stretched balloon stand for? Name one way the model is different from a real chest.
4. (5 pts) Define vital capacity. What instrument did John Hutchinson invent to measure it, and what pattern did he find between vital capacity and height?
5. (5 pts) A jug spirometer is marked every 250 mL. A student's three trials reached the 8th, 9th and 7th lines. Find each trial in mL and the average in liters.
6. (5 pts) A grown-up's lungs hold about 6 L in all, and the vital capacity is about 4.5 L. How much air stays in the lungs after the hardest breath out? What is this air called, and why is it needed?
7. (5 pts) A helper counts 9 breaths in 15 seconds right after jumping jacks. What is the breathing rate per minute? If the resting rate is 20, how much higher is it?
8. (5 pts) Why do you breathe faster and deeper when you run? Use the words *oxygen*, *carbon dioxide* and *cellular respiration*.
9. (5 pts) Describe how mucus and cilia keep the airways clean. Then name two ways tobacco smoke harms the body.
10. (5 pts) A student puts sticky cards in a bedroom and a garage for 48 hours to see which has more dust. Name what the student changes, two things to keep the same, what to measure, and a good control.

Unit project: my breathing lab book

Gather the work of this unit into a lab book that shows how your lungs work and how you tested them. Include a labeled drawing of the airway tree from nose to alveoli; your bottle lung model (or a photo of it) with a table of your diaphragm measurements; your family's spirometer data table and bar graph; your breathing-rate experiment with its bar graph and recovery time; and your sticky-card results with the control card.

End with a one-page letter to a younger child explaining, in your own words, how breathing works and three ways to care for their lungs.

- **Accuracy**: Parts of the respiratory system are named and labeled correctly, and explanations use diaphragm, air pressure, oxygen, carbon dioxide, cilia and mucus correctly.

- **Experiments**: Each experiment states the question, prediction, what was changed, what was kept the same, what was measured and the control where one was used.
- **Data**: Data tables are complete with units, averages are calculated correctly, and bar graphs have titles, labeled axes and even scales.
- **Care**: The lab book is neat, dated and well organized, and the letter is clear, kind and easy for a younger child to understand.

Answer key

1. Nose, trachea, bronchi, bronchioles, alveoli. Oxygen passes into the blood in the alveoli.
2. The diaphragm tightens and flattens downward (and the rib muscles lift the ribs), making the space inside the chest larger. The air pressure inside the lungs drops below the pressure outside, so outside air is pushed in through the nose or mouth.
3. Bottle: chest (rib cage). Straw: windpipe (trachea). Inside balloon: lung. Stretched balloon: diaphragm. Differences (any one): a real chest has two lungs; real ribs move; real lungs are spongy, not hollow; a thin slippery lining holds real lungs against the chest wall.
4. Vital capacity is the most air a person can breathe out after taking the deepest breath possible. Hutchinson invented the spirometer. He found that taller people have larger vital capacities.
5. 8 × 250 = 2,000 mL; 9 × 250 = 2,250 mL; 7 × 250 = 1,750 mL. Average: (2,000 + 2,250 + 1,750) ÷ 3 = 6,000 ÷ 3 = 2,000 mL = 2.0 L.
6. 6 − 4.5 = 1.5 L. This is the residual volume. It keeps the alveoli and small airways from collapsing.
7. 9 × 4 = 36 breaths per minute. 36 − 20 = 16 breaths per minute higher.
8. Running muscles do more work, so their cells carry out more cellular respiration, using more oxygen to release energy from food and making more carbon dioxide. The brain senses the extra carbon dioxide in the blood and signals the breathing muscles to work faster and deeper, bringing in more oxygen and getting rid of carbon dioxide.
9. Sticky mucus traps dust and germs, and the cilia beat together to sweep the mucus up to the throat, where it is swallowed or coughed out. Smoke harms (any two): tar coats the airways and slows or stops the cilia; it can break down the walls of the alveoli (emphysema); carbon monoxide takes oxygen’s place on red blood cells; chemicals in tar can cause cancer; nicotine is addictive.
10. Change: the place (bedroom or garage). Keep the same (any two): card size, amount of petroleum jelly, height of the card, the 48-hour time, the way of counting. Measure: the number of specks in a small square (averaged over three squares). Control: a card sealed in a clean plastic bag, to show the specks come from the air.

UNIT 5

Digestion

Every bite you take begins a journey. In this unit you will follow food from your teeth to your blood. You will meet **Dr. William Beaumont**, the army surgeon who, after a terrible accident on Mackinac Island in 1822, spent years watching a living stomach at work through an opening in the side of his patient, **Alexis St. Martin**. You will learn what each kind of tooth does and how cavities form, ride along with Walter Cannon as he watched food move on one of the first X-ray screens, and sail with James Lind, whose test of oranges and lemons in 1747 showed how one missing nutrient could make strong sailors sick.

Along the way you will work like a real scientist: timing sugar cubes as they dissolve, soaking eggshells in vinegar to see what acid does, measuring a folded model of the small intestine, laying out the whole 9-meter path in yarn, and testing foods for fat with brown paper. In every experiment you will name what you change, what you keep the same, what you measure and your control, and you will record your data in tables and graphs.

God gave food as a gift: “to you it shall be for meat” (Genesis 1:29). By the end of this unit you will know how wonderfully the body receives that gift, turning bread and beans into muscle, bone and blood, and you will be ready to eat, cook and give thanks with understanding.

BEFORE YOU BEGIN

- Can multiply and divide whole numbers and add decimals (for example, 8 × 9 and 0.25 + 6.5)
- Can measure with a metric ruler and a measuring cup and read a timer in seconds
- Knows that the body is made of cells, tissues and organs (Unit 1) and that blood carries food and oxygen to the cells (Unit 3)
- Can read a simple bar graph and data table

MASTERY CHECKLIST

- I can tell the story of William Beaumont and Alexis St. Martin and explain what Beaumont learned about the stomach and gastric juice.
- I can explain the difference between mechanical and chemical digestion and give examples of each.
- I can name the four kinds of teeth and the layers of a tooth, count the teeth of a child and an adult, and explain how cavities form.
- I can trace food through the digestive tract in order, tell what happens in each part, and explain how villi help the small intestine.
- I can name the six kinds of nutrients, find the Calories in a food from its grams of fat, carbohydrate and protein, and tell how Lind’s fair test defeated scurvy.
- I can plan a fair test that changes one variable, keeps other things the same and uses a control.

OPTIONAL BOOKS AND RESOURCES

- **KidsHealth: Your Digestive System** (https://kidshealth.org/en/kids/digestive-system.html): Free. A clear, child-friendly article on the path of food from mouth to large intestine, written by doctors at Nemours Children's Health. Good for review after Lesson 5.3.
- **MyPlate, from the U.S. Department of Agriculture** (https://www.myplate.gov/): Free. Simple pictures and tips for building a balanced plate from the five food groups. Use it while planning and cooking the meal in Lesson 5.4.
- **NIDDK: Your Digestive System and How It Works** (https://www.niddk.nih.gov/health-information/digestive-diseases/digestive-system-how-it-works): Free. A plain-language page from the National Institutes of Health with a labeled diagram of the digestive organs. Best read with a parent; good for checking the labels on your body-outline drawing.

5.1 William Beaumont and Alexis St. Martin (1822) ★

OBJECTIVES

- Tell how an accident on Mackinac Island in 1822 gave Dr. William Beaumont a window into a living stomach, and what his experiments showed.
- Explain the difference between mechanical digestion and chemical digestion and give an example of each.
- Run a fair test showing that smaller pieces and warmth make a substance break down faster, and record the results in a data table.

Warm-up. Put your hand flat on the left side of your belly, just below your ribs. Your stomach lies under your hand. Now think back: what did you eat for breakfast, and where do you think it is right now? Write your guess in one sentence. Then drink a glass of water slowly and try to feel where it goes. Keep your guess; you will check it at the end of the unit.

Video. Coming soon. William Beaumont and Alexis St. Martin stomach experiments, and how the stomach digests food; search history-of-medicine channels, Smithsonian, SciShow Kids, Homeschool Pop (Alternate), Crash Course Kids and medical-animation channels for children (parent preview).

KEY TERMS

digestion
The breaking down of food into pieces so small that they can pass into the blood and feed the body’s cells.

mechanical digestion
Breaking food into smaller pieces by chewing, churning and squeezing, without changing what it is made of.

chemical digestion
Breaking food down with digestive juices that change it into new, simpler substances the body can use.

gastric juice
The strong, acid juice made by the lining of the stomach that helps break down food, especially meat and other proteins.

stomach
A stretchy, muscular bag under the left ribs that stores food, churns it and mixes it with gastric juice.

CORE IDEAS

The story. On June 6, 1822, a crowd of fur traders filled the American Fur Company store on Mackinac Island, in the narrow waters between Lake Huron and Lake Michigan. Someone's musket went off by accident. The shot struck a young French-Canadian voyageur named **Alexis St. Martin** in his left side from less than a meter (about 3 feet) away. It broke his ribs and tore a hole right into his stomach. The army surgeon at Fort Mackinac, **Dr. William Beaumont**, hurried down the hill. He did not expect the young man to live through the day. But St. Martin did live. Week after week Beaumont cleaned and dressed the wound, and when the town would no longer pay for St. Martin's care, Beaumont took him into his own home.

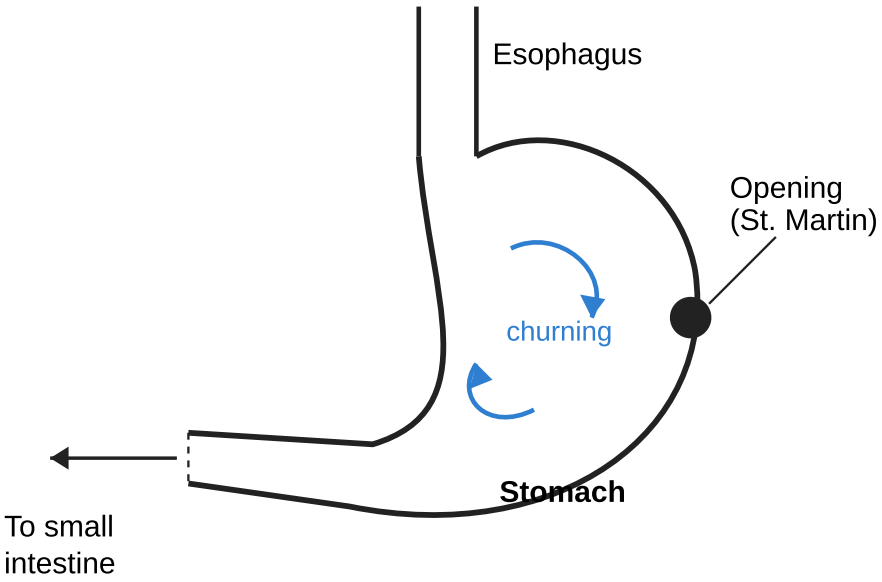
How they figured it out. The wound healed, but it never closed all the way. It left an opening from the outside of St. Martin's body straight into his stomach, with a soft flap of tissue over it like a little door. Beaumont saw that he had a window no one had ever looked through: a healthy, living stomach at work. Beginning in 1825, he tied bits of food, such as beef, bread and cabbage, to silk threads and lowered them through the opening. Every hour or so he pulled them out to see how much was gone. He drew out clear gastric juice, sealed it in a small glass vial, kept it warm at about body temperature and dropped in a piece of meat. Hours later the meat had broken down in the glass, outside the body. Off and on for about eight years, Beaumont ran 238 experiments and published them in 1833 in his book *Experiments and Observations on the Gastric Juice, and the Physiology of Digestion*.

What he learned. Beaumont watched the stomach lining make gastric juice when food arrived, but not when the stomach was empty. Chemists who tested the juice found that it held a strong acid, hydrochloric acid. He saw the stomach walls churn and roll the food. He found that food cut into small pieces digested faster than large lumps, that boiled rice was gone in about an hour while roast pork took more than five hours, and that when St. Martin was angry, feverish or ill, digestion slowed down. St. Martin was not always a happy patient. Sometimes he grew tired of the tests and went home to Canada, where he married and raised a family. Beaumont paid him wages and brought him back for more experiments. St. Martin lived until 1880, almost thirty years longer than his doctor.

The big idea. Digestion is the breaking down of food into pieces so tiny that they can pass into the blood and feed every cell. There are two kinds. **Mechanical digestion** makes food smaller without changing what it is: your teeth chop it and your stomach muscles churn it. **Chemical digestion** uses juices to change food into new, simpler substances. Beaumont's vial proved that chemical digestion is real, because nothing in the glass was churning, yet the meat still broke down. His lumps and small pieces showed why mechanical digestion matters too: small pieces have more *surface* where the juice can touch them, so they break down faster.

Try it and see. You can test Beaumont's two discoveries in your kitchen with sugar cubes and water. A whole cube and a crushed cube, dropped in the same amount of water, show what chewing does. Cubes in cold water and warm water show why Beaumont kept his vial warm. You will time each one and record the results like a real scientist.

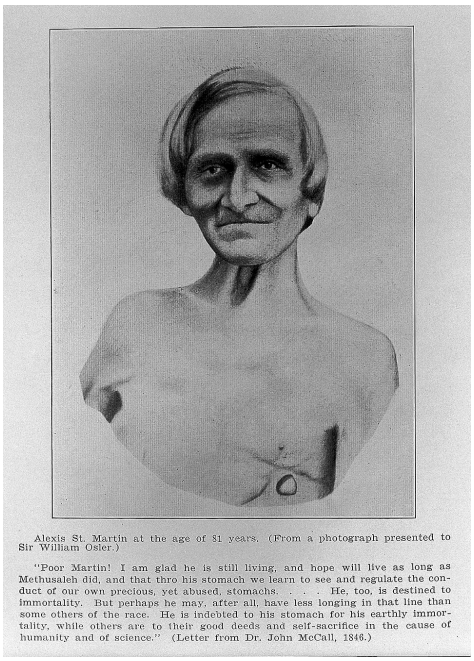
God’s handiwork. Gastric juice is strong enough to break down a steak, yet it does not digest the stomach that makes it. The stomach lining is covered with a thick coat of slippery mucus that keeps the acid away from the wall, and the cells of the lining are replaced every few days. Beaumont could see the pink, healthy lining through the opening and wrote about how carefully it worked. The God who formed us thought even of this.



Drawn facing the person: the body’s left side is on the right of the picture.

The stomach, drawn as if you are facing a person. St. Martin’s opening was on the left side of his body, on the stomach’s large outer curve.

PICTURE STUDY



Alexis St. Martin at the age of 81 years. (From a photograph presented to Sir William Osler.)

"Poor Martin! I am glad he is still living, and hope will live as long as Methusaleh did, and that thro his stomach we learn to see and regulate the conduct of our own precious, yet abused, stomachs. . . . He, too, is destined to immortality. But perhaps he may, after all, have less longing in that line than some others of the race. He is indebted to his stomach for his earthly immortality, while others are to their good deeds and self-sacrifice in the cause of humanity and of science." (Letter from Dr. John McCall, 1846.)

Portrait of Alexis St. Martin, Aged 81, Unknown photographer, Late 1800s · Photograph · Wellcome Collection, London (printed in J. S. Myer's *Life and Letters of Dr. William Beaumont*, 1912)

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

Most pictures in this course were drawn or painted by hand. This one is a photograph of the patient himself, Alexis St. Martin, taken many years after the accident on Mackinac Island. By then he was an old man who had worked as a voyageur and farmer in Canada and raised a large family. The opening in his stomach was still there under his coat.

When you look at an old photograph, remember that the person in it was as real as you are. St. Martin was not just a "case" in a book. He was a man with a family, a temper, a home he loved and a story that taught the whole world how the stomach works.

Look closely

- Look at the man's face. How old do you think he is? What clues tell you?
- Look at his clothes and his face. What kind of life do you think he lived?
- Old photographs needed people to sit very still for a long time. How can you tell he is holding still?
- Nothing in the picture shows his wound. Why might a person not want that part of his life to be what people remember?

Talk about it

1. How do you think St. Martin felt about being tested again and again for years?
2. Beaumont and St. Martin both helped science. What did each one give?
3. If you could ask St. Martin one question, what would it be?

> **Safety first.** Use warm tap water only, never boiling water. Do not drink the test water. A parent should help with the thermometer and wipe up spills so no one slips.

EXPERIMENT: BEAUMONT'S VIAL: THE SUGAR CUBE TEST

Beaumont found two things you can test at home: small pieces break down faster than big lumps, and warmth speeds up digestion. You will use sugar cubes dissolving in water as a model. Dissolving is not the same as digesting, but it follows the same two rules, and it is safe and easy to time.

Question: Does crushing a sugar cube make it dissolve faster? Does warm water make it dissolve faster than cold water? Write your predictions before you start.

You will need

- 6 sugar cubes
- 4 clear glasses or jars of the same size
- Measuring cup
- Cold water from the refrigerator, room-temperature water and warm tap water (not boiling)
- A kitchen thermometer if you have one
- A spoon, a zip bag and a rolling pin or can (for crushing)
- A timer or clock with a second hand
- Lab notebook and pencil

Steps

1. Rule a data table in your notebook with columns: Test, Water temperature, Whole or crushed, Time to dissolve (seconds).
2. **Test A (size).** Pour 250 mL (about 1 cup) of room-temperature water into each of two glasses. Put one whole sugar cube in a zip bag and crush it to powder with the rolling pin.
3. At the same moment, drop the whole cube into one glass and pour the crushed cube into the other. Stir each glass slowly, five stirs every 15 seconds, the same way for both.
4. Time how long until you can see no more sugar grains at the bottom. Record both times.
5. **Test B (warmth).** Pour 250 mL of cold water into one glass and 250 mL of warm tap water into another. Measure and record each temperature if you can.
6. Drop one whole cube into each glass at the same moment. Stir both the same way as before. Time and record.
7. Repeat each test a second time with fresh water and cubes, and find the average time for each.
8. Write your conclusion: What did crushing do? What did warmth do? How does this match what Beaumont saw in St. Martin's stomach?

Tips

- What we change: in Test A, the size of the sugar pieces; in Test B, the water temperature. What we keep the same: the amount of water, the kind of sugar, the glass and the stirring. What we measure: the time to dissolve.
- Stirring is your model of the churning stomach. If you stir one glass more than the other, the test is no longer fair.
- Your body keeps its inside at about 37 °C (98.6 °F). That is why Beaumont kept his vial of gastric juice warm.

Check your work

- I wrote a prediction before testing.
- I changed only one thing in each test and kept the rest the same.
- My data table has units (seconds, °C or °F) and two trials for each test.
- I can explain how my results match Beaumont’s discoveries.

NATURE NOTEBOOK

1. Draw a map of the Great Lakes region and mark Mackinac Island between Lake Huron and Lake Michigan. Add a small drawing of Fort Mackinac on its hill.
2. Draw the stomach from the lesson diagram. Label the esophagus, the stomach, St. Martin’s opening and the way to the small intestine. Add arrows showing the churning.
3. Make a two-column chart titled “Two Kinds of Digestion.” Under Mechanical, list three examples (chewing, churning, crushing). Under Chemical, list two (gastric juice in the stomach, the meat in Beaumont’s vial).

> **From history.** Beaumont’s gastric juice held something more than acid, though he could not find it. In 1836, three years after his book came out, the German scientist Theodor Schwann found the substance in gastric juice that breaks down meat and named it **pepsin**. It was one of the first enzymes ever discovered. An enzyme is a substance made by living things that speeds up a chemical change, and your body uses many different enzymes to digest your food.

WORKED EXAMPLES

Example 1. In the sugar cube test, a whole cube took 200 seconds to dissolve. A crushed cube in the same amount of water took 40 seconds. How many times faster did the crushed sugar dissolve? Write the whole cube’s time in minutes and seconds too.

1. To find how many times faster, divide the longer time by the shorter time: 200 ÷ 40 = 5.
2. To change 200 seconds to minutes, remember that 1 minute = 60 seconds. 60 × 3 = 180, and 200 − 180 = 20.
3. So 200 seconds = 3 minutes 20 seconds.

Answer: The crushed sugar dissolved 5 times faster. The whole cube took 3 minutes 20 seconds. Smaller pieces have more surface for the water to touch, just as chewed food has more surface for gastric juice.

Example 2. Beaumont recorded that boiled rice was digested in St. Martin’s stomach in about 1 hour, while roasted pork took about 5 hours 15 minutes. How much longer did the pork take, in minutes and in hours and minutes?

1. Change both times to minutes. Rice: 1 hour = 60 minutes.
2. Pork: 5 hours = 5 × 60 = 300 minutes, plus 15 minutes = 315 minutes.
3. Subtract: 315 − 60 = 255 minutes.
4. Change back: 255 = 240 + 15, and 240 minutes = 4 hours. So 255 minutes = 4 hours 15 minutes.

Answer: The pork took 255 minutes longer, which is 4 hours 15 minutes. Foods that are fatty and tough stay in the stomach much longer than soft, starchy foods like rice.

PRACTICE

1. EASY Where and in what year was Alexis St. Martin wounded? Who was the doctor who treated him?
2. EASY Sort each into mechanical or chemical digestion: (a) your teeth grinding a carrot, (b) gastric juice breaking down meat, (c) the stomach walls churning food.
3. MEDIUM Beaumont put gastric juice and a piece of meat in a warm glass vial, and the meat broke down. What did this experiment prove?
4. MEDIUM A student timed whole sugar cubes dissolving in 250 mL of water at three temperatures. Cold (10 °C, 50 °F): 300 seconds. Room (22 °C, 72 °F): 180 seconds. Warm (40 °C, 104 °F): 90 seconds. (a) Which dissolved fastest? (b) What pattern do you see? (c) About how many times faster was warm than cold?
5. MEDIUM St. Martin was wounded in 1822 and died in 1880. For how many years did he live with the opening in his stomach?

6. HARD Design a fair test to find out whether crackers broken into small bits break down in a cup of vinegar-and-water faster than whole crackers. Name the variable you change, three things you keep the same, what you measure, and a control you could add.
7. HARD Why did Beaumont keep his vial of gastric juice warm, near body temperature? What would you expect to happen if he had kept it cold?
8. CHALLENGE In three or four sentences, explain why St. Martin's stomach was called a "window," and describe two things Beaumont learned through it.

COMMON MISTAKES

- Thinking the stomach does all of digestion. It starts in the mouth, and most of the work of finishing digestion and taking in food happens later, in the small intestine (Lesson 5.3).
- Thinking the stomach is down by the belly button. It sits higher, mostly under the lower left ribs.
- Thinking digestion is only squeezing and mashing. Beaumont's vial showed that juices change food chemically, even with no churning at all.

> **Make it a game · Mechanical or Chemical?.** A parent names something that happens to food, such as "biting an apple," "stomach acid on a hot dog," "mashing potatoes with a fork," "saliva on a cracker" or "the stomach churning." Shout "Mechanical!" and make a chomping motion, or "Chemical!" and wiggle your fingers like bubbling juice. One point for each right answer, and a bonus point if you can say which part of Beaumont's story it reminds you of. Play to ten.

> **Scripture.** "And went to him, and bound up his wounds, pouring in oil and wine, and set him on his own beast, and brought him to an inn, and took care of him." (Luke 10:34, KJV)

Before Beaumont ever ran an experiment, he spent many months caring for a badly hurt young man and finally took him into his own home. Good science often grows out of patient care for a neighbor.

Practice answers

1. On Mackinac Island (in the Great Lakes, between Lake Huron and Lake Michigan) in 1822. The army surgeon Dr. William Beaumont of Fort Mackinac treated him.
2. (a) Mechanical. (b) Chemical. (c) Mechanical.
3. It proved that digestion is partly chemical: the juice itself breaks down food, even outside the body and without any churning by the stomach muscles.
4. (a) The cube in warm water. (b) The warmer the water, the faster the sugar dissolved. (c) 300 ÷ 90 ≈ 3.3, so a little more than 3 times faster.
5. 1880 − 1822 = 58 years.
6. Change: the size of the cracker pieces (whole or broken into bits). Keep the same: the kind and amount of cracker, the amount and mix of vinegar and water, the temperature, the cup and the stirring. Measure: the time until the cracker turns to mush, or how much is left after

a set time. Control: a whole cracker in the same liquid (or a cracker in plain water to compare with the vinegar).

7. Because inside the body the stomach is warm, about 37 °C (98.6 °F), and gastric juice works best at that temperature. In a cold vial, the meat would break down much more slowly, or hardly at all.
8. Before Beaumont, no one could watch a healthy, living stomach at work, but St. Martin’s healed wound left an opening straight into it. Through it Beaumont could look in, lower food on threads and take out gastric juice. He learned, for example, that the stomach makes acid gastric juice when food arrives and that the juice digests meat even in a glass vial. He also saw that the stomach churns food, that small pieces digest faster than big ones, and that anger or illness slows digestion.

5.2 Teeth ★

OBJECTIVES

- Name the four kinds of teeth, tell the job of each, and count the 20 baby teeth and 32 adult teeth with a simple formula.
- Label the parts of a tooth (crown, root, enamel, dentin, pulp) and explain how sugar, germs and acid cause cavities.
- Explain how chewing and saliva begin digestion, and test how acid affects a shell made of minerals, using a control.

Warm-up. Take a small mirror and count your own teeth, top and bottom. Write the number down. Then put one plain saltine cracker in your mouth and chew it slowly for one full minute without swallowing. Does the taste change? Many people notice it starts to taste a little sweet. Write down what you notice; you will find out why in this lesson.

Video. Coming soon. Kinds of teeth, parts of a tooth and how cavities form, for children; search dental-health education channels, SciShow Kids, Homeschool Pop (Alternate), Crash Course Kids, Science Max and Pierre Fauchard history-of-dentistry clips (parent preview).

KEY TERMS

incisors, canines, premolars, molars
The four kinds of teeth: incisors cut, canines tear, premolars crush, and molars grind food.

enamel
The hard, shiny outer layer of the crown of a tooth; the hardest material in the human body.

dentin and pulp
Dentin is the yellowish, bone-like layer under the enamel. The pulp is the soft center of the tooth, with nerves and blood vessels.

saliva
The watery juice made in the mouth that wets food and begins breaking starch down into sugar.

cavity
A hole in a tooth made when acid from germs feeding on sugar dissolves the enamel.

CORE IDEAS

The story. In 1728, in Paris, a surgeon named **Pierre Fauchard** published a two-volume book called *Le Chirurgien Dentiste*, “The Surgeon Dentist.” Before then, teeth were often cared for by barbers and traveling tooth-pullers at country fairs, and many people believed that toothaches were caused by little “tooth worms” eating holes in the teeth. Fauchard had

spent years looking carefully at real mouths. He described more than a hundred problems of the teeth and gums, showed how to fill holes and make false teeth, and taught people to clean their teeth every day. He doubted the old tooth-worm idea, since no one had ever truly found such worms. Today he is often called the father of modern dentistry.

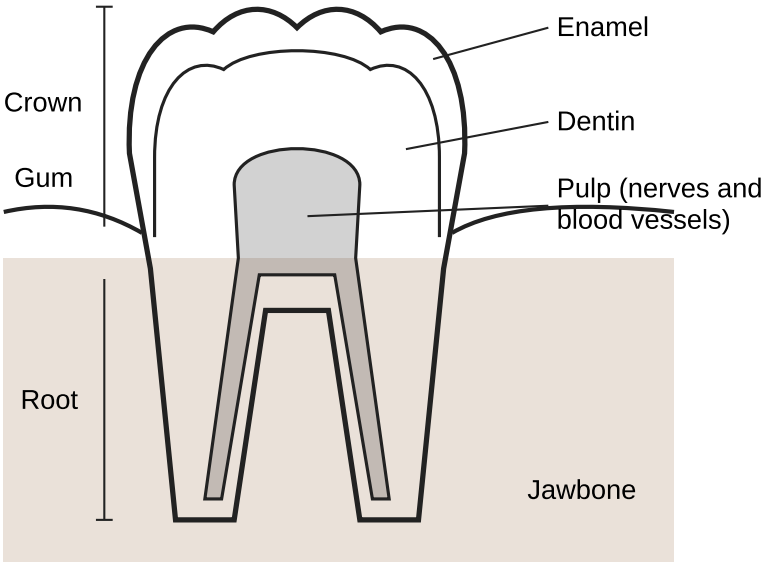
How they figured it out. The real cause of cavities was found by watching and testing. In the 1680s, Antoni van Leeuwenhoek scraped the white film off his own teeth, looked at it through his little microscope, and saw it swarming with tiny living things. Two hundred years later, an American dentist named Willoughby Miller showed that these germs, which we now call bacteria, feed on sugar and starch left in the mouth and give off acid. The acid slowly dissolves the hard minerals of the enamel. Brush the food and germs away, and there is much less acid to do harm.

The big idea. Your teeth are the first tools of **mechanical digestion**. The flat, sharp **incisors** in front cut, like scissors. The pointed **canines** beside them tear. The **premolars** crush, and the wide, bumpy **molars** in back grind food like millstones. Chopping food into small pieces gives it much more surface for digestive juices to work on. Children have 20 baby teeth (primary teeth). Starting at about age six, these fall out one by one as 32 permanent teeth grow in, including four “wisdom teeth” that come in last, if they come in at all.

Inside a tooth. The part you can see above the gum is the **crown**; the part hidden in the jawbone is the **root**. The crown is covered with **enamel**, the hardest material in the body, made almost entirely of minerals. On the Mohs hardness scale it rates about 5, as hard as the mineral apatite, which is very close to what enamel is made of. Under it lies the softer **dentin**, and in the center is the **pulp**, where nerves and blood vessels keep the tooth alive. That is why a deep cavity hurts: the acid has reached the parts that can feel.

Try it and see. Chewing also begins **chemical digestion**. Your mouth makes about a liter (about a quart) of **saliva** or more every day. Saliva wets food so you can swallow it, and it carries an enzyme that starts turning starch into sugar. That is why your cracker began to taste sweet in the warm-up. In this lesson’s project you will use eggshells, which are hard and made of minerals like enamel, to watch what acid does to them, and to test whether fluoride toothpaste protects them.

God’s handiwork. The Creator fitted each animal’s teeth to its food. A cow has broad, flat grinding teeth for grass; a lion has long canines and sharp, scissor-like back teeth for meat. You have all four kinds, fitted for bread and apples, cheese and meat, nuts and beans. And instead of one set of teeth for life, you get two: small ones for a small jaw, then larger ones as your jaw grows.



A molar cut in half. The crown sits above the gum; the roots are held in the jawbone.

PICTURE STUDY



The Tooth-Puller, Jan Steen, 1651 · Oil on canvas · Mauritshuis, The Hague, the Netherlands

Jan Steen was a Dutch painter who loved busy, funny scenes of everyday life. Here he shows something people in his time saw at fairs and markets: a traveling tooth-puller at work in the open air. There was no numbing medicine, and a bad tooth was simply pulled out while neighbors gathered to watch.

Seventy-seven years after Steen painted this, Pierre Fauchard wrote his book to turn tooth care into a careful, trained profession. Comparing this picture with a visit to a dentist today shows how much changed.

Look closely

- Find the man having his tooth pulled. How do his body, hands and feet show how he feels?
- Look at the tooth-puller. Does he seem calm or worried? What is he wearing?
- Look at the faces in the crowd. Who seems sorry for the patient, and who seems to be enjoying the show?
- Look around the tooth-puller for things he might use or sell.

Talk about it

1. Why do you think a tooth-puller worked outdoors at a fair instead of in an office?
2. What three things are different about a trip to the dentist today?
3. What could the man in the painting have done years earlier to keep his tooth?

> **Safety first.** A parent should boil the eggs. Do not eat the eggs after the experiment, and wash your hands after handling them. Vinegar is safe to touch but stings the eyes; if it splashes in an eye, rinse with plenty of water.

EXPERIMENT: ACID AND THE EGGSHELL: A FLUORIDE TEST

Enamel is made of hard calcium minerals. Eggshells are made of a different calcium mineral, but acid attacks both. In this experiment you will soak hard-boiled eggs in vinegar, a weak acid like the acid germs make in your mouth, and see what happens to the shell. You will also test whether fluoride toothpaste helps protect it.

Question: Does vinegar damage an eggshell? Does a coat of fluoride toothpaste protect the shell? Write your predictions first.

You will need

- 3 white hard-boiled eggs, cooled (a parent boils them)
- 3 clear jars or cups, labeled A, B and C
- White vinegar (enough to cover two eggs)
- Water
- Fluoride toothpaste (check the label for “fluoride”)
- A spoon, paper towels and a magnifying glass
- Lab notebook and pencil

Steps

1. Make a data table with columns: Egg, What it soaked in, Bubbles? (none, few, many), Shell after 24 hours (hard, a little soft, very soft), Other observations.

2. Coat egg C completely with a thick layer of fluoride toothpaste. Let it sit for 4 hours (or overnight in the refrigerator), then gently rinse off the paste.
3. Put egg A in jar A and cover it with plain water. This is your **control**.
4. Put egg B (no toothpaste) in jar B and egg C (toothpaste-treated) in jar C. Cover each with the same amount of vinegar.
5. Watch for 5 minutes with the magnifying glass. Record whether bubbles form on each shell.
6. After 24 hours, lift each egg out with the spoon, pat it dry and gently press the shell with a fingertip. Record what you find.
7. Compare: How did vinegar change egg B? Was egg C damaged less? What did egg A show you?
8. Write a conclusion connecting your results to sugar, germs, acid and brushing with fluoride toothpaste.

Tips

- What we change: what the egg soaks in, and whether it was treated with toothpaste. What we keep the same: the kind and size of egg, the amount of liquid, the jar and the time. What we measure: bubbles and how hard the shell feels.
- The bubbles are a gas made when the acid reacts with the minerals in the shell.
- An eggshell is a model, not a real tooth. Real enamel is harder, and your saliva helps repair small acid damage between meals.

Check your work

- I wrote predictions before I started.
- I used plain water as a control.
- I recorded bubbles and shell hardness for all three eggs.
- I can explain what my eggs teach about sugar, acid and brushing.

NATURE NOTEBOOK

1. Draw the tooth cross-section from the lesson. Label the crown, root, enamel, dentin, pulp, gum and jawbone.
2. Make a mouth map: draw a large horseshoe for your upper teeth. Using a mirror, draw and label each incisor, canine, premolar and molar you have. Mark any baby teeth that are loose or missing.
3. Sketch the teeth of two animals from pictures or a museum skull, such as a cow and a dog. Next to each, write what kind of food those teeth are made for.

> **From history.** Through much of history, people cleaned their teeth with chew sticks, twigs frayed at one end. Toothbrushes with bristles set in a handle of bone or wood were used in China hundreds of years ago, and in England around 1780 a man named William Addis made toothbrushes to sell, starting a company that went on making them for generations. Nylon bristles, which most toothbrushes have today, came in the late 1930s.

WORKED EXAMPLES

Example 1. Dentists count teeth by quarters of the mouth (upper right, upper left, lower right, lower left). In each quarter, an adult has 2 incisors, 1 canine, 2 premolars and 3 molars. A child with all baby teeth has 2 incisors, 1 canine, 0 premolars and 2 molars in each quarter. How many teeth does each have in all?

1. Adult, one quarter: $2 + 1 + 2 + 3 = 8$ teeth.
2. Adult, whole mouth: 8×4 quarters $= 32$ teeth.
3. Child, one quarter: $2 + 1 + 0 + 2 = 5$ teeth.
4. Child, whole mouth: $5 \times 4 = 20$ teeth.
5. Difference: $32 - 20 = 12$ more teeth in an adult.

Answer: An adult has 32 teeth and a child has 20 baby teeth, so an adult has 12 more. (The 3rd molar in each quarter is a wisdom tooth, which some adults never get.)

Example 2. Why does chewing help digestion? Model it: a cube of cheese 2 cm on each side is cut into 8 small cubes, each 1 cm on a side. Find the total surface area before and after cutting.

1. Before: each face of the big cube is $2 \text{ cm} \times 2 \text{ cm} = 4 \text{ cm}^2$. A cube has 6 faces, so $6 \times 4 = 24 \text{ cm}^2$.
2. After: each face of a small cube is $1 \text{ cm} \times 1 \text{ cm} = 1 \text{ cm}^2$. Each small cube has 6 faces, so 6 cm^2 each.
3. 8 small cubes $\times$ $6 \text{ cm}^2 = 48 \text{ cm}^2$.
4. Compare: $48 \div 24 = 2$.

Answer: The surface area grows from 24 cm^2 to 48 cm^2, twice as much, even though the amount of cheese is the same. Chewing gives saliva and digestive juices much more surface to work on.

PRACTICE

1. EASY Match each kind of tooth to its job: incisor, canine, molar. Jobs: grind, cut, tear.
2. EASY Name the three layers of a tooth from the outside in. Which one has nerves and blood vessels?
3. MEDIUM Why did your cracker begin to taste sweet after you chewed it for a minute? Is this mechanical or chemical digestion?
4. MEDIUM A student soaked dry pieces of eggshell (each 5 grams) for 2 days and weighed them again after drying. Water: 5 g. Vinegar: 2 g. Vinegar, after a fluoride toothpaste coating: 4 g. (a) Which lost the most mass? (b) How much mass did each vinegar shell lose? (c) What does the water shell tell us?

5. MEDIUM A ten-year-old has lost 8 baby teeth, and 8 permanent teeth have grown in their places. Four permanent first molars have also come in behind the baby teeth. How many teeth does this child have now?
6. HARD You want to test whether apple juice or water causes more damage to an eggshell. Name the variable you change, three things you keep the same, what you measure, and your control.
7. HARD A cube of carrot 3 cm on a side is cut into 27 cubes 1 cm on a side. What is the surface area before and after? How many times larger is it?
8. CHALLENGE In three or four sentences, explain how a cavity forms, starting with a sugary snack. Then give two ways to prevent it.

COMMON MISTAKES

- Thinking baby teeth don't matter because they fall out. They hold the space for the permanent teeth and help you chew and speak for years.
- Thinking cavities are caused by tiny worms or by sugar itself. Bacteria eat the sugar and make acid, and the acid makes the hole.
- Thinking teeth are bones. Teeth and bones are both hard and full of calcium, but teeth are not bones: enamel is harder than bone, and a broken tooth cannot heal itself the way a bone can.

> **Make it a game · Tooth Tool Relay.** Set out real kitchen tools: a pair of scissors, a fork, a garlic press or potato masher, and a mortar and pestle or two flat stones. A parent names a tooth (incisor, canine, premolar or molar) or a food (celery, jerky, peanuts, a cracker). Run and grab the tool that works most like the right tooth, and say the tooth's name and job. One point for each match; a bonus point if you can point to that tooth in your own mouth.

> **Scripture.** "Thy teeth are like a flock of sheep that are even shorn, which came up from the washing; whereof every one bear twins, and none is barren among them." (Song of Solomon 4:2, KJV)

This ancient poem praises teeth that are clean, white, even and none missing, with each one matched by its twin. Look in the mirror: your teeth come in matching pairs, left and right, and keeping them clean is a way of caring for the body God gave you.

Practice answers

1. Incisor: cut. Canine: tear. Molar: grind.
2. Enamel, dentin, pulp. The pulp has the nerves and blood vessels.
3. Saliva has an enzyme that begins breaking starch in the cracker down into sugar, which tastes sweet. This is chemical digestion (the chewing that mashed the cracker was mechanical).
4. (a) The shell in plain vinegar. (b) Plain vinegar: $5 - 2 = 3$ g lost. Toothpaste-treated: $5 - 4 = 1$ g lost. (c) It is the control: water alone did not dissolve the shell, so the loss was caused by the acid in the vinegar.

5. Start with 20 baby teeth. $20 - 8 = 12$ baby teeth left. $12 + 8$ permanent replacements $= 20$, plus 4 first molars $= 24$ teeth.
6. Change: the liquid (apple juice or water). Keep the same: the size and kind of eggshell, the amount of liquid, the jar, the soaking time and the temperature. Measure: the shell's mass before and after (or how soft it feels and whether bubbles form). Control: the shell in plain water.
7. Before: $6 \times (3 \times 3) = 54$ cm². After: $27 \times 6 \times (1 \times 1) = 162$ cm². $162 \div 54 = 3$ times larger.
8. After a sugary snack, sugar stays on and between the teeth. Bacteria living in the film on the teeth feed on the sugar and give off acid. Over time the acid dissolves the minerals in the enamel and makes a hole, and if it reaches the dentin and pulp, it can hurt. To prevent it: brush with fluoride toothpaste and floss to remove food and germs, and eat fewer sugary snacks between meals (or rinse with water afterward).

5.3 The 9-Meter Path

OBJECTIVES

- Trace a bite of food in order through the mouth, esophagus, stomach, small intestine and large intestine, and tell what happens in each.
- Explain how peristalsis moves food, what the liver and pancreas add, and how villi help the small intestine take food into the blood.
- Read a bar graph of the lengths of the digestive tract, build a scale model, and test a folded model of the intestine lining against a flat one.

Warm-up. Push a tennis ball (or a ball of socks) into the top of a long tube sock. Now move it to the toe without pulling it, only by squeezing the sock just behind the ball, again and again. Try it with the sock held upside down. Does the ball still move? That squeeze-behind motion is how your body moves food. Write one sentence describing what your hands did.

Video. Coming soon. The journey of food through the digestive system, peristalsis and intestinal villi, for children; search SciShow Kids, Crash Course Kids, Homeschool Pop (Alternate), Science Max, medical-animation channels and Walter Cannon X-ray history clips (parent preview).

KEY TERMS

esophagus
The muscular tube, about 25 cm (10 inches) long, that carries swallowed food from the throat to the stomach.

peristalsis
Waves of muscle squeezing that push food along the digestive tract, the way you pushed the ball through the sock.

small intestine
The long, coiled tube after the stomach, about 6 to 7 meters (20 to 23 feet) long, where most digestion finishes and food passes into the blood.

villi
Millions of tiny, finger-like bumps lining the small intestine that give it a huge surface for taking in food.

large intestine
The wider tube, about 1.5 meters (5 feet) long, that takes water back into the body and forms the leftover waste.

CORE IDEAS

The story. In 1895 a German scientist, Wilhelm Röntgen, discovered X-rays, and within a year doctors everywhere were trying them out. At Harvard Medical School, a first-year student named **Walter Cannon** was asked by his teacher, Henry Bowditch, to try something new: use X-rays to watch food move inside a living animal. Beginning late in 1896, Cannon mixed animals' food with a white powder made from the metal bismuth, which blocks X-rays. Then, in a darkened room, he watched on a glowing X-ray screen as the dark shadow of the food slid down the throat and into the stomach of a cat, and saw the stomach squeeze it along in slow, steady waves. No one had ever watched digestion so plainly in a body that was not hurt.

How they figured it out. Cannon watched for hours and drew what he saw. He noticed something surprising: when a cat was frightened or upset, the waves in its stomach stopped. When it was calm and purring, they started again. Beaumont had seen something like this in St. Martin, but now it could be watched on a screen. The bismuth "meal" Cannon used is the ancestor of the barium drink that doctors still use today to take X-ray pictures of the stomach and intestines.

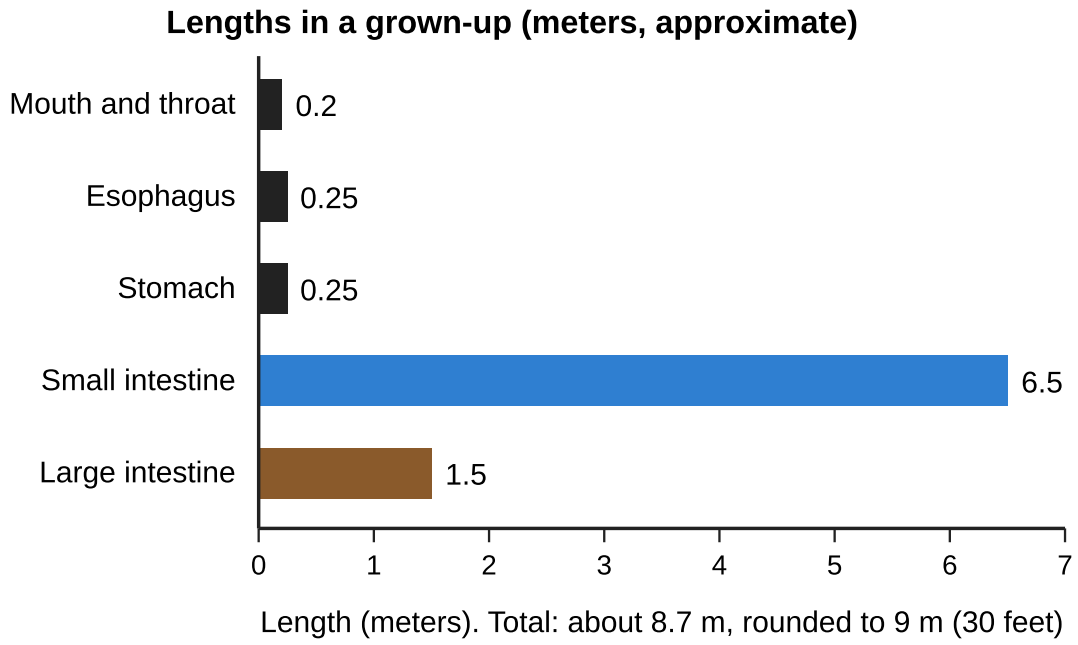
The big idea. Food travels a single long tube, the **digestive tract**, from the mouth to the place where waste leaves the body. In a grown-up it is about **9 meters (30 feet)** long when measured stretched out. In the living body, muscles keep it shorter and neatly folded. After you swallow, the **esophagus** squeezes food down to the stomach in waves called **peristalsis**; that is why you can swallow even upside down. The stomach churns food with gastric juice for about two to four hours, turning it into a thick soup. Then it lets the soup out, a little at a time, into the **small intestine**, which is about 6 to 7 meters (20 to 23 feet) long.

The helpers and the finish. Two organs that food never passes through pour juices into the small intestine. The **liver** makes bile, which is stored in the gallbladder and breaks fat into tiny droplets, the way dish soap breaks up grease. The **pancreas** makes a juice full of enzymes that finish breaking down starch, protein and fat. The lining of the small intestine is covered with millions of tiny fingers called **villi**. Each villus has blood vessels inside, and the digested food passes through its thin wall into the blood. Folds and villi give the small intestine a surface of about 30 square meters (about 320 square feet), like the floor of a large living room, packed inside your belly. What is left moves into the **large intestine**, about 1.5 meters (5 feet) long, which takes water back into the body and is home to helpful bacteria. The leftovers leave the body as waste. The whole trip usually takes one to three days.

Try it and see. In this lesson you will build a model of the lining of the small intestine. One piece of cloth will be flat. A longer piece will be folded into the same space, like the folds and villi. Which one soaks up more water? You will measure and find out.

God's handiwork. Every part of this path works without your thinking about it. You choose to chew and swallow, and then muscles, juices and villi take over, day and night, while you

play, read and sleep. Cannon later wrote about how the body keeps itself steady and balanced. He was amazed at how many parts work together to keep the whole body fed.



Approximate lengths of the digestive tract in a grown-up, measured stretched out. The total, about 8.7 meters, is usually rounded to 9 meters (30 feet).

PICTURE STUDY



The Beaneater, Annibale Carracci, About 1580–1590 · Oil on canvas · Galleria Colonna, Rome, Italy

Annibale Carracci was an Italian painter from Bologna. In his day most great paintings showed kings, saints or heroes, but here he painted a plain working man eating his lunch.

The man looks up as if someone just walked in, with his spoon in the air and his mouth open.

Every meal you see in a painting is the start of the 9-meter path. Those beans, that bread and those onions are about to be chewed, swallowed, churned and carried, bit by bit, into the man's blood.

Look closely

- Find each food on the table. How many can you name?
- Look at the spoon and the man's mouth. What is about to happen?
- Look at his hands. Does he look like he works hard? What clues tell you?
- The painter used quick, loose brushstrokes. Look closely at the bread and beans. Do they look smooth or rough?

Talk about it

1. Starting with the spoonful of beans, name each stop on the path in order.
2. Which parts of this meal do you think would stay in the stomach longest? Why?
3. Why might an artist want to paint an ordinary meal instead of a feast?

> **Safety first.** Wipe up spilled water right away so no one slips. Use scissors carefully. When you lay out the yarn path, keep it out of walkways where someone could trip.

EXPERIMENT: FLAT OR FOLDED? A VILLI MODEL TEST

The small intestine is not a smooth pipe. Its lining is folded, and the folds are covered with villi. Do folds and fingers really help it take in more? You will model the lining with paper towel or cloth and measure how much water each model soaks up.

Question: Will a folded lining soak up more water than a flat lining that fills the same space? Write your prediction.

You will need

- Paper towels (or two thin dishcloths of the same kind)
- Scissors and a ruler
- A shallow tray or baking dish
- A measuring cup marked in milliliters
- Water
- A timer
- A tape measure and 9 meters (30 feet) of yarn or string
- Masking tape and a marker
- Lab notebook and pencil

Steps

1. Cut a **flat lining**: a strip of paper towel 10 cm by 10 cm (about 4 by 4 inches).

2. Cut a **folded lining**: a strip 10 cm wide and 40 cm long. Fold it back and forth like a fan until it fits in the same 10 cm by 10 cm square.
3. Pour exactly 100 mL of water into the tray. Lay the flat lining in the water for 30 seconds, lift it out and let it drip over the tray for 5 seconds.
4. Pour the water left in the tray into the measuring cup. Subtract from 100 mL to find how much the lining soaked up. Record it.
5. Dry the tray, pour in a fresh 100 mL, and repeat with the folded lining, keeping it folded. Record.
6. Do each test twice and average your results. Make a bar graph comparing the two.
7. **Build the 9-meter path.** Lay out 9 meters of yarn down a hallway or across the yard. Using the bar graph in this lesson, mark each part with a tape flag: mouth and throat (0.2 m), esophagus (0.25 m), stomach (0.25 m), small intestine (6.5 m), large intestine (1.5 m). Walk the path from start to finish.
8. Write a conclusion: How did folding change how much water was soaked up? How do the folds and villi help the small intestine?

Tips

- What we change: whether the lining is flat or folded. What we keep the same: the kind of towel, the 10 cm by 10 cm space, the amount of water, the soaking time and the dripping time. What we measure: milliliters of water soaked up.
- The flat lining is your control.
- Real villi are much tinier than your folds, about 1 millimeter long, but there are millions of them.

Check your work

- I kept the space the same and changed only the folding.
- I measured the water in milliliters and did two trials of each.
- I made a bar graph with a title and labeled axes.
- I can explain why villi help the body take in food.

NATURE NOTEBOOK

1. Trace your body outline on a large sheet of paper (or draw a person). Draw the path of food in order and label the mouth, esophagus, stomach, liver, pancreas, small intestine and large intestine.
2. Draw a close-up of three villi, like tiny fingers, with blood vessels inside each one. Add arrows showing digested food passing into the blood.
3. Make a comic strip with six boxes called “The Journey of a Bean,” one box for each stop from the spoon to the large intestine. Write one sentence under each picture.

> **From history.** Walter Cannon went on to become a famous professor at Harvard. He studied how fear and anger change the body, such as a faster heartbeat and a stomach that stops churning, and he described what he called the “fight or flight” response. He

> also gave a name, homeostasis, to the way the body keeps things like its temperature and the sugar in its blood steady, and wrote a book about it in 1932 called *The Wisdom of the Body*.

WORKED EXAMPLES

Example 1. Use the bar graph of the digestive tract. (a) What is the total length? (b) About what fraction of the whole path is the small intestine? (c) About how many feet is the total? (1 meter is about 3.3 feet.)

1. Read each bar: mouth and throat 0.2 m, esophagus 0.25 m, stomach 0.25 m, small intestine 6.5 m, large intestine 1.5 m.
2. Add: 0.2 + 0.25 + 0.25 = 0.7 m. Then 0.7 + 6.5 = 7.2 m, and 7.2 + 1.5 = 8.7 m.
3. Fraction for the small intestine: 6.5 ÷ 8.7 ≈ 0.75, which is about three-fourths.
4. Feet: 8.7 × 3.3 ≈ 28.7 feet.

Answer: (a) About 8.7 m, which is rounded to about 9 m. (b) The small intestine is about three-fourths of the whole path. (c) About 29 feet, which is rounded to about 30 feet.

Example 2. You eat breakfast at 7:00 a.m. Suppose the food stays in your stomach 3 hours, moves through your small intestine in 5 more hours, and then spends 24 hours in the large intestine. At what time does it leave the stomach? The small intestine? How long is the whole trip?

1. Stomach: 7:00 a.m. + 3 hours = 10:00 a.m.
2. Small intestine: 10:00 a.m. + 5 hours = 3:00 p.m.
3. Large intestine: 3:00 p.m. + 24 hours = 3:00 p.m. the next day.
4. Whole trip: 3 + 5 + 24 = 32 hours, which is 1 day and 8 hours.

Answer: It leaves the stomach at 10:00 a.m. and the small intestine at 3:00 p.m. The leftovers leave the body about 3:00 p.m. the next day, after 32 hours. Real times vary from person to person and meal to meal, but one to three days is usual.

PRACTICE

1. EASY Put these in the order food passes through them: small intestine, esophagus, mouth, large intestine, stomach.
2. EASY What is peristalsis? How did the warm-up with the sock show it?
3. EASY Food never passes through the liver or the pancreas. What does each one add to digestion?
4. MEDIUM Use the bar graph in this lesson. (a) Which part of the digestive tract is longest? (b) About how many times longer is the small intestine than the large intestine? (c) Which two parts have the same length on the graph?

5. MEDIUM You build a model of the digestive tract at 1/10 of real size. The real tract is about 8.7 m long, the small intestine 6.5 m and the large intestine 1.5 m. How long should each be in your model, in centimeters?
6. MEDIUM In the villi test, a student got these results. Flat lining: 9 mL and 11 mL. Folded lining: 31 mL and 29 mL. Find the average for each and say how many times more the folded lining soaked up.
7. HARD Design a test to find out whether a lining with many tiny “fingers” (cut fringe) soaks up more than a smooth one. Name the variable you change, three things you keep the same, what you measure and your control.
8. CHALLENGE In four or five sentences, tell the journey of a bite of bread from your mouth to your blood. Name at least four organs and say what happens at each.

COMMON MISTAKES

- Thinking the small intestine is called “small” because it is short. It is the longest part. It is called small because it is narrower than the large intestine.
- Thinking food falls down to the stomach by gravity. Muscles push it by peristalsis, which is why astronauts can eat in space and you can swallow lying down.
- Thinking food passes through the liver and pancreas. Food stays in the tube; the liver and pancreas send their juices into the small intestine through small ducts.

Make it a game · Walk the Path. Use your 9-meter yarn path with tape flags. A parent calls out a happening, such as “bile breaks up fat,” “water is taken back,” “teeth chop,” “peristalsis down a 25-centimeter tube,” “acid churning” or “villi soak up food.” Race to stand on the right part of the path and name it. Score a point for each, and a bonus point if you can say how long that part is.

Scripture. “These wait all upon thee; that thou mayest give them their meat in due season. That thou givest them they gather: thou openest thine hand, they are filled with good.” (Psalm 104:27–28, KJV)

In the King James Bible, “meat” means food of any kind. Every creature, from the cat on Cannon’s X-ray screen to you, is fed from God’s open hand, and every body He made has a wonderful way to turn that food into life.

Practice answers

1. Mouth, esophagus, stomach, small intestine, large intestine.
2. Peristalsis is waves of muscle squeezing that push food along the digestive tract. Squeezing the sock just behind the ball, over and over, pushed the ball forward, even upside down, just as the muscles of the esophagus and intestines push food.
3. The liver makes bile (stored in the gallbladder), which breaks fat into tiny droplets. The pancreas makes a juice full of enzymes that break down starch, protein and fat in the small intestine.
4. (a) The small intestine (6.5 m). (b) 6.5 ÷ 1.5 ≈ 4.3, so a little more than 4 times longer. (c) The esophagus and the stomach (0.25 m each).

5. Whole tract: 8.7 m ÷ 10 = 0.87 m = 87 cm. Small intestine: 6.5 m ÷ 10 = 65 cm. Large intestine: 1.5 m ÷ 10 = 15 cm.
6. Flat: (9 + 11) ÷ 2 = 10 mL. Folded: (31 + 29) ÷ 2 = 30 mL. 30 ÷ 10 = 3, so the folded lining soaked up 3 times as much.
7. Change: whether the paper-towel lining is smooth or cut into fringe. Keep the same: the kind and size of towel, the amount of water, the soaking time and the dripping time. Measure: the milliliters of water soaked up. Control: the smooth lining.
8. In the mouth, teeth chop the bread and saliva begins turning its starch into sugar. The tongue pushes the soft lump back to be swallowed, and the esophagus squeezes it down to the stomach by peristalsis. The stomach churns it with gastric juice into a thick soup and lets it into the small intestine a little at a time. There, bile from the liver and enzymes from the pancreas finish breaking it down, and the digested food passes through the thin walls of the villi into the blood. Whatever is left moves on to the large intestine, where water is taken back.

5.4 Nutrition (with Cooking & Food)

OBJECTIVES

- Tell how James Lind ran one of the first fair tests in medicine in 1747 and what it showed about scurvy and fresh fruit.
- Name the six kinds of nutrients, give a food rich in each and tell what each does for the body, and figure the Calories in a food from its grams of fat, carbohydrate and protein.
- Test foods for fat with a brown-paper test that uses a control, and explain how cooking changes food.

Warm-up. Look at a box or can in your kitchen that has a Nutrition Facts label. Find three numbers: grams of total fat, grams of total carbohydrate and grams of protein. Write them down. Then look at the list of ingredients. What is the first ingredient? (The first one is the one there is most of.)

Video. Coming soon. James Lind scurvy experiment and the six nutrients for children; search history-of-medicine and naval history channels, SciShow Kids, Crash Course Kids, Homeschool Pop (Alternate), USDA MyPlate kids videos and cooking-science channels such as Science Max (parent preview).

KEY TERMS

nutrient
A substance in food that the body needs to grow, move, heal and stay healthy. The six kinds are carbohydrates, proteins, fats, vitamins, minerals and water.

carbohydrate
Starches and sugars, found in bread, rice, potatoes and fruit; the body’s main source of quick energy.

protein
The body’s building material for muscles, skin, blood and more, found in meat, fish, eggs, milk, beans and nuts.

vitamin
A substance the body needs in tiny amounts to work properly; vitamin C, from fresh fruits and vegetables, prevents scurvy.

Calorie
A unit for the energy stored in food. One gram of carbohydrate or protein gives about 4 Calories; one gram of fat gives about 9.

CORE IDEAS

The story. For hundreds of years, sailors on long voyages feared a sickness called **scurvy**. Their gums swelled and bled, their teeth grew loose, old wounds opened, and they grew so

weak they could not stand. On many long voyages more men died of scurvy than of storms or battles. In the spring of 1747, a Scottish naval surgeon named **James Lind** was serving aboard the British warship HMS *Salisbury*. On May 20, 1747, he chose twelve sailors with scurvy whose cases were as much alike as he could find. He kept them in the same part of the ship and gave them all the same basic meals.

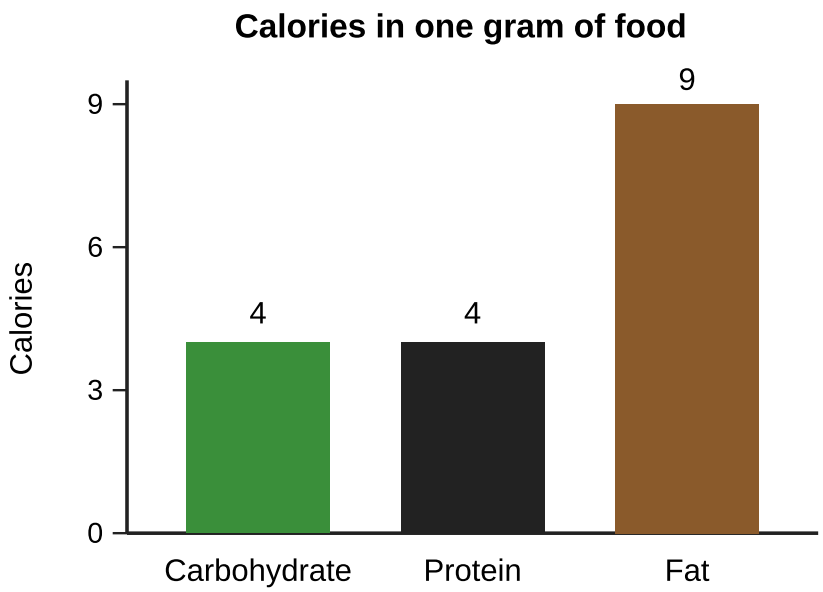
How they figured it out. Then Lind split the twelve men into six pairs and gave each pair a different remedy that people had suggested. One pair drank cider. One took drops of a weak acid. One took vinegar, one drank seawater, and one swallowed a spicy paste. The last pair ate **two oranges and one lemon** every day. Within about six days, one of the fruit-eaters was fit for duty, and the other was well enough to help nurse the rest. No other pair improved nearly so much. Lind had run a **fair test**: he changed one thing, the remedy, and kept everything else as much the same as he could. He published his results in 1753, and in 1795 the Royal Navy began giving lemon juice to its sailors.

The big idea. Lind did not know why fruit worked. Today we know that oranges and lemons are rich in **vitamin C**, which the body cannot make for itself and needs to build strong gums, skin and blood vessels. Vitamin C is one of many **nutrients**, the substances in food that the body needs. There are six kinds. **Carbohydrates** (starches and sugars) give quick energy. **Proteins** build muscles, skin and blood. **Fats** store energy and help the body use some vitamins. **Vitamins** and **minerals**, such as calcium for bones and teeth and iron for blood, are needed in small amounts. And **water** makes up more than half of your body. Plants also give us fiber, which the body cannot digest but which helps the large intestine do its work. Everything you learned in this unit, from teeth to villi, exists to deliver these nutrients to your cells.

Energy in food. The energy in food is measured in **Calories**. A gram of carbohydrate or a gram of protein gives about 4 Calories, but a gram of fat gives about 9, more than twice as much. That is why butter and nuts are packed with energy, and why a hard-working farmer or a growing child needs plenty of good food. A healthy plate has variety: grains, vegetables, fruits, protein foods and milk or cheese.

Try it and see (with Cooking & Food). Cooking is kitchen science. Heat changes the proteins in an egg white, so the clear, runny liquid turns white and firm. Heat softens the starch in rice and potatoes so they are easier to chew and digest. Cooking also kills many germs. But long boiling destroys some vitamin C, which is why fresh fruit and lightly cooked vegetables matter. In this lesson you will test foods for fat with brown paper, and then cook a simple meal with a parent and name the nutrients on your plate.

God’s handiwork. On the sixth day God said, “Behold, I have given you every herb bearing seed, which is upon the face of all the earth, and every tree, in the which is the fruit of a tree yielding seed; to you it shall be for meat” (Genesis 1:29). The lemon that saved Lind’s sailors and the grain in your bread were given as gifts. Paul wrote, “Whether therefore ye eat, or drink, or whatsoever ye do, do all to the glory of God” (1 Corinthians 10:31). Eating well, with thanks, is one way to do it.



Calories in one gram of each energy nutrient. Fat has more than twice as much energy per gram as carbohydrate or protein.

PICTURE STUDY



The Milkmaid, Johannes Vermeer, About 1657–1658 · Oil on canvas · Rijksmuseum, Amsterdam, the Netherlands

Johannes Vermeer lived in the Dutch city of Delft and painted quiet rooms filled with soft light from a window. Here a kitchen maid pours milk with great care. On the table lie loaves and broken pieces of bread. Many people who study the painting think she is making a bread pudding, a thrifty way to use stale bread.

Look at this kitchen with the eyes of this lesson. Milk, bread and the cook's steady work are all here: protein, fat and minerals in the milk, carbohydrates in the bread, and the patient skill of cooking that turns plain food into a good meal.

Look closely

- Follow the thin stream of milk from the jug to the bowl. How did Vermeer make it look like it is moving?
- Find the bread. How many different pieces or loaves can you see? How did he make the crust look rough and crunchy?
- Where does the light come from? What does it shine on most brightly?
- Look at the maid's face and arms. What do they tell you about how she works?

Talk about it

1. Which nutrients can you find on this table? Name the food and the nutrient.
2. What could this cook add to make the meal more balanced?
3. Why do you think Vermeer chose to paint an ordinary kitchen task so carefully?

> **Safety first.** A parent must work the stove and handle hot pans and sharp knives. Wash hands before cooking and after touching raw eggs. Do not eat the food samples used on the paper squares. Check for food allergies (such as peanuts or milk) before testing or cooking.

EXPERIMENT: THE BROWN-PAPER FAT TEST AND A BALANCED PLATE

Fat leaves a see-through spot on brown paper that does not dry away. Water leaves a spot too, but it dries and disappears. You will use this to test which foods contain fat, using water as a control. Then, with a parent, you will cook and plate a balanced meal, which pairs with the Cooking & Food course.

Question: Which of these foods contain fat? Write a prediction (fat or no fat) for each food before you test.

You will need

- A brown paper grocery bag, cut into 10 squares about 8 cm (3 inches) on a side
- A pencil for labeling each square
- Small samples: butter, a slice of apple, a cracker, peanut butter, cheese, a potato chip, a slice of banana, cooked egg white
- Water and a little cooking oil
- Cotton swabs or a spoon
- A sunny window or lamp
- Lab notebook and pencil
- For the meal: ingredients your parent chooses, such as eggs, bread, fruit, a vegetable and milk

Steps

1. Label the squares with the name of each food, plus “water” and “oil.” Make a data table with columns: Sample, Prediction, Spot after 30 minutes (yes or no), Contains fat?
2. Rub each food firmly on its own square for about 10 seconds. Rub a drop of water on the “water” square and a drop of oil on the “oil” square.
3. Scrape off any crumbs and let all the squares dry for 30 minutes.
4. Hold each square up to the window or lamp. A clear, greasy spot that lets light through means the food contains fat. Record your results.
5. Compare each food with the two controls. The water square shows what “no fat” looks like after drying; the oil square shows what fat looks like.
6. **Cook with a parent.** Make a simple meal, such as scrambled eggs, toast, fruit and milk. Before cooking, look closely at a raw egg; after cooking, look again. Write what changed.
7. Draw your plate in your notebook. Label each food with its main nutrient (carbohydrate, protein, fat, vitamins or minerals).
8. Write a conclusion: Which foods had fat? Were any results a surprise? How did cooking change the egg?

Tips

- What we change: the food sample. What we keep the same: the paper, the rubbing time and the drying time. What we measure: whether a see-through spot remains. Controls: water (no fat) and oil (fat).
- Foods with only a little fat, like a cracker, may leave a faint spot. Record faint spots as “a little fat.”
- Say a blessing before you eat what you cook, and thank the cook!

Check your work

- I made a prediction for every food.
- I used water and oil as controls and kept the test the same for every sample.
- My data table is complete.
- I can name the main nutrient in each food on my plate and explain how cooking changed the egg.

NATURE NOTEBOOK

1. Draw an orange and a lemon from life, as carefully as Lind’s sailors might have looked at them. Label the peel, pulp and seeds, and write one sentence about vitamin C.
2. Draw a dinner plate divided into sections and fill it with a meal you like. Label each food with its main nutrient.
3. Copy one Nutrition Facts label into your notebook. Circle the grams of fat, carbohydrate and protein, and figure the Calories from each.

From history. Lind never knew about vitamins. The word was invented in 1912 by the Polish-born scientist Casimir Funk, who thought these substances were “vital amines.” Vitamin C itself was first separated in the late 1920s and early 1930s by the Hungarian scientist Albert Szent-Györgyi, using, among other things, Hungarian paprika peppers, which turned out to be loaded with it. He received the Nobel Prize in 1937.

WORKED EXAMPLES

Example 1. One serving of a granola bar has 8 grams of fat, 20 grams of carbohydrate and 5 grams of protein. About how many Calories does it have? Which nutrient gives the most Calories?

1. Fat: 8 g × 9 Calories per gram = 72 Calories.
2. Carbohydrate: 20 g × 4 Calories per gram = 80 Calories.
3. Protein: 5 g × 4 Calories per gram = 20 Calories.
4. Total: 72 + 80 + 20 = 172 Calories.

Answer: About 172 Calories. Carbohydrate gives the most (80 Calories), but fat comes close (72 Calories) even though there are far fewer grams of it, because each gram of fat holds more than twice the energy.

Example 2. In Lind’s 1747 test, 12 sailors were split into 6 pairs, and only the pair that ate oranges and lemons got well quickly. (a) What did Lind change? (b) Name two things he kept the same. (c) What fraction of the 12 sailors got the fruit?

1. (a) The thing Lind changed was the remedy each pair was given: cider, a weak acid, vinegar, seawater, spicy paste, or oranges and lemons.
2. (b) He kept the same: the kind of sickness (all had scurvy, as much alike as he could find), the place on the ship, and the basic meals.
3. (c) 2 sailors out of 12 got the fruit: 2/12 = 1/6.

Answer: (a) The remedy. (b) For example, the same sickness, the same place on the ship and the same basic diet. (c) 1/6 of the sailors. Because everything else was alike, Lind could say the fruit, not something else, made the difference.

PRACTICE

1. EASY Name the six kinds of nutrients.
2. EASY Match each food to the nutrient it is richest in: bread, eggs, butter, oranges. Nutrients: protein, carbohydrate, vitamin C, fat.
3. MEDIUM Here are a student’s brown-paper results after 30 minutes. Water: no spot. Oil: clear spot. Apple: no spot. Peanut butter: clear spot. Cracker: faint spot. Cheese: clear spot. (a) Which foods contain fat? (b) Why did the student test water and oil too?

4. MEDIUM How many Calories are in 10 grams of fat? In 10 grams of carbohydrate? How many times more is the fat?
5. MEDIUM Give three reasons people cook food. Why does an egg white turn from clear to white when it is cooked?
6. HARD In Daniel 1, Daniel asked to eat pulse (vegetables and seeds) and drink water for ten days, while other young men ate the king's meat. At the end, the steward compared their faces. Describe this as a test: What was changed? What was kept the same? What was measured? Which group was the comparison (control)?
7. HARD A serving of rice has 0 grams of fat, 45 grams of carbohydrate and 4 grams of protein. A serving of peanuts has 14 grams of fat, 6 grams of carbohydrate and 7 grams of protein. Which has more Calories, and by how much?
8. CHALLENGE In four or five sentences, explain why sailors on long voyages got scurvy, why Lind's oranges and lemons helped, and how scurvy connects to what you learned about teeth in Lesson 5.2.

COMMON MISTAKES

- Thinking fat is always bad. The body needs some fat for energy, to build cells and to use certain vitamins; the goal is balance, not none.
- Thinking Calories are something in food, like an ingredient. A Calorie is a unit for measuring the energy that food gives, just as a meter measures length.
- Thinking one "super food" can give everything you need. No single food has every nutrient, which is why a healthy diet has variety.

> **Make it a game · Nutrient Grocery Dash.** A parent calls out a nutrient: carbohydrate, protein, fat, vitamin C, calcium or water. You have 20 seconds to find a real food in the kitchen rich in that nutrient and bring it back (or point to it). Score a point for each correct food, and a bonus point if you can say what the nutrient does in the body. After six rounds, use the foods you gathered to plan a balanced meal.

> **Scripture.** "Prove thy servants, I beseech thee, ten days; and let them give us pulse to eat, and water to drink." (Daniel 1:12, KJV)

"Prove" means test. Long before Lind, Daniel proposed a simple test of diet with a set time and a comparison group, trusting God with the outcome. At the end of ten days, Daniel and his friends looked healthier than those who ate the king's food (Daniel 1:15).

Practice answers

1. Carbohydrates, proteins, fats, vitamins, minerals and water.
2. Bread: carbohydrate. Eggs: protein. Butter: fat. Oranges: vitamin C.
3. (a) Peanut butter, cheese and (a little) the cracker. The apple showed no fat. (b) They are controls: water shows what a spot with no fat looks like after drying, and oil shows what a fat spot looks like, so each food can be compared fairly.

4. Fat: 10 × 9 = 90 Calories. Carbohydrate: 10 × 4 = 40 Calories. 90 ÷ 40 = 2.25, so fat gives 2¼ times as much.
5. Cooking kills many germs, softens starches so they are easier to chew and digest, and makes food taste better (and can make it safe to eat). The heat changes the proteins in the egg white so they tangle together, turning it white and firm.
6. Changed: the diet (pulse and water, or the king's food and wine). Kept the same: the length of the test (ten days) and the kind of people (young men in the king's training). Measured: how healthy their faces looked at the end. Control: the young men who ate the king's meat.
7. Rice: 0 + (45 × 4) + (4 × 4) = 180 + 16 = 196 Calories. Peanuts: (14 × 9) + (6 × 4) + (7 × 4) = 126 + 24 + 28 = 178 Calories. The rice has 196 − 178 = 18 more Calories.
8. On long voyages, sailors ate food that kept for months, such as salted meat and hard biscuits, and had no fresh fruits or vegetables. Their bodies ran out of vitamin C, which the body cannot make and needs to build strong gums, skin and blood vessels. Oranges and lemons are rich in vitamin C, so the sailors who ate them recovered. One sign of scurvy is swollen, bleeding gums and loose teeth, because the gums that hold the teeth in the jawbone grow weak without vitamin C.

Unit 5 review

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

1. (5 pts) Who were William Beaumont and Alexis St. Martin? Where and when did their story begin, and why could Beaumont study a living stomach?
2. (5 pts) Beaumont put gastric juice and meat in a warm vial, and the meat broke down. (a) Was this mechanical or chemical digestion? (b) Why did he keep the vial warm?
3. (5 pts) A whole sugar cube dissolved in 240 seconds, and a crushed cube in the same water dissolved in 60 seconds. How many times faster was the crushed sugar? How does this relate to chewing?
4. (5 pts) Name the four kinds of teeth and the job of each. How many teeth does a child with all baby teeth have, and how many does an adult have?
5. (5 pts) Name the three layers of a tooth from the outside in, and explain how sugar leads to a cavity.
6. (5 pts) List in order the five main parts of the digestive tract that food passes through, from the mouth on. Then name the part where most digested food passes into the blood.
7. (5 pts) The small intestine is about 6.5 m long and the large intestine about 1.5 m. (a) What is their total length? (b) Why is the “small” intestine called small? (c) What is peristalsis?
8. (5 pts) You test a flat paper-towel lining and a folded one that fits in the same space to see which soaks up more water. Name the variable you change, two things you keep the same, what you measure and your control.
9. (5 pts) What did James Lind do in 1747, and what did he find? What nutrient explains his result?
10. (5 pts) (a) Name the six kinds of nutrients. (b) A snack has 5 g of fat, 15 g of carbohydrate and 3 g of protein. How many Calories does it have?

Unit project: my digestion field guide

Trace your own body outline on a large sheet of paper and draw the digestive tract inside it: mouth, teeth, esophagus, stomach, liver, pancreas, small intestine and large intestine, each labeled with its job and its length. Add a close-up of a tooth with its layers and a close-up of the villi. Beside the drawing, include your lab pages from the unit: the sugar cube data table, the eggshell results, the villi bar graph and the brown-paper fat table. Finish with a one-page report titled “The Journey of My Lunch” that follows one real meal you ate from your plate to your blood, names the main nutrient in each food, and tells how Beaumont, Cannon and Lind each helped people understand it.

- **Accuracy**: Organs are drawn in the right order and place, labeled correctly, and their jobs and lengths match the lessons.

- **Data and graphs**: Tables are complete with units; calculations (times, averages, surface areas, Calories) are correct; the bar graph has a title, labeled axes and correct bars.
- **Fair testing**: Each experiment names the question, prediction, the variable changed, what was kept the same, the control and a clear conclusion.
- **Explanation and care**: The report traces the meal correctly through mechanical and chemical digestion, tells the scientists' stories accurately, and the field guide is neat, dated and easy to read.

Answer key

1. Beaumont was the army surgeon at Fort Mackinac; St. Martin was a young French-Canadian voyageur. On Mackinac Island in 1822, St. Martin was accidentally shot in the left side. Beaumont saved his life, but the wound healed with an opening into the stomach, so Beaumont could look in, put food in on threads and take out gastric juice.
2. (a) Chemical digestion: the juice broke the meat down with no churning. (b) To keep it near body temperature, about 37 °C (98.6 °F), as it is inside the stomach, where the juice works best.
3. 240 ÷ 60 = 4 times faster. Crushing, like chewing, breaks something into small pieces with much more surface, so water (or digestive juice) can work on it faster.
4. Incisors cut, canines tear, premolars crush and molars grind. A child has 20 baby teeth; an adult has 32 permanent teeth (including 4 wisdom teeth).
5. Enamel, dentin, pulp. Bacteria on the teeth feed on sugar left in the mouth and give off acid; the acid dissolves the minerals of the enamel and makes a hole (a cavity).
6. Mouth, esophagus, stomach, small intestine, large intestine. Most digested food passes into the blood through the villi of the small intestine.
7. (a) 6.5 + 1.5 = 8 m. (b) Because it is narrower than the large intestine, not because it is shorter; it is the longest part. (c) Waves of muscle squeezing that push food along the digestive tract.
8. Change: flat or folded lining. Keep the same: the kind of towel, the space it fills, the amount of water, the soaking time. Measure: milliliters of water soaked up. Control: the flat lining.
9. Aboard HMS Salisbury, Lind gave six pairs of sailors with scurvy six different remedies while keeping their conditions alike. Only the pair that ate oranges and lemons recovered quickly. Citrus fruit is rich in vitamin C, which prevents scurvy.
10. (a) Carbohydrates, proteins, fats, vitamins, minerals and water. (b) (5 × 9) + (15 × 4) + (3 × 4) = 45 + 60 + 12 = 117 Calories.

UNIT 6

Brain and Nerves

Every move you make, every word you speak and every memory you keep depends on your **nervous system**: the brain, the spinal cord and the nerves that reach to the tips of your fingers and toes. It is built of tens of billions of nerve cells, called neurons, that pass tiny electrical messages to one another faster than you can blink. In this unit you will find out how messages travel through the body, how the two halves of the brain share the work, how we remember and why we must sleep.

You will meet the scientists who first measured these hidden things: Charles Sherrington and the reflex arc, Paul Broca and his patient who could say only “tan,” Hermann Ebbinghaus testing his own memory with nonsense syllables, and Eugene Aserinsky watching his sleeping son’s eyes dart back and forth. Like them, you will measure and record: your reaction time with a falling ruler, the hand, foot and eye dominance of your family, how many words you can remember with different strategies and how long you sleep each night. Along the way you will see again that we are “fearfully and wonderfully made” (Psalm 139:14).

BEFORE YOU BEGIN

- Knows that the body is made of cells, tissues and organs (Unit 1)
- Knows that muscles work in pairs to move bones (Unit 2)
- Can find the average of a set of numbers and change a fraction to a percent
- Can add and subtract hours and minutes

MASTERY CHECKLIST

- I can name the brain, spinal cord, nerves and neurons and trace the path of a reflex arc.
- I can measure my reaction time with a ruler drop and explain why a reflex is faster than a reaction.
- I can name the cerebrum, cerebellum, brain stem and corpus callosum and explain why the left hemisphere controls the right side of the body.
- I can describe the forgetting curve and use grouping and spaced practice to remember more.
- I can describe the stages of a sleep cycle, including REM, and explain why children need 9 to 12 hours of sleep.
- I can plan a fair test by naming what I change, what I measure and what I keep the same.

OPTIONAL BOOKS AND RESOURCES

- **Neuroscience for Kids (Eric Chudler, University of Washington)** (https://faculty.washington.edu/chudler/neurok.html): Free. A large, long-running site

by a university neuroscientist with brain facts, reaction-time and memory experiments, and simple activities. A parent should preview pages, since some link to outside sites.

- **Hermann Ebbinghaus, *Memory: A Contribution to Experimental Psychology* (1885; English translation 1913)** (https://psychclassics.yorku.ca/Ebbinghaus/index.htm): Free, from the Classics in the History of Psychology collection. For the parent: read a few paragraphs aloud from the chapters where Ebbinghaus describes his nonsense syllables and his rules for testing himself (Lesson 6.3).

6.1 Reflexes ★

OBJECTIVES

- Name the main parts of the nervous system (brain, spinal cord, nerves, neurons) and tell what each one does.
- Trace the path of a reflex arc from a sense receptor through the spinal cord to a muscle, and explain why a reflex is faster than a thought-out action.
- Measure reaction time with a ruler drop, find an average of several trials, and use a table to change catch distance into time.

Warm-up. Sit on the edge of a table or a high bed so your lower legs hang loose. Have a helper tap gently just below your kneecap with the side of a flat hand. Did your leg kick? Now try to stop it from kicking. Next, look into a mirror in a dim room, then switch on a light. Watch the black dot in the middle of your eye. What did your body do without asking you first?

Video. Coming soon. Reflexes and the nervous system for kids: the reflex arc, knee-jerk test and ruler-drop reaction time (search SciShow Kids, Homeschool Pop (Alternate), Science Max, Crash Course Kids and university neuroscience outreach channels).

KEY TERMS

neuron
A nerve cell. Neurons carry messages as tiny electrical signals. Your brain alone has tens of billions of them.

nerve
A cable-like bundle of long neuron fibers that carries messages between the brain or spinal cord and the rest of the body.

spinal cord
The thick bundle of nerve tissue that runs down the middle of the backbone and joins the brain to the nerves of the body.

reflex
A quick, automatic action the body makes without waiting for you to decide, such as blinking or pulling your hand off something hot.

reflex arc
The short path a reflex message takes: from a sense receptor, along a sensory nerve to the spinal cord, and back out along a motor nerve to a muscle.

reaction time
The time between noticing something (seeing, hearing, feeling) and moving in answer to it.

CORE IDEAS

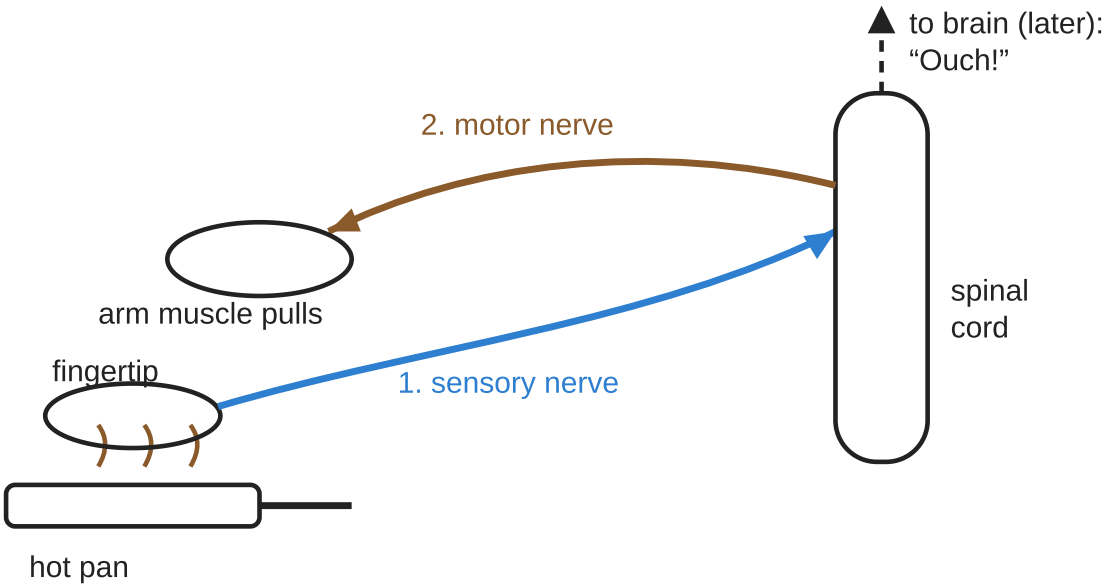
The story. In 1875 two German doctors, Wilhelm Erb and Carl Westphal, each wrote about the same small surprise. When they tapped the tendon just below a patient's kneecap, the leg kicked forward all by itself. Soon doctors everywhere were carrying little rubber hammers. A strong, normal kick told them the nerves in that leg and the lower back were working; a missing or wild kick warned them something was wrong. Twenty years later an English scientist, Charles Sherrington, set out to learn *how* such reflexes work. He spent most of his life on the question, gave the world the word **synapse** for the tiny gap where one nerve cell passes its message to the next, and wrote a famous book in 1906, *The Integrative Action of the Nervous System*. In 1932 he shared the Nobel Prize for his work on nerves.

How they figured it out. Sherrington noticed that a reflex is not random. The same tap always gives the same kick, and it comes very fast, faster than anyone could decide to move. He also saw that when one muscle tightens in a reflex, its partner on the other side of the joint relaxes, so the two never fight. (You met muscle pairs in Unit 2.) By carefully testing which nerves had to be whole for a reflex to happen, he and others showed that many reflexes travel only out to the **spinal cord** and straight back, without waiting for the brain.

The big idea. Your nervous system has three main parts: the **brain**, the **spinal cord** and the **nerves** that branch out to every part of you. All of them are built of **neurons**, cells with long thin arms that carry electrical signals. Most of the time a message goes all the way up to the brain, where you think about it and choose what to do. A **reflex** takes a shortcut called a **reflex arc**. Touch a hot pan, and heat sensors in your skin fire. The signal races along a sensory nerve to the spinal cord. There it is handed across to a motor nerve that runs straight back to your arm muscles, and your hand jerks away. A copy of the message also travels up to the brain, but it arrives a moment later. That is why you often pull away *first* and feel "Ouch!" *second*.

Try it and see. A reflex and a **reaction** are not the same. Catching a falling ruler is a reaction: your eyes must see it drop, your brain must decide, and only then can your fingers squeeze. The fastest nerve fibers in your body carry signals at about 100 meters per second (about 220 miles per hour), but the deciding takes time. Most people your age need about 0.15 to 0.25 seconds to catch a dropped ruler. Because a falling ruler speeds up at a known rate, the distance it falls before you grab it tells you your reaction time. You can measure it with nothing but a ruler and a friend.

God's handiwork. Reflexes are like guards who never sleep. You blink before dust reaches your eye. Your pupils shrink in bright light to protect the back of the eye. You cough when a crumb goes down the wrong way, and you throw out your hands when you trip. A newborn baby already grips a finger tightly and turns toward a touch on the cheek to find milk. None of this had to be learned. The psalmist wrote, "I will praise thee; for I am fearfully and wonderfully made" (Psalm 139:14), and the quiet, fast work of your reflexes is one small piece of that wonder.



The reflex arc: the message turns around in the spinal cord, so the hand moves before the brain feels pain.

PICTURE STUDY



Snap the Whip, Winslow Homer, 1872 · Oil on canvas · Butler Institute of American Art, Youngstown, Ohio (a smaller version is at the Metropolitan Museum of Art, New York)

Winslow Homer was an American painter who loved to show ordinary country life. Here a line of schoolboys plays “snap the whip” at recess. The boy at one end stops short and swings the line around, and the boys at the far end whip around so fast that some of them lose their footing.

Every boy in this painting is using his nervous system at full speed: eyes watching, muscles tightening and loosening, reflexes catching a fall before the boy has time to think.

Look closely

- Find the boys who have fallen. Where are their hands? What reflex do you think made them reach out like that?
- Find the boy whose feet are planted to hold the line. How is his body leaning to keep his balance?
- Look at the schoolhouse and the hills behind. What time of year do you think it is?
- Follow the line of joined hands from one end to the other. Where would you have to be to feel the strongest pull?

Talk about it

1. Which actions in this painting are reflexes, and which are choices the boys are making on purpose?
2. Why do you think Homer painted the boys barefoot and in the open air instead of inside at their desks?
3. Have you ever caught yourself in a fall before you knew you were falling? What happened?

> **Safety first.** Tap knees only with the side of a flat hand, gently, never with a hammer or hard object. Never test a reflex by poking near the eyes, startling someone on stairs or using real heat. In the ruler drop, let the ruler fall straight down; do not throw it.

EXPERIMENT: THE RULER-DROP REACTION LAB

Question: **Is my reaction time faster with my writing hand or my other hand?** You will drop a ruler, measure how far it falls before you catch it, and turn that distance into a time using the table below. Real scientists repeat each test several times and take the average, so you will too.

Ruler-drop table (distance fallen before the catch → reaction time): 5 cm (2 in) → 0.10 s; 10 cm (4 in) → 0.14 s; 15 cm (6 in) → 0.17 s; 20 cm (8 in) → 0.20 s; 25 cm (10 in) → 0.23 s; 30 cm (12 in) → 0.25 s.

You will need

- A 30-centimeter (12-inch) ruler, wooden or stiff plastic
- A helper
- A table and a chair
- Lab notebook and pencil

Steps

1. Write your prediction: Which hand will catch the ruler sooner (shorter distance)? Why do you think so?
2. Sit with your forearm resting on the table and your hand just past the edge. Hold your thumb and first finger open about 2.5 cm (1 inch) apart.
3. Your helper holds the ruler at the top so the 0 mark is exactly level with the top of your thumb.
4. Without warning, your helper lets go. Catch the ruler as fast as you can. Read the number just above your thumb. That is the distance in centimeters.
5. Do 5 trials with your writing hand. Your helper should wait a different number of seconds each time so you cannot guess.
6. Now do 5 trials with your other hand. Keep everything else the same: same ruler, same helper, same chair, same starting gap.
7. Make a table: Trial 1 to 5, Writing hand (cm), Other hand (cm). Find the average for each hand.
8. Use the ruler-drop table to change each average into a reaction time in seconds.
9. Write your conclusion: Was your prediction right? How big was the difference?

Tips

- What we change: the hand. What we keep the same: the ruler, the helper, the starting gap, the arm position. What we measure: the catch distance.
- Smaller distance means faster reaction. Do not let your fingers creep closer before the drop.
- If you miss the ruler completely, record “missed” and do one more trial.

Check your work

- I recorded 5 trials for each hand in a neat table.
- I found each average and changed it into seconds with the table.
- I can explain why catching a ruler is a reaction and not a reflex.

NATURE NOTEBOOK

1. Draw the reflex arc for touching a hot pan. Label: heat sensor in the skin, sensory nerve, spinal cord, motor nerve, arm muscle, brain. Use arrows to show which way the message travels.
2. Shine a flashlight near (not into) a family member’s eye in a dim room and sketch the pupil before and after. Write one sentence on why this reflex protects the eye.
3. Make a list titled “Reflexes That Guard Me” with at least five reflexes (blink, cough, sneeze, knee jerk, pupil, pulling away from pain, catching a fall). Beside each, write what it protects.

> **From history.** Charles Sherrington did not start out studying the nervous system. As a young doctor he helped study an outbreak of cholera in Spain in 1885. Later, at Liverpool and then at Oxford, he spent years mapping which nerves control which muscles. He was

also a teacher and wrote poetry. When he shared the 1932 Nobel Prize in Physiology or Medicine with Edgar Adrian, he was in his seventies and still working. Sherrington's student Wilder Penfield became a famous brain surgeon in Canada.

WORKED EXAMPLES

Example 1. Ben did the ruler drop five times with his writing hand. His catch distances were 18 cm, 15 cm, 16 cm, 14 cm and 17 cm. What was his average catch distance, and about what was his reaction time? Use the ruler-drop table: 15 cm → 0.17 s, 20 cm → 0.20 s.

1. Add the five distances: 18 + 15 + 16 + 14 + 17 = 80 cm.
2. Divide by the number of trials: 80 ÷ 5 = 16 cm. That is the average.
3. 16 cm is between 15 cm (0.17 s) and 20 cm (0.20 s), and much closer to 15 cm.
4. So his reaction time is a little more than 0.17 s, about 0.18 s.

Answer: Average distance 16 cm (about 6 1/4 in); reaction time about 0.18 seconds.

Example 2. The fastest nerve fibers carry a signal about 100 meters per second. A reflex message from your foot to your spinal cord travels about 1 meter. How long does that trip take? Compare it with a ruler-drop reaction time of 0.18 seconds.

1. Time = distance ÷ speed = 1 m ÷ 100 m per second = 0.01 second.
2. Compare: 0.18 ÷ 0.01 = 18.
3. So the reaction takes about 18 times as long as the nerve trip itself. Most of the reaction time is spent in the eye and the brain: seeing, deciding and sending the command.

Answer: About 0.01 second (one hundredth of a second), about 18 times faster than the ruler-drop reaction.

PRACTICE

1. EASY Name the three main parts of the nervous system.
2. EASY What is a reflex? Give two examples.
3. EASY Put the parts of the hot-pan reflex arc in order: motor nerve, spinal cord, heat sensor in skin, arm muscle, sensory nerve.
4. MEDIUM Data table. Four children did the ruler drop. Average catch distances: Anna 12 cm, Sam 20 cm, Ruth 15 cm, Eli 25 cm. Using the table (10 cm → 0.14 s, 15 cm → 0.17 s, 20 cm → 0.20 s, 25 cm → 0.23 s), who was fastest, who was slowest, and what were their reaction times?
5. MEDIUM Find the average of these catch distances: 22 cm, 19 cm, 21 cm, 18 cm. Is this person faster or slower than someone who averages 15 cm?

6. MEDIUM Why does a doctor tap your knee during a checkup?
7. HARD Experiment design. Grace wants to know if playing a fast video game for 10 minutes changes her ruler-drop reaction time. Name the variable she changes, the thing she measures, two things she must keep the same, and her control.
8. CHALLENGE Explain in two or three sentences why you often pull your hand off a hot stove before you feel the pain.

COMMON MISTAKES

- Thinking every action starts in the brain. Many reflexes turn around in the spinal cord, and the brain only hears about them afterward.
- Calling a ruler catch or a baseball catch a reflex. Those are reactions: you have to see, decide and move, which takes longer. Practice can make reactions faster, but a true reflex happens the same way without practice.
- Thinking a longer catch distance means a better score. In the ruler drop, a shorter distance means a faster reaction.

> **Make it a game · Reflex or Reaction?.** A parent calls out an action, such as “blinking at a puff of air,” “catching a ball,” “sneezing,” “hitting a baseball,” “jerking away from a bee sting” or “answering the phone.” Shout “Reflex!” if it happens automatically through the spinal cord or brain stem, or “Reaction!” if you have to see or hear, decide and then move. Score one point for each right answer and a bonus point if you can name what the reflex protects. Then finish with a ruler-drop challenge: best of three catches wins.

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

Job did not know about neurons or reflex arcs, but he knew God had built and guarded his body. Our reflexes are part of that fence: quick, faithful protectors we never have to remember to switch on.

Practice answers

1. The brain, the spinal cord and the nerves.
2. A quick, automatic action the body makes without waiting for you to decide. Examples: blinking when something comes at your eye, the knee jerk, pulling away from a hot pan, coughing, the pupil shrinking in bright light.
3. Heat sensor in skin → sensory nerve → spinal cord → motor nerve → arm muscle.
4. Anna was fastest (shortest distance, 12 cm, between 0.14 and 0.17 s, about 0.15 s). Eli was slowest (25 cm, 0.23 s).
5. 22 + 19 + 21 + 18 = 80; 80 ÷ 4 = 20 cm. Slower, because the ruler fell farther before the catch.
6. To test the nerves and spinal cord. A normal kick shows that the sensory nerve, the spinal cord and the motor nerve to the thigh muscle are all working. A missing or very strong kick can warn the doctor of a problem.

7. Variable changed: whether she played the game for 10 minutes first. Measured: the catch distance (reaction time). Kept the same (any two): same ruler, same helper, same hand, same starting gap, same time of day, same number of trials. Control: ruler-drop trials done without playing the game first (after 10 minutes of sitting quietly).
8. The pull-away is a reflex. The signal from the heat sensors goes only to the spinal cord, which sends a command straight back to the arm muscles. The message that lets you *feel* pain has to travel farther, up to the brain, so it arrives a moment after your hand has already moved.

6.2 Left and Right: The Two Halves of the Brain

OBJECTIVES

- Name the main parts of the brain (cerebrum with its two hemispheres, corpus callosum, cerebellum, brain stem) and tell one job of each.
- Explain that each half of the cerebrum mostly controls and feels the opposite side of the body, and tell how Paul Broca found that speech depends on the left side in most people.
- Survey hand, foot and eye dominance in a group, record the results in a table and find a percentage.

Warm-up. Answer quickly without thinking: Which hand do you write with? Which foot do you kick a ball with? Now make a small hole with your thumb and finger, stretch out your arms and look through the hole at a doorknob with both eyes open. Close your left eye, then your right. Whichever eye still sees the doorknob through the hole is your dominant eye. Are you “right” or “left” on all three?

Video. Coming soon. Parts of the brain for kids: cerebrum, cerebellum, brain stem, left and right hemispheres and the corpus callosum; Paul Broca and the speech area (search SciShow Kids, Homeschool Pop (Alternate), Crash Course Kids, Science Max and university neuroscience outreach channels).

KEY TERMS

cerebrum
The largest, wrinkled part of the brain. It handles thinking, speaking, remembering, the senses and the movements you choose to make.

hemisphere
One half of the cerebrum. There is a left hemisphere and a right hemisphere.

corpus callosum
A thick bridge of millions of nerve fibers that joins the two hemispheres so they can share messages.

cerebellum
The “little brain” at the back, below the cerebrum. It helps with balance and smooth, well-timed movement.

brain stem
The stalk at the base of the brain that joins it to the spinal cord. It runs breathing, heartbeat and other life-keeping jobs automatically.

dominant
The side you prefer and use with more skill, such as your dominant hand, foot or eye.

CORE IDEAS

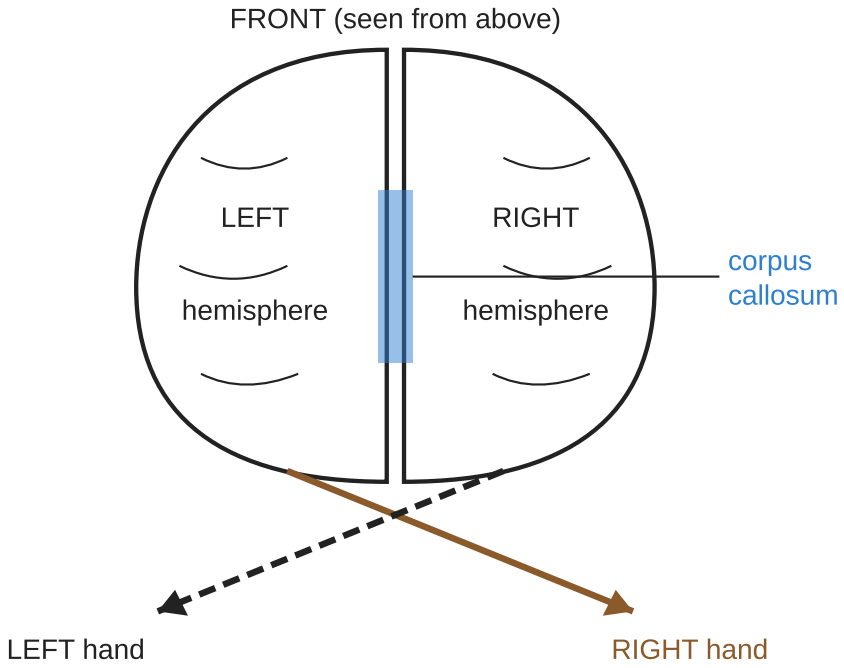
The story. In April 1861 a French surgeon named Paul Broca was asked to see a patient at the Bicêtre Hospital near Paris. The man, Louis Victor Leborgne, had lost the power of speech many years before. He understood what people said to him and could answer with gestures, but the only word he could say was “tan,” so the hospital called him “Tan.” A few days after Broca met him, Leborgne died. Broca examined his brain and found a damaged spot on the *left* side, toward the front. Over the next few years Broca studied more patients who had lost speech, and again and again the injury was on the left. Today that region is called **Broca’s area**.

How they figured it out. Broca could not look inside a living brain, so he did what a careful scientist does: he compared many cases and looked for a pattern. Doctors had also long noticed something strange about injuries to the head. A stroke on the right side of the brain often weakened the *left* arm and leg, and a stroke on the left side weakened the *right*. Later scientists traced the reason: most of the nerve fibers running between the brain and the body cross over to the other side in the lower brain stem. So the left hemisphere moves and feels your right hand, and the right hemisphere moves and feels your left hand.

The big idea. Your brain weighs about 1.4 kilograms (3 pounds) when you are grown, yet it uses about one-fifth of all the energy your body burns at rest. Its biggest part is the wrinkled **cerebrum**, split from front to back into two **hemispheres**. They are joined by the **corpus callosum**, a bridge of nerve fibers that lets the two halves share everything, so you work as one person, not two. Some jobs lean more to one side. In most people, speaking and understanding words depend mostly on the left hemisphere, while judging shapes, faces and where things are in space leans more on the right. Below the cerebrum sits the **cerebellum**, which keeps your balance and smooths your movements; it is small, but it holds more than half of all the brain’s neurons. The **brain stem** keeps you breathing and your heart beating even while you sleep.

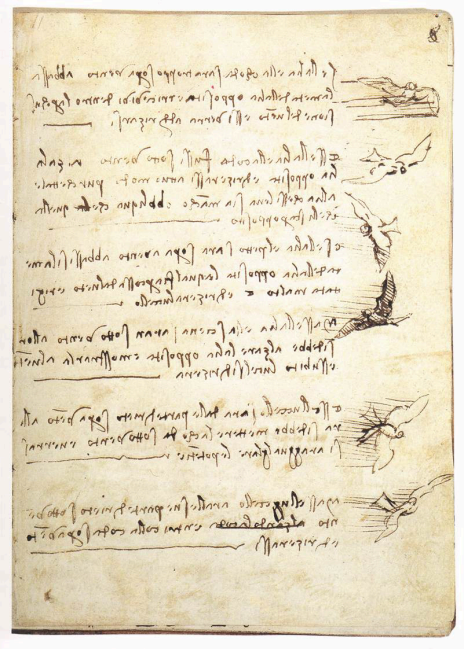
In the world today. About 9 out of 10 people are right-handed. Most right-handed people also kick with their right foot, but eyes do not always match: some right-handers have a dominant left eye. Left-handed people are found in every land, and some of the finest artists, musicians and athletes have been left-handed. You may have heard that people are either “left-brained” (logical) or “right-brained” (creative). That is a myth. Scientists who scan healthy brains see both hemispheres working together on almost everything you do, from reading a poem to solving a math problem.

God’s handiwork. Scripture often speaks of the right hand as the hand of strength and skill: “Thy right hand, O LORD, is become glorious in power” (Exodus 15:6). Yet the book of Judges tells of seven hundred chosen left-handed men of Benjamin who could sling stones “at an hair breadth, and not miss” (Judges 20:16). God gives different gifts to different people, and two halves of one brain, working as one, are a picture of that harmony.



Seen from above: each hemisphere mostly controls the opposite side of the body. The corpus callosum joins the two halves.

PICTURE STUDY



A Page from the Codex on the Flight of Birds, Leonardo da Vinci, about 1505 · Pen and ink (with some red chalk) on paper · Biblioteca Reale (Royal Library), Turin, Italy

Leonardo da Vinci was an Italian painter, engineer and student of nature. He was left-handed, and he filled his notebooks with “mirror writing,” running from right to left, so that it reads normally only when you hold the page up to a mirror. One idea is that writing this way kept his left hand from smearing the wet ink.

In this small notebook Leonardo studied how birds use their wings and tails to rise, turn and balance in the wind, hoping one day to build a flying machine. He also studied the human body, and he made careful drawings of the nerves and of the hollow spaces inside the brain.

Look closely

- Look at the handwriting. Which way does it run? Try reading a word by holding a mirror beside the page.
- Find the little bird sketches. What is each bird doing with its wings and tail?
- Notice how drawings and writing are mixed together on the page. Why might a scientist do that in a notebook?

Talk about it

1. Why might a left-handed writer find it easier to write from right to left with a quill pen?
2. Leonardo watched birds keep their balance in gusty wind. Which part of *your* brain does that job for you when you ride a bike?
3. What would you put in a notebook if you wanted to learn how something in nature works?

EXPERIMENT: THE DOMINANCE SURVEY

Question: **In my family and friends, how many are right-dominant and left-dominant for hand, foot and eye, and do the three always match?** You will test at least 6 people (more is better) and record your results in a data table.

You will need

- A soft ball or a crumpled paper ball
- A paper towel tube or a sheet of paper rolled into a tube
- A sheet of paper with a small hole (about 2.5 cm or 1 inch) cut in the middle
- A pencil and paper for each person
- Lab notebook and pencil

Steps

1. Write your prediction: Will most people be right-handed? Will everyone’s hand, foot and eye match?
2. Make a table with columns: Name, Hand, Foot, Eye, All match? (yes/no).
3. **Hand test.** Hand each person a pencil and ask them to write their name. Record which hand they use.
4. **Foot test.** Roll the ball gently toward the person and say “Kick it!” Record which foot kicks.
5. **Eye test.** Ask the person to hold the paper with the hole at arm’s length with both hands and look through it at a small object across the room with both eyes open. Then ask them to close one eye at a time. The eye that still sees the object through the hole

is the dominant eye. Check again with the paper tube: the person will put it up to one eye without thinking.

6. Fill in the table for every person. Do not tell people what you are testing until afterward, so they do not try to “help.”
7. Count how many are right-handed. Find the percent: (number right-handed ÷ total) × 100.
8. Count how many people had all three sides match. Write two sentences comparing your results with the fact that about 9 in 10 people are right-handed.

Tips

- Test everyone the same way: same ball, same distance, same hole. That keeps your survey fair.
- A small group may not match the whole world. If only 6 people are tested, one left-hander changes the percent a lot.
- Eye dominance often surprises people. Do the hole test twice to be sure.

Check your work

- I tested at least 6 people for hand, foot and eye and recorded every result.
- I found the percent of right-handed people correctly.
- I can explain why the left hemisphere controls the right hand.

NATURE NOTEBOOK

1. Draw a side view of the brain. Label the cerebrum, cerebellum and brain stem, and write one job of each beside it.
2. Draw the brain from above, like the lesson figure, with crossing arrows to the right and left hands. Label the corpus callosum.
3. Try writing your name in mirror writing like Leonardo. Check it in a real mirror. Which hand did you use, and how did it feel?

> **From history.** Broca kept Leborgne’s brain, and it is still preserved in Paris, more than 150 years later. In 2007 scientists scanned it with an MRI machine and found that the damage reached deeper inside the brain than Broca could see from the surface. Broca’s method of matching a lost ability to an injured place was a great step forward, and it helped doctors begin to map which parts of the brain do which jobs.

WORKED EXAMPLES

Example 1. Sarah surveyed 20 people. 18 were right-handed and 2 were left-handed. What percent were right-handed? What percent were left-handed?

1. Right-handed: 18 ÷ 20 = 0.90.
2. Change to a percent: 0.90 × 100 = 90%.
3. Left-handed: 2 ÷ 20 = 0.10, which is 10%.
4. Check: 90% + 10% = 100%. Her group matches the usual figure of about 9 in 10 right-handed.

Answer: 90% right-handed and 10% left-handed.

Example 2. Tom tapped a pencil dot onto paper as fast as he could for 10 seconds with each hand. He made 46 dots with his right hand and 34 dots with his left hand. How many more dots did his right hand make? How many dots per second did each hand make?

1. Difference: 46 − 34 = 12 more dots with the right hand.
2. Right hand rate: 46 ÷ 10 = 4.6 dots per second.
3. Left hand rate: 34 ÷ 10 = 3.4 dots per second.
4. The right hand was faster, so Tom is most likely right-handed. His left hemisphere is guiding that faster hand.

Answer: 12 more dots; right hand 4.6 dots per second, left hand 3.4 dots per second.

PRACTICE

1. EASY Which hemisphere of the brain mostly controls your left hand?
2. EASY Match each part to its job: cerebrum, cerebellum, brain stem. Jobs: (a) balance and smooth movement, (b) breathing and heartbeat, (c) thinking, speaking and remembering.
3. EASY What is the corpus callosum and why is it important?
4. MEDIUM What did Paul Broca discover in 1861, and how did he discover it?
5. MEDIUM Data table. A class survey found: Right hand 22, Left hand 3; Right foot 21, Left foot 4; Right eye 17, Left eye 8. (a) How many people were surveyed? (b) Which kind of dominance had the most left-side people? (c) What percent were right-eye dominant?
6. MEDIUM A man has a stroke that hurts the left side of his brain. Which side of his body is most likely to become weak? What other ability might he have trouble with?
7. HARD Experiment design. Leah wants to test whether people stack more pennies in 30 seconds with their dominant hand than with their other hand. Name the variable she changes, what she measures, two things she keeps the same, and why she should test many people instead of one.

8. CHALLENGE Your friend says, “I’m right-brained, so I’m creative but bad at math.” In two or three sentences, explain what scientists actually know.

COMMON MISTAKES

- Thinking the left brain controls the left side of the body. It is crossed: the left hemisphere controls the right side.
- Believing people are “left-brained” or “right-brained” types. Both halves work together all the time.
- Thinking a bigger brain always means a smarter person. Brain size varies from person to person, and it does not decide how wise or clever someone is.

Make it a game · Crossed Signals. A parent calls out commands fast: “Touch your left ear with your right hand!” “Hop on your right foot!” “Wink your left eye!” After each one, the player must also say which hemisphere is in charge (“Right hand, left brain!”). A wrong move or wrong hemisphere ends your turn. Then try the harder round: pat your head with one hand while rubbing your stomach with the other, and switch when the parent claps. Which part of your brain is working hardest to keep the rhythm?

Scripture. “Among all this people there were seven hundred chosen men lefthanded; every one could sling stones at an hair breadth, and not miss.” (Judges 20:16, KJV)

These left-handed slingers were prized for their skill. Whether you are right-handed or left-handed, your hands are a gift, and practice can make them very skillful.

Practice answers

1. The right hemisphere.
2. Cerebrum (c); cerebellum (a); brain stem (b).
3. It is a thick bridge of nerve fibers joining the left and right hemispheres, so the two halves can share messages and work together.
4. He found that his patient Leborgne (“Tan”), who could not speak, had a damaged area on the left front of the brain. By comparing more patients who had lost speech, he found the damage was usually on the left side, showing that speech depends mostly on the left hemisphere in most people.
5. (a) 22 + 3 = 25 people. (b) Eye dominance (8 left). (c) 17 ÷ 25 = 0.68, so 68%.
6. His right side. Because speech depends mostly on the left hemisphere in most people, he might also have trouble speaking or understanding words.
7. Variable changed: which hand is used (dominant or other). Measured: the number of pennies stacked in 30 seconds. Kept the same (any two): same pennies, same table, same 30-second timer, same starting position, same rules for a fallen stack. She should test many people because one person might be unusual; more people give a fairer, more trustworthy result.
8. That is a myth. Some jobs lean more on one hemisphere (such as speech on the left in most people), but scans of healthy brains show both hemispheres working together on almost every task, joined by the corpus callosum. Being good at math or art depends on practice and gifts, not on using only one half of the brain.

6.3 Memory

OBJECTIVES

- Tell how Hermann Ebbinghaus measured his own memory and describe his forgetting curve.
- Explain the difference between short-term and long-term memory, name the hippocampus as a helper in making new memories, and describe how practice strengthens connections between neurons.
- Test a memory strategy (such as grouping or a story) with a fair experiment and report the results as percents.

Warm-up. Have a parent put 12 small household things on a tray (a spoon, a key, a button, a coin and so on). Look for 30 seconds, then cover the tray with a towel. Write down everything you remember. How many did you get? Which ones did you forget, and why do you think you forgot those?

Video. Coming soon. How memory works for kids: short-term and long-term memory, the hippocampus, the forgetting curve and spaced practice (search SciShow Kids, Homeschool Pop (Alternate), Crash Course Kids, Science Max and university neuroscience outreach channels).

KEY TERMS

memory
The brain’s power to take in, keep and later bring back information, skills and experiences.

short-term memory
The brain’s small “notepad” that holds a few things (about 7) for a short time, such as a phone number you are about to dial.

long-term memory
Memory that can last for days, years or a lifetime, such as your address, a Bible verse you know by heart or how to ride a bike.

hippocampus
A curved part deep inside each side of the brain, named for its seahorse shape, that helps turn new experiences into long-term memories.

forgetting curve
A graph showing how quickly we forget something after learning it: fast at first, then more slowly.

spaced practice
Reviewing something several times with breaks of hours or days in between, instead of all at once.

CORE IDEAS

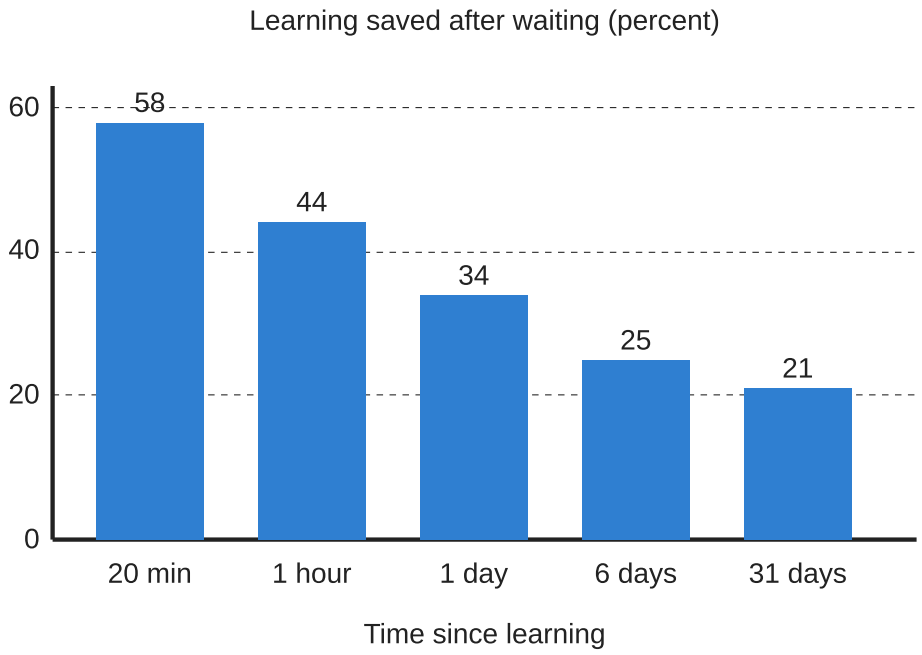
The story. In the early 1880s a young German scientist named Hermann Ebbinghaus wanted to do something no one had done: measure memory with numbers. He knew that a poem or a story is easier to remember if it means something to you, so he invented about 2,300 nonsense syllables, made of a consonant, a vowel and a consonant (like WID, ZOF or LAJ). Then, for years, he tested the only person always ready for the job: himself. In 1885 he published his results in a small book called *On Memory*.

How they figured it out. Ebbinghaus would read a list of syllables aloud, at a steady pace set by a ticking clock, until he could say the whole list without a mistake. Later, after waiting 20 minutes, an hour, a day or a month, he learned the same list again and counted how much less work it took the second time. The time he "saved" showed how much his memory had kept. His results made a famous shape, the **forgetting curve**. He forgot most quickly in the first hour; after that, forgetting slowed down a great deal. He also found that spreading his practice over several days took far fewer repetitions than cramming it all into one sitting. That is the secret of **spaced practice**.

The big idea. Your brain has more than one kind of memory. **Short-term memory** is a small notepad. It holds only about 7 things at once, and they fade in less than a minute unless you repeat them. **Long-term memory** is a huge library that can keep things for a lifetime. Deep inside each side of the brain is the **hippocampus**, shaped a little like a seahorse, which helps move new memories into long-term storage. When you learn something, groups of **neurons** fire together. Each time you practice, the connections (synapses) between those neurons grow stronger, like a path through tall grass that gets clearer every time you walk it.

Try it and see. Good learners use tricks that work with the brain, not against it. **Grouping** (or chunking) turns many small pieces into a few big ones: a 10-digit phone number is easier as three chunks. **Meaning** helps too: linking new words into a picture or a story gives the brain hooks to hang them on. **Testing yourself** is stronger than just rereading. And **spaced practice** beats cramming: a few minutes each day for a week will stick far better than an hour the night before.

God's handiwork. For thousands of years God's people have memorized His words. Children learned the Psalms by heart, and Jesus answered every temptation in the wilderness with Scripture He knew by heart: "It is written" (Matthew 4:4). The psalmist wrote, "Thy word have I hid in mine heart" (Psalm 119:11). Every verse you learn by repeating it day after day is written into the connections of your brain, and it can come back to you when you need it most.



Ebbinghaus's forgetting results (rounded): most forgetting happens soon after learning, then it slows down.

PICTURE STUDY



Old Woman Reading (probably the Prophetess Anna), Rembrandt van Rijn, 1631 · Oil on panel · Rijksmuseum, Amsterdam

Rembrandt painted this when he was a young man in Leiden, in the Netherlands. The old woman is often thought to be the prophetess Anna, who "departed not from the temple" and recognized the baby Jesus (Luke 2:36–38). Some think Rembrandt's own mother sat as his model.

Rembrandt has put almost all the light on the great book and the old hand resting on it. The woman has spent a lifetime reading, and the words she has read have become part of her.

Look closely

- Where is the brightest light in the painting? What does it make you look at first?
- Look closely at the pages of the book. Can you see that Rembrandt painted lines of tiny letters?
- Find her hand. How does it rest on the page? What might that tell you about how she reads?
- Her face is mostly in shadow. Why might the painter have chosen to hide it?

Talk about it

1. Anna was very old when she met the baby Jesus. How might a lifetime of reading and remembering Scripture have prepared her for that day?
2. Do you know an older person who can recite many verses or poems by heart? How did they learn them?
3. What is one passage you would like to know by heart when you are old?

EXPERIMENT: THE MEMORY STRATEGY EXPERIMENT

Question: **Do I remember more words when I sort them into groups than when I just read them over?** You will learn two word lists, one by plain reading and one by grouping, and test yourself the same way each time.

You will need

- Two lists of 15 everyday words, made by a parent ahead of time. Each list should have 5 animals, 5 foods and 5 tools, mixed up in random order (for example List A: hammer, apple, horse, spoon, carrot, sheep, ladder, bread, goose, rake, cheese, rabbit, needle, plum, otter).
- A timer
- Index cards to cover the lists
- Lab notebook and pencil

Steps

1. Write your prediction: Which method will help you remember more words?
2. **Round 1, plain reading.** Study List A for exactly 1 minute by reading it over and over. Cover it.
3. Count backward by 3s from 100 for 1 minute out loud. (This clears your short-term notepad, so you are testing longer memory.)
4. Write every word you can remember in 2 minutes. Count how many are correct.
5. **Round 2, grouping.** Study List B for exactly 1 minute, but this time sort the words in your head into animals, foods and tools. Cover it.

6. Count backward by 3s for 1 minute, then write all the words you remember in 2 minutes. Count your correct words.
7. Find the percent for each round: (correct ÷ 15) × 100.
8. **Next day.** Without looking, write both lists again. Count and record. Which method held up better overnight?
9. Write your conclusion in two or three sentences.

Tips

- What we change: the study method. What we keep the same: number of words, kinds of words, study time, the counting-backward break, writing time. What we measure: the number of words remembered.
- Use two different lists so you are not helped by having already seen the words.
- For a stronger test, have a parent or sibling do the experiment too, and compare.

Check your work

- I kept the study time and test time the same for both methods.
- I recorded my scores and changed them to percents correctly.
- I can explain why grouping helps the brain remember.

NATURE NOTEBOOK

1. Draw a “memory path”: two neurons connected by a thin line labeled “first try,” then thicker lines labeled “practice 2,” “practice 5,” “practice 10.” Write one sentence about what practice does to the connection.
2. Copy the forgetting curve bar graph into your notebook. Draw a second, taller set of bars showing what you think would happen if Ebbinghaus reviewed the list each day.
3. Write a Bible verse you are memorizing this week. Each day, cover it and write it from memory, then put a check mark if you got it all right. Keep the record for seven days.

> **From history.** In 1953 a young man named Henry Molaison had brain surgery to stop terrible seizures. The surgeons removed parts of the brain that included the hippocampus on both sides. His seizures improved, but afterward he could not form new long-term memories: he could chat with someone and forget them minutes later. A Canadian scientist, Brenda Milner, studied him for many years. She found something surprising: he could still learn new *skills*, such as tracing a star while watching his hand only in a mirror, and he got better day after day even though he did not remember practicing. This showed scientists that the brain has different kinds of memory stored in different ways.

WORKED EXAMPLES

Example 1. Use the forgetting curve graph. Ebbinghaus's savings were about 58% after 20 minutes, 34% after 1 day and 21% after 31 days. How much did his savings drop from 20 minutes to 1 day? How much from 1 day to 31 days? What does this tell you?

(Use the map or drawing "Read the bars at 20 minutes, 1 day and 31 days." shown earlier in this lesson.)

1. From 20 minutes to 1 day: 58 − 34 = 24 percentage points.
2. From 1 day to 31 days: 34 − 21 = 13 percentage points.
3. The first drop happened in less than one day. The second, smaller drop took a whole month.
4. So forgetting is fastest right after learning and then slows down.

Answer: A drop of 24 points in the first day but only 13 points over the next 30 days: we forget fastest soon after learning, so reviewing early helps most.

Example 2. Maria studied a list of 15 words by reading it over and remembered 6. She studied a second list of 15 words by grouping them and remembered 12. What percent did she remember each time, and how many times as many words did grouping give her?

1. Plain reading: 6 ÷ 15 = 0.40, so 40%.
2. Grouping: 12 ÷ 15 = 0.80, so 80%.
3. Compare: 12 ÷ 6 = 2.

Answer: 40% by reading, 80% by grouping. Grouping helped her remember twice as many words.

PRACTICE

1. EASY About how many things can short-term memory hold at once?
2. EASY Which part of the brain, named for its seahorse shape, helps make new long-term memories?
3. EASY Why did Ebbinghaus use nonsense syllables like ZOF and WID instead of real words?
4. MEDIUM Graph reading. On the forgetting curve, the savings were about 58% after 20 minutes and 44% after 1 hour. How many percentage points were lost in those 40 minutes? Is that more or less than the loss from 6 days (25%) to 31 days (21%)?
5. MEDIUM Show how chunking makes the number 8 0 0 5 5 5 1 2 1 2 easier to remember.
6. MEDIUM Jonah has a spelling test on Friday. Plan A: study 50 minutes on Thursday night. Plan B: study 10 minutes each day Monday through Friday morning. Which plan is better, and why? How many minutes does each plan use?

7. HARD Experiment design. Ruth thinks she remembers more words when soft music plays than in a quiet room. Describe a fair test: the variable she changes, what she measures, three things she keeps the same, and her control.
8. CHALLENGE In two or three sentences, explain what happens in the brain when you practice a Bible verse every day for a week.

COMMON MISTAKES

- Thinking memory works like a video camera that records everything exactly. The brain rebuilds memories each time you recall them, so they can fade or change, which is why careful notes and records matter in science.
- Believing cramming the night before is the best way to study. Spaced practice over several days lasts much longer.
- Thinking some people simply have a “good memory” and others do not. Strategies like grouping, testing yourself and spaced review help everyone remember more.

> **Make it a game · The Grocery Chain.** Sit in a circle. The first player says, “I went to the market and bought an apple.” The next player repeats the list and adds one item: “… an apple and a broom.” Keep going around the circle. If you miss an item or get the order wrong, you are out. The last player in wins. Afterward, talk about the tricks you used: did you picture the items, make a silly story or group them?

> **Scripture.** “Thy word have I hid in mine heart, that I might not sin against thee.” (Psalm 119:11, KJV)

To “hide” God’s word in your heart is to know it so well that it stays with you. Spaced, daily practice is exactly how the brain stores a verse for life.

Practice answers

1. About 7.
2. The hippocampus.
3. Real words and poems have meaning, which makes some easier to remember than others. Nonsense syllables were all about equally hard, so his measurements were fairer.
4. 58 − 44 = 14 points in 40 minutes. That is more than the loss from 6 days to 31 days (25 − 21 = 4 points), even though that was 25 days.
5. Break the 10 digits into 3 chunks: 800 – 555 – 1212. Three chunks fit easily in short-term memory, while ten separate digits are more than the usual limit of about 7.
6. Plan B is better because spaced practice strengthens memory more than cramming, as Ebbinghaus found. Both plans use 50 minutes (Plan B: 5 × 10 = 50).
7. Variable changed: music or no music while studying. Measured: the number of words remembered. Kept the same (any three): same number and kind of words (two matched lists), same study time, same break, same writing time, same time of day, same room. Control: the round studied in a quiet room with no music.
8. Each time you say the verse, the same groups of neurons fire together, and the connections (synapses) between them grow stronger. The hippocampus helps move the verse into long-

term memory, and reviewing it on different days fights the fast early drop of the forgetting curve, so the verse stays with you.

6.4 Sleep

OBJECTIVES

- Tell how Eugene Aserinsky and Nathaniel Kleitman discovered REM sleep and describe the stages of a sleep cycle.
- Explain at least three things the brain and body do during sleep and how much sleep children your age need.
- Keep a one-week sleep log, calculate hours slept and averages, and compare sleep with morning reaction time.

Warm-up. Think back to last night. Write down what time you went to bed and what time you woke up, then work out how many hours you slept. Did you dream? Can you remember any of it? How do you feel this morning on a scale of 1 (very tired) to 5 (full of energy)?

Video. Coming soon. Why we sleep, for kids: sleep cycles, REM sleep and dreams, what the brain does at night and how much sleep children need (search SciShow Kids, Homeschool Pop (Alternate), Crash Course Kids, NIH and university sleep-research outreach channels).

KEY TERMS

sleep cycle
One trip through the stages of sleep, from light sleep to deep sleep to REM sleep. A cycle lasts about 90 minutes, and a night has several.

deep sleep
The stage of slowest brain waves, when it is hardest to wake up; breathing and heartbeat slow, and the body does much of its growth and repair.

REM sleep
Rapid eye movement sleep: the stage when the eyes dart back and forth under the lids, the brain is very active and most vivid dreams happen.

EEG
Electroencephalogram: a machine that records the brain’s tiny electrical waves through small sensors placed on the scalp.

melatonin
A chemical messenger the body makes mostly in the evening darkness that helps you feel sleepy. Bright light at night slows its release.

CORE IDEAS

The story. In the early 1950s, at the University of Chicago, a graduate student named Eugene Aserinsky worked in the laboratory of Nathaniel Kleitman, a scientist who had spent

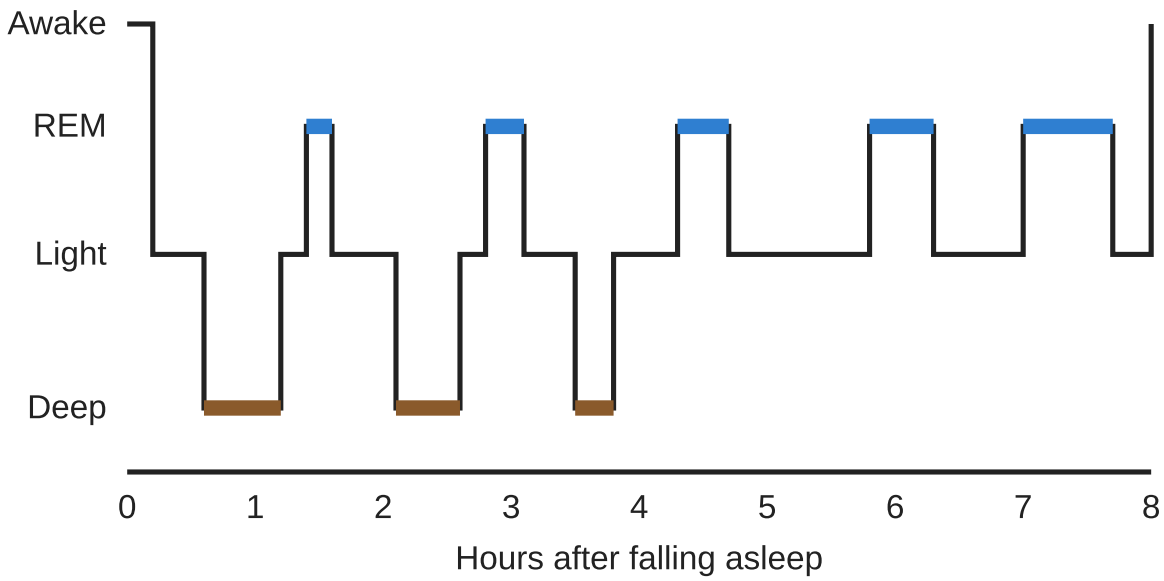
his life studying sleep. Kleitman asked him to watch the eyes of sleeping people. One night Aserinsky brought his young son Armond to the lab, taped small sensors near his eyes and on his head, and watched the pens of the recording machine scratch across the paper. Several times during the night the pens jumped wildly: Armond's eyes were darting back and forth under his closed lids, and his brain waves looked almost like those of someone awake. In 1953 Aserinsky and Kleitman reported their discovery. They called it **rapid eye movement** sleep, or **REM**.

How they figured it out. Before this, most people thought sleep was simply the brain switching off, like a lamp. The two scientists, joined by William Dement, recorded many sleepers all night long with an **EEG**. They found the same pattern again and again. When they woke people during REM, most said they had been dreaming, often in vivid pictures. When they woke them at other times, dreams were reported much less often. The brain, it turned out, was busy all night.

The big idea. Sleep comes in **cycles** of about 90 minutes. You drift into **light sleep**, then sink into **deep sleep**, when your brain waves become slow and big and it is hard to wake you. Then you rise back toward lighter sleep and into **REM**. Most deep sleep comes early in the night; REM periods grow longer toward morning. During deep sleep your body releases growth hormone and repairs muscles and tissues. During REM your arm and leg muscles go limp, so you do not act out your dreams. All night long the brain sorts through the day, strengthening important memories (Lesson 6.3) and clearing away waste. Children ages 6 to 12 need about 9 to 12 hours of sleep each night.

Try it and see. Sleep scientists keep careful records, and you can too. A **sleep log** lists the time you went to bed, the time you woke and how you felt. Your body keeps a daily rhythm, a kind of inner clock, and as evening darkness falls it releases **melatonin**, which makes you sleepy. Bright light at night, including the glow of screens, can delay it. That is why a regular bedtime, a dark room and putting screens away before bed help you fall asleep faster. You can even test whether a good night's sleep sharpens your ruler-drop reaction time from Lesson 6.1.

God's handiwork. God built rest into creation itself: evening and morning, day and night, and a day of rest each week. Sleep is a daily reminder that we are creatures who depend on Him. We must stop and let go of our work, but the One who made us never needs to: "he that keepeth Israel shall neither slumber nor sleep" (Psalm 121:4). So the psalmist could lie down without fear: "I will both lay me down in peace, and sleep: for thou, LORD, only makest me dwell in safety" (Psalm 4:8).



A simplified night of sleep: deep sleep (brown) comes mostly early, and REM (blue) grows longer toward morning. Each dip and rise is about one 90-minute cycle.

PICTURE STUDY



Noon – Rest from Work (after Millet), Vincent van Gogh, 1890 · Oil on canvas · Musée d'Orsay, Paris

Vincent van Gogh deeply admired the French painter Jean-François Millet, who painted farm families at work. In 1890 Van Gogh painted his own colorful copy of a Millet picture of two harvesters taking a midday nap. Van Gogh used bold blue for the shadows and the sky and bright yellow for the cut wheat.

The two workers have been cutting grain since early morning. Now, in the heat of the day, they rest in the shade before going back to work.

Look closely

- Find the tools the workers have put down. What job were they doing?
- Look at the shoes. Why do you think the man took his off?
- Find the shady place where they lie. How did Van Gogh show the difference between sun and shade?
- Look at the man’s hat. Why might it be over his face?

Talk about it

1. What does this painting say about the connection between hard work and rest?
2. Why might farm workers long ago have needed a nap at midday during harvest?
3. Van Gogh painted a copy of another artist’s work. What can you learn by copying a picture or a scientific drawing carefully?

EXPERIMENT: MY SLEEP AND REACTION STUDY

Question: **On mornings after I sleep longer, is my ruler-drop reaction time faster?** For seven days you will keep a sleep log like a sleep scientist and test your reaction time each morning with the ruler drop from Lesson 6.1.

This is an *observational* study: you do not cut your sleep on purpose. You keep your normal bedtime and watch what happens naturally from night to night.

You will need

- A clock or watch by your bed
- A 30-centimeter (12-inch) ruler and a helper
- Lab notebook and pencil
- Colored pencils for a graph

Steps

1. Write your prediction.
2. Make a log table with columns: Day, Bedtime, Wake time, Hours slept, Morning feeling (1 to 5), Average catch distance (cm).
3. Each night, write down the time you turn out the light.
4. Each morning, write your wake time and work out the hours slept.
5. Within 30 minutes of getting up, do 5 ruler-drop trials with your writing hand and find the average distance. Do it at the same place each day.
6. Rate how you feel from 1 (very tired) to 5 (full of energy).
7. After 7 days, find your average hours of sleep for the week.
8. Make a bar graph: one bar per day showing hours slept. Write the average catch distance above each bar.

9. Write your conclusion: Did longer sleep go with shorter catch distances? Were the differences big or small? Why might 7 days not be enough to be sure?

Tips

- What changes on its own: hours slept. What we measure: reaction time and how you feel. What we keep the same: the ruler, the helper, the hand, the time after waking.
- Use the time you turn out the light, not the time you get into bed, as your bedtime.
- If you are sick one night, note it in the log. Scientists always record anything unusual.

Check your work

- My log has all 7 days filled in.
- I calculated hours slept and the weekly average correctly.
- I made a bar graph and wrote an honest conclusion, even if the results did not match my prediction.

NATURE NOTEBOOK

1. Copy the sleep graph from the lesson. Color the deep sleep sections brown and the REM sections blue. Count how many cycles you see.
2. Draw your bedroom at night as a sleep scientist would. Label things that help sleep (dark curtains, quiet, cool air) and things that might get in the way.
3. Write down one dream you remember this week in a few sentences, with the date. Next to it, write whether you woke up slowly or quickly.

> **From history.** Nathaniel Kleitman was famous for testing ideas on himself. In the summer of 1938 he and a student, Bruce Richardson, lived for about a month deep inside Mammoth Cave in Kentucky, where there is no sunlight and the temperature hardly changes. They tried to live on a 28-hour day instead of a 24-hour day to see if the body's daily rhythm could be changed. Richardson adjusted somewhat, but Kleitman's body kept stubbornly to its old 24-hour schedule. The experiment helped show that the body has a strong inner daily clock.

WORKED EXAMPLES

Example 1. Abby went to sleep at 8:30 p.m. and woke at 6:45 a.m. How long did she sleep? Is that within the 9 to 12 hours children her age need?

1. From 8:30 p.m. to midnight (12:00): 3 hours 30 minutes.
2. From midnight to 6:45 a.m.: 6 hours 45 minutes.
3. Add: 3 h 30 min + 6 h 45 min = 9 h 75 min.
4. 75 minutes = 1 hour 15 minutes, so the total is 10 hours 15 minutes.

Answer: 10 hours 15 minutes, which is within the healthy range of 9 to 12 hours.

Example 2. One sleep cycle lasts about 90 minutes. About how many cycles fit into 9 hours of sleep?

(Use the map or drawing "Count the dips and rises: each is about one 90-minute cycle." shown earlier in this lesson.)

1. Change hours to minutes: 9 × 60 = 540 minutes.
2. Divide by the length of one cycle: 540 ÷ 90 = 6.

Answer: About 6 sleep cycles.

PRACTICE

1. EASY What does REM stand for, and what usually happens during REM sleep?
2. EASY How many hours of sleep do children ages 6 to 12 need each night?
3. EASY Name three things the body or brain does during sleep.
4. MEDIUM Data table. Caleb's sleep log: Mon 9 h, Tue 9.5 h, Wed 10 h, Thu 8.5 h, Fri 8 h, Sat 10.5 h, Sun 7.5 h. (a) What was his average? (b) On which nights did he sleep less than 9 hours?
5. MEDIUM Jacob went to bed at 9:15 p.m. and woke at 7:00 a.m. How long did he sleep?
6. MEDIUM Why can looking at a bright screen right before bed make it harder to fall asleep?
7. HARD Experiment design. A family wants to test whether a warm (not hot) bath before bed helps their children fall asleep faster. Name the variable they change, what they measure, two things they keep the same, and the control.
8. CHALLENGE Before 1953 many people believed sleep was just the brain "switching off." In two or three sentences, explain what Aserinsky and Kleitman's recordings showed instead.

COMMON MISTAKES

- Thinking the brain shuts off during sleep. It stays busy all night, sorting memories, dreaming and running breathing and heartbeat.
- Thinking you can "catch up" on a whole week of short nights by sleeping late on Saturday. A steady bedtime every night works much better.
- Thinking dreams happen only once, right before you wake up. Most people pass through several REM periods each night, though they usually remember only the last dream.

Make it a game · Sleep Cycle Hopscotch. Chalk or tape four squares in a row labeled Awake, Light, Deep and REM. A parent calls out a clue, such as "Eyes darting, dreaming!" (REM), "Hardest to wake up, growing and repairing!" (Deep), "Drifting off, easy to wake!" (Light) or "Alarm clock!" (Awake). Hop to the right square. Then play a full night: start at Awake and hop through 5 cycles of Light, Deep, Light, REM in order,

skipping Deep in the last two cycles, just as real nights have less deep sleep toward morning.

Scripture. “I will both lay me down in peace, and sleep: for thou, LORD, only makest me dwell in safety.” (Psalm 4:8, KJV)

David wrote this in troubled times, yet he could sleep because he trusted the Lord to keep watch. Sleep is God’s good gift for body and mind, and we can rest in His care.

Practice answers

1. Rapid eye movement. The eyes dart back and forth under the lids, the brain is very active, the arm and leg muscles go limp and most vivid dreams happen.
2. About 9 to 12 hours.
3. Any three: releases growth hormone; repairs muscles and tissues; strengthens important memories; clears away waste in the brain; slows breathing and heartbeat in deep sleep; dreams during REM.
4. (a) 9 + 9.5 + 10 + 8.5 + 8 + 10.5 + 7.5 = 63 hours; 63 ÷ 7 = 9 hours average. (b) Thursday, Friday and Sunday.
5. 9:15 p.m. to midnight = 2 h 45 min; midnight to 7:00 a.m. = 7 h. Total 9 hours 45 minutes.
6. Darkness signals the body to release melatonin, which makes you sleepy. Bright light at night, including from screens, slows its release, so sleepiness comes later.
7. Variable changed: a warm bath before bed or no bath. Measured: how many minutes it takes to fall asleep (or the time from lights out to sleep, judged by the parent or the child’s log). Kept the same (any two): same bedtime, same room, same darkness, no screens, same supper time, same children. Control: nights with the usual bedtime routine and no bath.
8. Their EEG and eye recordings showed that during sleep the brain goes through repeating cycles, and in REM sleep the eyes move rapidly and brain waves look almost like waking. People woken in REM usually reported dreams, which showed the brain is very busy during sleep, not switched off.

Unit 6 review

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

1. (5 pts) Put the parts of a reflex arc in order, starting with touching a hot pan: spinal cord, arm muscle, sensory nerve, heat sensor in skin, motor nerve. Why do you pull away before you feel pain?
2. (5 pts) In five ruler-drop trials Hannah caught the ruler at 12, 10, 11, 9 and 8 cm. Find her average. Using the table (10 cm → 0.14 s, 15 cm → 0.17 s), about what was her reaction time?
3. (5 pts) Is catching a falling ruler a reflex or a reaction? Explain.
4. (5 pts) Name the part of the brain for each job: (a) balance and smooth movement, (b) breathing and heartbeat, (c) thinking and speaking, (d) joining the two hemispheres.
5. (5 pts) What did Paul Broca learn from his patient Leborgne in 1861? Which hemisphere moves your right hand?
6. (5 pts) In a survey of 40 people, 36 were right-handed. What percent were right-handed? What percent were left-handed?
7. (5 pts) Ebbinghaus's savings were about 58% after 20 minutes and 34% after 1 day, but still about 21% after 31 days. What does this tell you about forgetting, and what is the best way to study for a test?
8. (5 pts) Explain the difference between short-term and long-term memory, and name the part of the brain that helps make new long-term memories.
9. (5 pts) Eli went to sleep at 8:45 p.m. and woke at 6:15 a.m. How long did he sleep? About how many 90-minute sleep cycles is that?
10. (5 pts) Experiment design. You want to test whether 10 hours of sleep gives a faster ruler-drop reaction time than 8 hours. Name the variable you change, what you measure, two things you keep the same, and describe what REM sleep is.

Unit project: my brain and nerves lab book

Gather your experiments from this unit into one lab book that a real scientist would be proud of. Include a large labeled drawing of the brain (cerebrum with its two hemispheres, corpus callosum, cerebellum, brain stem) connected to the spinal cord and a reflex arc in the arm. Then add your four studies, each with its question, prediction, data table, average or percent, and conclusion: the ruler-drop reaction lab, the dominance survey, the memory strategy experiment and the one-week sleep log with its bar graph.

Finish with a one-page letter to a younger child explaining three ways to take care of the brain God gave them (for example: sleep enough, practice and review, protect your head with a helmet), with one Scripture verse from this unit copied neatly at the bottom.

- **Accuracy**: Brain parts and the reflex arc are drawn and labeled correctly, with correct jobs for each part.

- **Records**: All four studies have complete, dated data tables with averages, percents and hours calculated correctly.
- **Fair tests**: Each study names what was changed, what was measured and what was kept the same, and the conclusions honestly match the data.
- **Care and explanation**: The lab book is neat and easy to read, and the letter clearly explains three ways to care for the brain in plain words.

Answer key

1. Heat sensor in skin → sensory nerve → spinal cord → motor nerve → arm muscle. The message turns around in the spinal cord, so the hand moves before the separate message reaches the brain, where the pain is felt.
2. 12 + 10 + 11 + 9 + 8 = 50; 50 ÷ 5 = 10 cm. Her reaction time was about 0.14 seconds.
3. A reaction. You must see the ruler fall, the brain must decide, and then it sends a command to the fingers. A reflex happens automatically, often through the spinal cord alone, without deciding.
4. (a) Cerebellum. (b) Brain stem. (c) Cerebrum. (d) Corpus callosum.
5. Leborgne could understand but could not speak (he could only say “tan”). After he died, Broca found damage on the left front part of his brain, showing that speech depends mostly on the left hemisphere. The left hemisphere moves the right hand.
6. 36 ÷ 40 = 0.90, so 90% right-handed; 4 ÷ 40 = 0.10, so 10% left-handed.
7. Forgetting is fastest right after learning and then slows down. The best way to study is spaced practice: review a little each day, starting soon after you first learn it, instead of cramming the night before.
8. Short-term memory holds about 7 things for less than a minute unless you repeat them. Long-term memory can keep things for years or a lifetime. The hippocampus helps make new long-term memories.
9. 8:45 p.m. to midnight = 3 h 15 min; midnight to 6:15 a.m. = 6 h 15 min; total 9 h 30 min = 570 minutes. 570 ÷ 90 = 6 1/3, so about 6 cycles.
10. Variable changed: hours of sleep (10 or 8). Measured: ruler-drop catch distance (reaction time). Kept the same (any two): same ruler, helper, hand, time after waking, number of trials. REM (rapid eye movement) sleep is the stage when the eyes dart under the lids, the brain is very active, the limbs go limp and most vivid dreams happen.

UNIT 7

Senses

Everything you know about the world outside your body came to you through your senses. Light, sound waves, molecules floating in the air, chemicals in your food and the press of a hand all reach special receptor cells, which turn them into nerve signals for the brain to read. In this unit you will follow each of those paths. You will meet **Christoph Scheiner**, who looked through the back of an animal's eye and saw the world painted upside down; **Alexander Graham Bell**, whose study of the human ear led to the telephone; **Kikunae Ikeda**, who found the fifth taste in a bowl of seaweed broth; and **Ernst Weber**, who mapped the skin with a pair of compass points.

You will work like a real scientist all the way through: dissecting a cow's eye (or building a model eye with a magnifying lens), timing thunder to find the distance to a storm, testing whether two ears find sounds better than one, running a jelly bean experiment with a control, and making a touch map of your own body. You will record your data in tables, find averages and percents, and draw bar graphs.

Scripture says, "The hearing ear, and the seeing eye, the LORD hath made even both of them" (Proverbs 20:12). By the end of this unit you will be able to explain how each sense works, and you will have many new reasons to thank the God who gave them.

BEFORE YOU BEGIN

- Knows that nerves carry signals between the body and the brain (Unit 6)
- Can measure in millimeters and centimeters with a metric ruler
- Can find the average of three numbers and change a score out of 10 or 20 to a percent
- Can read and draw a simple bar graph

MASTERY CHECKLIST

- I can name the parts of the eye, tell how the cornea and lens make an upside-down image on the retina, and explain the blind spot.
- I can trace sound through the outer, middle and inner ear and tell what the semicircular canals do.
- I can use the speed of sound to find how far away a lightning strike or an echoing wall is.
- I can name the five basic tastes and explain why flavor depends on smell as well as taste.
- I can measure and explain the two-point threshold and tell why Braille is read with the fingertips.
- I can plan a fair test with one variable, a control and things kept the same, and show the results in a table and a bar graph.

OPTIONAL BOOKS AND RESOURCES

- **Cow’s Eye Dissection, from the Exploratorium** (https://www.exploratorium.edu/learning_studio/cow_eye/): Free. A step-by-step, photographed guide to dissecting a cow’s eye from the San Francisco science museum, with a short explanation of each part. Preview with your child before Lesson 7.1, whether or not you do a real dissection.
- **KidsHealth: Your Ears** (https://kidshealth.org/en/kids/ears.html): Free. A clear, child-friendly article on the outer, middle and inner ear and how to protect hearing, written by doctors at Nemours Children’s Health. Good review after Lesson 7.2.
- ***The Story of My Life* by Helen Keller (free at Project Gutenberg)** (https://www.gutenberg.org/ebooks/2397): Free. Read aloud Helen Keller’s own account of the day at the water pump when she learned that “everything had a name” (Lesson 7.4). A parent may choose passages; the early chapters suit this age best.

7.1 The Eye: Looking Inside a Cow's Eye ★

OBJECTIVES

- Name the main parts of the eye (cornea, iris, pupil, lens, retina, optic nerve) and tell the job of each, using a cow-eye dissection or a good model.
- Explain how the lens makes a small, upside-down picture on the retina and how the brain makes sense of it.
- Measure the pupil and the blind spot, record the numbers in a table, and find an average.

Warm-up. Stand in front of a bathroom mirror with the light off and the door almost closed for one minute. Now flip the light on and watch your own pupils, the black circles in the middle of your eyes. What happens in the first second? Turn the light off and on again. Draw your eye "in the dark" and "in the light" side by side.

Video. Coming soon. Cow eye dissection and how the human eye forms an image, for children; search the Exploratorium cow-eye dissection, SciShow Kids, Homeschool Pop (Alternate), Science Max, Moody Science classics, and university outreach or optometry school demonstrations of the eye and lenses.

KEY TERMS

cornea
The clear, curved window at the front of the eye. It lets light in and does most of the bending of light.

iris
The colored ring of muscle around the pupil. It makes the pupil bigger in dim light and smaller in bright light.

pupil
The round opening in the middle of the iris that lets light into the eye. It looks black because the inside of the eye is dark.

lens
The clear, bean-shaped part behind the pupil that changes shape to focus light sharply on the retina.

retina
The thin layer at the back of the eye, full of light-sensing cells called rods and cones.

optic nerve
The thick bundle of nerve fibers that carries signals from the retina to the brain.

CORE IDEAS

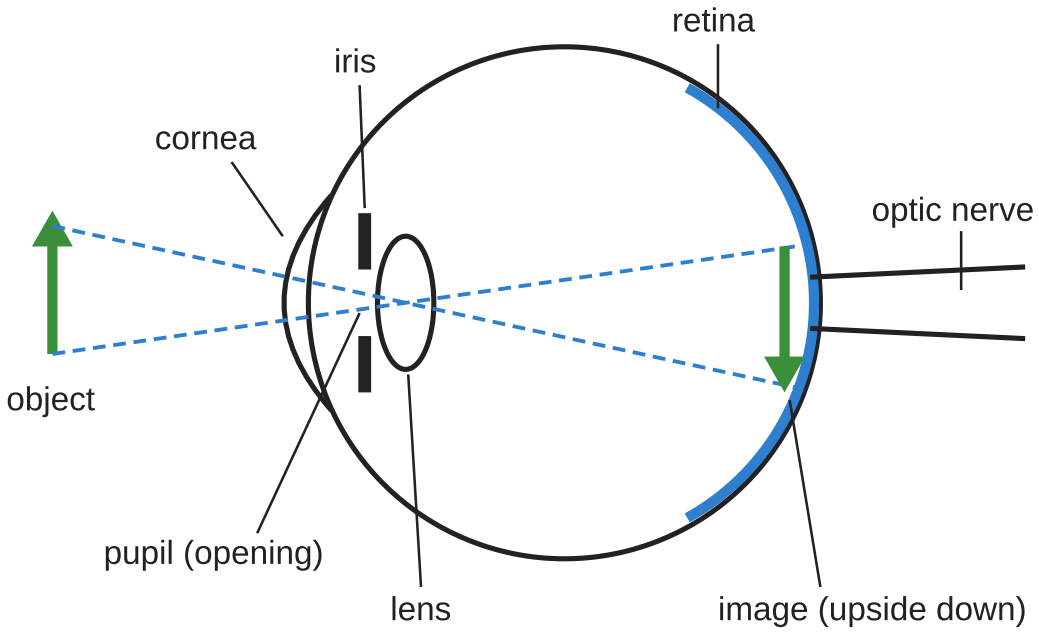
The story. In the early 1600s everyone knew that the eye lets us see, but nobody was sure where the picture is actually made. In 1604 the German astronomer Johannes Kepler reasoned with geometry that the light passing into the eye must paint a small picture on the **retina**, the thin layer at the back. Could anyone see that picture with his own eyes? Christoph Scheiner, a German Jesuit priest and astronomer who also studied sunspots, decided to look. He took the eye of an animal such as an ox, carefully scraped away the tough coats at the back until they were thin enough for light to pass through, and pointed the eye toward a bright scene. On the back of the eye was a tiny, sharp, colored picture of the world, and it was *upside down*. Scheiner wrote about it in his book *Oculus* ("The Eye"), published in 1619.

How they figured it out. Students still learn the eye the way Scheiner did: by looking inside a real one. A cow's eye is larger than yours (a human eyeball is about 2.5 cm, or 1 inch, across), but it is built on the same plan. Outside is the tough white *sclera*, with fat and muscles that once turned the eye. At the front is the clear dome of the **cornea** (it turns cloudy in a preserved eye). Behind it is the dark **iris** with its opening, the **pupil**, which in a cow is a sideways oval. Behind the pupil sits the **lens**, a clear, firm bead that can magnify printed letters. The middle of the eye is filled with clear jelly. Lining the back is the thin, cream-colored retina, fastened at only one spot, where the **optic nerve** leaves. Under the retina a cow has a shiny blue-green layer called the *tapetum*, which bounces light back through the retina and helps it see at dusk. You do not have one; that is why a cow's eyes shine in headlights and yours do not.

The big idea. Light from an object passes through the cornea, which bends it, then through the pupil. The iris acts like the shutter of a camera, opening wide in dim light and squeezing small in bright light. The lens bends the light a little more and focuses it on the retina. Tiny muscles change the shape of your lens: fatter for near things, thinner for far things. Because the light rays cross inside the eye, the picture on the retina is upside down and reversed, just as Scheiner saw. The retina has about 120 million *rods*, which work in dim light and see in shades of gray, and about 6 million *cones*, which need brighter light and see color. These cells turn light into nerve signals, the optic nerve carries them to the back of the brain, and the brain turns the picture into the right-side-up world you see.

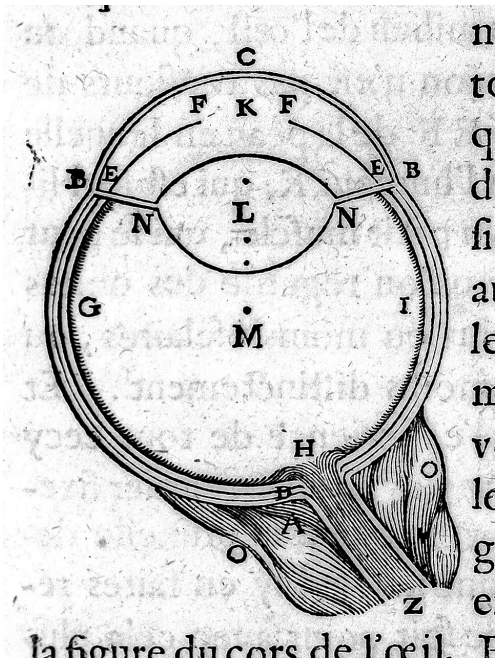
Try it and see. Where the optic nerve leaves the eye there are no rods or cones at all, so each eye has a *blind spot*. You can find yours with a card, a dot and a cross (see the practice items). You can watch your pupils change in a mirror, and you can make your own "eye" with a magnifying glass: in a dim room, hold it between a bright window and a white card, and an upside-down picture of the window appears on the card, exactly as on a retina.

God's handiwork. Your eye focuses itself in a split second, adjusts to sunlight and starlight, cleans itself with every blink, and keeps itself wet with tears. Two eyes set a little apart give the brain two slightly different pictures, so you can judge how far away a ball is when you catch it. The psalmist asked a fair question: if God formed the eye, "shall he not see?" (Psalm 94:9). The One who designed seeing sees everything.



How the eye makes a picture: the cornea and lens bend the light, the rays cross, and an upside-down image forms on the retina.

PICTURE STUDY



The Parts of the Eye, from Descartes's La Dioptrique, Engraving in René Descartes's *La Dioptrique* (Optics), 1637 · Woodcut or engraving printed in a book · Published in Leiden, Netherlands, with Descartes's *Discourse on Method*; copies are in many libraries

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

The French thinker René Descartes wrote a book on light and lenses in 1637. In it he told readers to do what Scheiner had done: take the eye of a man who has just died (or, if that

cannot be had, of an ox or another large animal), thin the back of it, set it in the window of a dark room, and look at the back. You will see, he said, a small picture of the things outside, upside down.

His book included careful drawings of the eye. This one shows an eyeball cut through the middle, with each part marked by a letter so readers could follow his explanation: the clear cornea at the front, the lens, the clear jelly that fills the eye, the retina lining the back and the optic nerve that leads to the brain.

Look closely

- Find the front of the eye. Which letters mark the clear front part?
- Find the round lens near the middle (marked L). What does a lens do to light?
- Find the thick bundle leaving the back of the eye. That is the optic nerve. Where does it go?
- Notice the words printed around the drawing. Why might Descartes put a picture right in the middle of his explanation?

Talk about it

1. Descartes said that in a dark room you could see an upside-down picture on the back of an eye. Why would the room need to be dark?
2. How is Descartes’s drawing like the eye diagram in this lesson? What does each one show best?
3. If the picture on your retina is upside down, why does the world not look upside down to you?

> **Safety first.** Dissection is done only with a parent. Buy a preserved cow eye from a science supplier; do not use eyes from a butcher unless a parent has checked that they are fresh and clean. Wear disposable gloves and safety glasses, cut on a tray, and let an adult handle the scalpel or sharp scissors. Wash hands and tools well afterward. Never look at the sun, through a magnifying glass or otherwise, and never leave a magnifying glass lying in sunlight, because it can start a fire.

EXPERIMENT: BUILD A MODEL EYE (AND LOOK INSIDE A REAL ONE)

A magnifying glass works much like the lens of your eye. In this experiment you will use one to make an upside-down picture on a paper “retina,” then find out how the distance from the lens to the screen must change when the object is near instead of far. If your family is able, you will finish by dissecting a cow’s eye and finding every part for yourself.

You will need

- A magnifying glass (a reading lens about 5–10 cm, or 2–4 inches, across)
- A white index card or sheet of paper for a screen
- A metric ruler or tape measure

- A lamp with a shade
- A room with one bright window that you can darken otherwise
- Lab notebook and pencil
- Optional, with a parent: a preserved cow eye, dissecting tray, gloves, safety glasses, small sharp scissors or scalpel, and a hand lens

Steps

1. **Question.** When an object is closer to a lens, does the screen need to be closer to the lens or farther away to get a sharp picture?
2. **Prediction.** Write your guess in your notebook before you start.
3. **Far object.** Darken the room except for the window. Stand across the room from the window. Hold the card still and slowly move the magnifying glass toward it until a sharp picture of the window appears. Have a partner measure the distance from the lens to the card in centimeters. Do this three times and record each number.
4. **Near object.** Turn on the lamp and stand about 1 meter (about 3 feet) from it. Repeat: find the sharp picture of the lamp, measure the lens-to-card distance three times, and record.
5. **What we change:** how far away the object is. **What we keep the same:** the same lens, the same card, the same person measuring. **What we measure:** the lens-to-card distance for a sharp picture.
6. Find the average of each set of three measurements. Which distance was longer? Was the picture upright or upside down?
7. **Dissection (optional, with a parent).** Look at the outside of the cow eye: find the fat, muscles, white sclera, cornea and optic nerve. Cut through the sclera about 1 cm (about half an inch) behind the cornea and go all the way around, so the eye opens into a front half and a back half.
8. In the front half, find the iris and pupil, and gently remove the lens. Set the lens on a page of print. Does it magnify the letters?
9. In the back half, find the clear jelly, the thin retina and the spot where it is attached to the optic nerve. Find the shiny blue-green tapetum underneath. Draw everything you find and label it.
10. Write two sentences comparing your magnifying-glass model with the real eye.

Tips

- For a far object, the sharp picture comes when the card is about one lens-length (the lens’s focal length) behind the lens. For a near object it is farther back.
- Your eye cannot move its retina back and forth, so instead it changes the shape of its lens. The magnifying glass cannot change shape, so you move the card instead.
- In a preserved eye the cornea and lens are often cloudy. In a living eye they are perfectly clear.

Check your work

- I can name and point to the cornea, iris, pupil, lens, retina and optic nerve on a diagram or a real eye.
- I can explain why the picture on the retina is upside down.
- I measured the lens-to-screen distance three times for each object and found the averages.

NATURE NOTEBOOK

1. Draw a large side view of the eye from memory and label the cornea, iris, pupil, lens, retina and optic nerve. Then check it against the lesson diagram and fix any mistakes in a different color.
2. Look closely at a family member’s eye (or your own in a mirror). Draw the iris carefully, with all its lines and flecks of color, and write the date and the light in the room.
3. Draw what you saw on the card in your model-eye experiment: the window, upside down. Beside it, write one sentence about Christoph Scheiner.

> **From history.** Benjamin Franklin needed one pair of spectacles for reading and another for seeing far away, and he grew tired of switching them. He had the lenses of two pairs cut in half and fitted together in one frame, with the far-seeing halves on top and the reading halves on the bottom. In a 1785 letter to a friend in London he described these “double spectacles,” which we now call bifocals, and explained that at dinner in France they let him see both what he was eating and the faces of the people across the table who spoke to him.

WORKED EXAMPLES

Example 1. Ruth’s brother measured the width of her pupil with a ruler held near her eye (without touching it) in three kinds of light. Bright sunlight by a window: 2 mm. Ordinary room light: 4 mm. Dim room after 1 minute: 7 mm. How much wider was her pupil in dim light than in bright sunlight? About how many times as wide?

1. Write the data in a table: bright sunlight 2 mm, room light 4 mm, dim room 7 mm.
2. Find the difference between dim and bright: 7 mm − 2 mm = 5 mm.
3. Find how many times as wide: 7 mm ÷ 2 mm = 3.5.
4. Explain: in dim light the iris relaxes and opens the pupil wide to let in more light; in bright light it squeezes the pupil small to protect the retina.

Answer: The pupil was 5 mm wider in dim light, or about 3.5 times as wide.

Example 2. Caleb finds his blind spot. He draws an X and a dot 8 cm apart on a card, closes his left eye, stares at the X with his right eye, and slowly moves the card toward his face. The dot disappears at these distances in three trials: 28 cm, 31 cm and 30 cm. What is the average distance? About how many inches is that?

1. Add the three trials: 28 + 31 + 30 = 89 cm.
2. Divide by the number of trials: 89 ÷ 3 = 29.7 cm, or about 30 cm.
3. Convert: 1 inch = 2.54 cm, so 29.7 ÷ 2.54 ≈ 11.7 inches, or about 12 inches.
4. Explain: at that distance the light from the dot lands on the place where the optic nerve leaves the retina. There are no rods or cones there, so nothing is seen.

Answer: The average is about 29.7 cm (about 30 cm, or about 12 inches).

PRACTICE

1. EASY Which part of the eye is the colored ring, and what does it do?
2. EASY Which part of the eye holds the cells that sense light? Name the two kinds of light-sensing cells and what each is best at.
3. MEDIUM Put these in the order that light passes through them: lens, cornea, retina, pupil. Then tell what carries the message to the brain.
4. MEDIUM A student measured a friend’s pupil after the lights were turned off. At 0 seconds: 3 mm. At 10 seconds: 5 mm. At 30 seconds: 6 mm. At 60 seconds: 7 mm. (a) How much did the pupil grow in all? (b) During which time span did it grow the most?
5. MEDIUM In a cow-eye dissection you find a shiny blue-green layer behind the retina. What is it called, how does it help the cow, and do people have one?
6. HARD Plan a fair experiment to test whether pupil size changes with the brightness of the light. Name the variable you change, what you keep the same, what you measure, and your control.
7. HARD Why does each eye have a blind spot?
8. CHALLENGE If every eye has a blind spot, why do you not see a dark hole in the world all day long? Give two reasons.

COMMON MISTAKES

- Thinking the pupil is a black part of the eye. It is an opening, a hole, and it looks black because the inside of the eye is dark.
- Thinking the eye sends out something to “reach” objects. Light travels from the object into the eye; the eye receives light and sends nothing out.
- Thinking we “see” with the eye alone. The eye makes the picture, but the brain reads the signals from the optic nerve and makes sense of them, including turning the upside-down image into the world as it is.

Make it a game · Path of Light Relay. Write CORNEA, PUPIL, LENS, RETINA, OPTIC NERVE and BRAIN on six cards and lay them in a line across the room. Your parent shines a flashlight and calls “Go!” You carry a paper “light ray” along the cards in the right order, saying what each part does at each card. Then your parent shuffles the cards and you set them back in order against a timer. Beat your best time three rounds in a row.

Scripture. “He that planted the ear, shall he not hear? he that formed the eye, shall he not see?” (Psalm 94:9, KJV)

The more we learn about the eye, with its lens, iris and millions of rods and cones, the more sense this verse makes. Seeing is a gift from the God who sees all.

Practice answers

1. The iris. It is a ring of muscle that makes the pupil smaller in bright light and larger in dim light.
2. The retina. Rods work in dim light and see in shades of gray; cones need brighter light and see color.
3. Cornea, pupil, lens, retina. The optic nerve carries the signals to the brain.
4. (a) $7 - 3 = 4$ mm. (b) From 0 to 10 seconds, when it grew 2 mm (from 10 to 30 seconds it grew 1 mm, and from 30 to 60 seconds it grew 1 mm).
5. It is the tapetum. It reflects light back through the retina, giving the rods a second chance to catch it, so the cow sees better in dim light. People do not have one.
6. Change: the brightness of the light (for example, dim room, room light, bright window). Keep the same: the same person, the same ruler and measurer, the same distance from the light, the same wait time (such as 1 minute) before each measurement. Measure: pupil width in millimeters, three times at each brightness. Control: the ordinary room light measurement, used for comparison.
7. The optic nerve leaves the back of the eye at one spot, and there are no rods or cones there, so light falling on that spot is not sensed.
8. First, with both eyes open, each eye sees the part the other eye misses, because their blind spots fall on different parts of the scene. Second, even with one eye closed, the brain fills in the missing spot with the colors and patterns around it, and the eyes are always moving a little, so we do not notice the gap.

7.2 The Ear

OBJECTIVES

- Trace a sound from the air through the outer, middle and inner ear to the brain, naming the eardrum, the three tiny bones, the cochlea and the auditory nerve.
- Explain that sound is a vibration, use the speed of sound to find distances, and tell how the semicircular canals help us keep our balance.
- Carry out a fair test of how well we locate sounds with two ears and with one, and record the results in a table.

Warm-up. Hold one end of a metal spoon tied to the middle of a 1-meter (about 3-foot) string. Wrap the two ends of the string around your fingers and touch your fingers gently to the outside of your ears, not inside. Let the spoon swing and bump a table. What do you hear? Now try it with your fingers away from your ears. What carried the sound the first time?

Video. Coming soon. How the ear hears and how the inner ear helps balance, for children; search SciShow Kids, Homeschool Pop (Alternate), Science Max, Moody Science classics, the Smithsonian, and children's hospital or audiology channels showing the eardrum, the three ear bones and the cochlea.

KEY TERMS

vibration
A quick back-and-forth movement. Every sound starts as a vibration that pushes on the air.

eardrum
A thin, tight skin at the end of the ear canal that vibrates when sound waves strike it.

ossicles
The three tiny bones of the middle ear (the hammer, anvil and stirrup) that carry vibrations from the eardrum to the inner ear.

cochlea
The snail-shaped, fluid-filled tube of the inner ear, lined with hair cells that turn vibrations into nerve signals.

semicircular canals
Three curved, fluid-filled tubes in the inner ear that sense turning and help you keep your balance.

decibel (dB)
The unit used to measure how loud a sound is. A whisper is about 30 dB; ordinary talking is about 60 dB.

CORE IDEAS

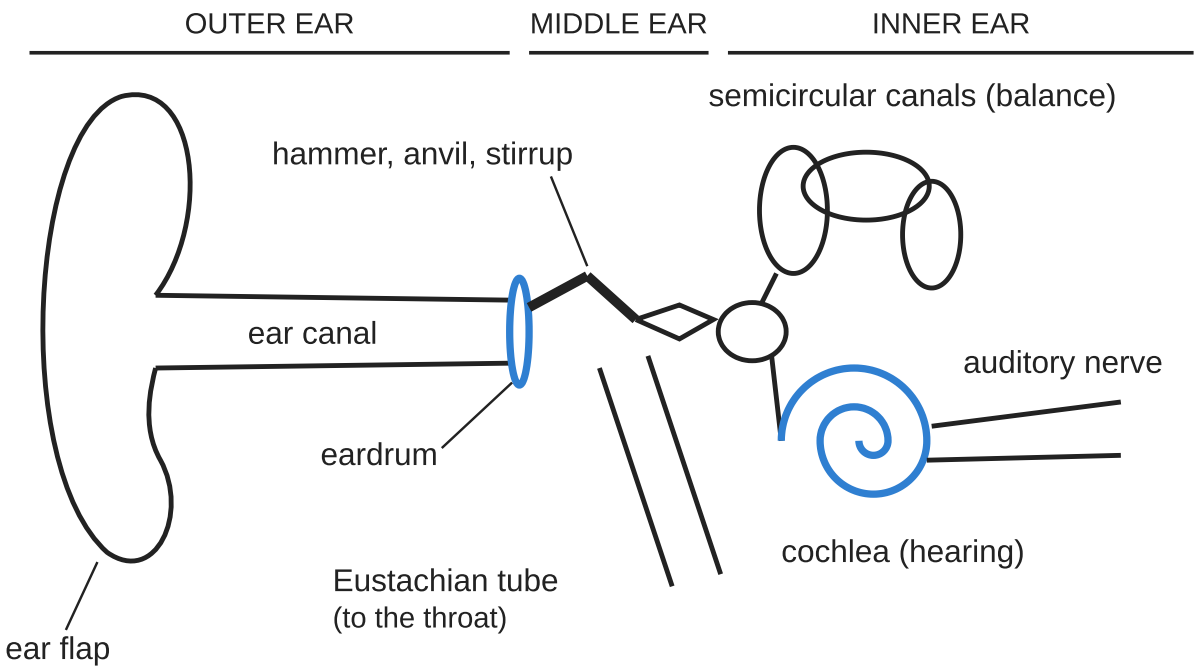
The story. In 1874 a young Scottish-born teacher named Alexander Graham Bell was working in Boston, teaching deaf students to speak. His own mother was nearly deaf, and he spent his life helping people who could not hear. Bell wanted to *see* what sound does inside the ear. With the help of a Boston ear doctor, Clarence Blake, he obtained a real human ear that had been kept for study at a medical school. He attached a thin straw to the tiny bones inside, so that it touched a piece of smoked glass. When Bell spoke or sang into the ear, the eardrum shook, the little bones moved, and the straw traced wavy lines in the soot: a picture of his voice. Bell was amazed that such a thin, delicate eardrum could move such heavy bones. If a thin skin could do that, he thought, perhaps a thin metal plate could turn the voice into an electric current. Less than two years later, in March 1876, he spoke the first clear sentence ever sent by telephone, calling his assistant Thomas Watson to come to him.

How they figured it out. Doctors had cut open ears for centuries and had named the parts, but the inner ear is tiny, buried in the hardest bone of the skull and filled with fluid, so how it works was hard to see. In the 1900s a Hungarian scientist named Georg von Békésy spent many years making careful models of the cochlea and watching real ones under the microscope. He showed that different pitches make different places along the cochlea shake the most, high notes near the start and low notes near the far end. He received the Nobel Prize in 1961 for this work.

The big idea. Every sound begins as a **vibration** that pushes the air into waves. The *outer ear*, the flap you can see, catches those waves and funnels them down the ear canal to the **eardrum**, which vibrates. In the *middle ear*, three tiny bones called the **ossicles** (the hammer, the anvil and the stirrup) pass the vibrations along. The stirrup is the smallest bone in your body, only about 3 mm (about 1/8 inch) long. It pushes on the *inner ear*, where the fluid in the **cochlea** ripples and bends thousands of tiny hair cells. They turn the motion into nerve signals, and the auditory nerve carries them to the brain, which hears them as music, speech or a barking dog. A thin tube, the Eustachian tube, runs from the middle ear to the back of the throat. When it opens to even out the air pressure, your ears “pop.”

Your balance organs. Right beside the cochlea are three loops called the **semicircular canals**, set at right angles to one another like the floor and two walls of a room corner. They are filled with fluid. When you turn your head, the fluid lags behind and bends tiny hairs, telling your brain which way you are turning. When you spin around and suddenly stop, the fluid keeps swirling for a moment, and that is why the room seems to keep spinning.

In the world today. Sound in air travels about 343 meters (about 1,125 feet) every second, far slower than light. That is why you see lightning before you hear thunder, and why you can find the distance to a storm by counting seconds. Loudness is measured in **decibels**. Sounds of about 85 dB or more, such as a lawn mower, can harm the hair cells if you hear them for a long time, and hair cells that are destroyed do not grow back. That is why people who run loud machines wear ear protection. God made the hearing ear (Proverbs 20:12); wise people take care of it.



The three parts of the ear. Sound travels from the ear flap down the ear canal to the eardrum, across the three tiny bones, and into the cochlea; the semicircular canals sense balance.

PICTURE STUDY



Alexander Graham Bell Opening the Telephone Line from New York to Chicago, Unknown photographer, 1892 · Photograph · Library of Congress, Washington, D.C.

Sixteen years after his first telephone call, Alexander Graham Bell was invited to open the new long-distance line between New York and Chicago, more than 1,100 km (about 700 miles) apart. This photograph shows him speaking into the mouthpiece while officials of the telephone company look on.

Bell always remembered that his invention grew out of his work with the deaf and his study of the human ear. The telephone works the way your ear does, but in reverse and then forward again: a thin plate vibrates with the voice, the vibrations become an electric signal, and at the other end another thin plate turns the signal back into vibrations in the air.

Look closely

- Find Bell. How can you tell he is the most important person in the picture?
- Look at the mouthpiece. What shape is it, and why might that shape help catch the sound of a voice?
- Look at the men standing behind. How do they seem to feel about this moment?
- Find any wires, boxes or other parts of the telephone you can see.

Talk about it

1. How is the cone-shaped mouthpiece like the flap of your outer ear?
2. Bell's first telephone sentence went only into the next room. This call went from New York to Chicago. Why do you think people gathered to watch?
3. How did Bell's care for deaf people lead to an invention that changed everyone's life?

> **Safety first.** Never put anything into your ear canal, including fingers, cotton swabs, pencils or the ends of the string; touch only the outside of the ear. Keep all test sounds soft (a click of two spoons is plenty) and never shout, bang a pan or blow a whistle near anyone's ear. A blindfolded partner should sit still in a clear space, with no furniture to bump.

EXPERIMENT: WHERE IS THAT SOUND? TWO EARS OR ONE

Your two ears are on opposite sides of your head. Does that help you tell where a sound is coming from? In this experiment you will find out by counting how many times you can point to a sound correctly with two ears, and then with one ear gently covered. You will also build a model eardrum to see sound make something move.

You will need

- A blindfold or scarf
- A chair in the middle of an open room
- Two metal spoons (to click together softly)
- Painter's tape and a marker (to mark 8 spots on the floor)
- A tape measure
- For the model eardrum: a bowl, plastic wrap, a rubber band, a pinch of dry rice and a pot lid or pan
- Lab notebook and pencil

Steps

1. **Question.** Can you point to where a sound comes from more accurately with two ears than with one?
2. **Prediction.** Write how many out of 10 you think you will get right each way.
3. Set the chair in the middle of the room. With tape, mark 8 spots in a circle around it, each 2 meters (about 6.5 feet) from the chair: front, back, left, right and the four spots in between. Number them 1 to 8.
4. Make a table with three columns: Trial, Two ears (right or wrong), One ear covered (right or wrong).
5. **Two ears.** Sit blindfolded. Your partner stands quietly on a spot chosen by rolling a die or drawing a number, clicks the spoons once softly, and you point. Your partner records right or wrong. Do 10 trials.
6. **One ear.** Cup your hand flat and firmly over the outside of one ear (do not push anything in). Do 10 more trials the same way.
7. **What we change:** two ears or one ear. **What we keep the same:** the same spots, the same distance, the same soft click, the same listener. **What we measure:** how many out of 10 you point to correctly.
8. Count your correct answers each way and draw a bar graph. Which spots were hardest? Were front and back ever mixed up?
9. **Model eardrum.** Stretch plastic wrap tightly over the bowl and hold it with the rubber band. Sprinkle a few grains of rice on top. Hold a pot lid about 30 cm (1 foot) away and tap it with a spoon. Watch the rice jump as the “eardrum” vibrates.
10. Write two sentences: What did your results show, and how is the plastic wrap like your eardrum?

Tips

- A sound off to one side reaches the nearer ear a tiny bit sooner and a little louder. Your brain uses that difference to find the direction.
- Sounds straight in front and straight behind reach both ears at the same time, so people often mix them up. Turning your head a little helps.
- If you can, repeat the whole test with a second listener and compare results.

Check your work

- I can trace sound from the ear flap to the brain and name each part on the way.
- I kept everything the same except the one thing I changed (two ears or one).
- I recorded 10 trials each way and made a bar graph of the results.

NATURE NOTEBOOK

1. Draw the ear diagram from memory, color the outer ear, middle ear and inner ear in three colors, and label the eardrum, the three tiny bones, the cochlea and the semicircular canals.
2. Sit outdoors for five quiet minutes with your eyes closed. List every sound you hear and draw an arrow on a circle to show which direction each came from.

3. Draw the stirrup bone at its real size (about 3 mm long) and then draw it again ten times bigger. Write one sentence about why it matters even though it is so small.

> **From history.** In 1817 Thomas Hopkins Gallaudet, a minister from Connecticut, and Laurent Clerc, a deaf teacher from France, opened a school for deaf children in Hartford, Connecticut. It was the first lasting school for the deaf in the United States and is now called the American School for the Deaf. Gallaudet had traveled to Europe to learn how deaf children were taught, and he met Clerc in London, visited the Paris school where Clerc taught, and persuaded him to come to America. Clerc taught there for over forty years.

WORKED EXAMPLES

Example 1. During a summer storm, Hannah sees a flash of lightning and counts 6 seconds before she hears the thunder. Sound travels about 343 meters each second. About how far away was the lightning, in meters and kilometers? About how many miles is that?

1. Light reaches Hannah almost instantly, so the 6 seconds is the time the sound took to travel.
2. Distance = speed × time = 343 m per second × 6 seconds = 2,058 m.
3. Change to kilometers: 2,058 m ÷ 1,000 = about 2.1 km.
4. Change to miles: 1 mile is about 1,609 m, so 2,058 ÷ 1,609 ≈ 1.3 miles.
5. A handy rule: about 3 seconds for each kilometer, or about 5 seconds for each mile.

Answer: About 2,058 m, or about 2 km (about 1.3 miles) away.

Example 2. Samuel stands in a field and claps toward the flat wall of a big barn. He hears the echo 0.4 seconds later. Using 343 meters per second for the speed of sound, how far away is the barn wall?

1. An echo goes to the wall and comes back, so the sound traveled the distance twice.
2. Total distance traveled: 343 m per second × 0.4 seconds = 137.2 m.
3. Distance to the wall is half of that: 137.2 m ÷ 2 = 68.6 m.
4. In feet: 68.6 m × 3.28 ≈ 225 feet.

Answer: About 69 m (about 225 feet).

PRACTICE

1. EASY Name the three tiny bones of the middle ear, in order from the eardrum inward.
2. EASY What does the cochlea do?

3. MEDIUM You count 9 seconds between a lightning flash and its thunder. Using 343 meters per second, about how far away was the lightning?
4. MEDIUM Read the table. Whisper: 30 dB. Ordinary talking: 60 dB. Lawn mower: 90 dB. Chain saw: 110 dB. (a) How many decibels louder is a lawn mower than ordinary talking? (b) Sounds of about 85 dB or more can harm hearing over time. Which sounds in the table are in that range?
5. MEDIUM When an airplane climbs or lands, your ears sometimes “pop.” Which part of the ear is at work, and what is it doing?
6. HARD Design a fair test of whether cupping your hand behind your ear helps you hear a soft sound, such as a ticking kitchen timer. Name the variable you change, what you keep the same, what you measure and your control.
7. HARD Why do you feel dizzy for a moment after you spin around and stop suddenly?
8. CHALLENGE Explain in two or three sentences why two ears help you tell where a sound is coming from.

COMMON MISTAKES

- Thinking the ear is just the flap on the side of the head. The flap only catches sound; the real work of hearing is done deep inside the skull, in the cochlea.
- Thinking sound can travel through empty space. Sound needs something to travel through, such as air, water or solid material; in a vacuum there is no sound.
- Thinking the ear is only for hearing. The semicircular canals in the inner ear are balance organs.

Make it a game · Sound Detective. One player sits blindfolded in the middle of the room. The others take turns making one soft sound (crumpling paper, a spoon on a cup, a page turning, a single snap). The detective must name the sound and point to where it came from. One point for the right sound, one point for the right direction. After each round, the detective tells which part of the ear did the hard work. Switch detectives after five sounds.

Scripture. “The hearing ear, and the seeing eye, the LORD hath made even both of them.” (Proverbs 20:12, KJV)

The eardrum, the three tiny bones and the coiled cochlea all work together in a space smaller than a grape. Solomon reminds us who made them.

Practice answers

1. The hammer (malleus), the anvil (incus) and the stirrup (stapes).
2. It is the fluid-filled, snail-shaped tube in the inner ear. Its hair cells turn vibrations into nerve signals that the auditory nerve carries to the brain.
3. 343 × 9 = 3,087 m, about 3 km (about 1.9 miles).
4. (a) 90 − 60 = 30 dB louder. (b) The lawn mower (90 dB) and the chain saw (110 dB).

5. The Eustachian tube, which connects the middle ear to the back of the throat. It opens to let air in or out so the pressure inside the middle ear matches the pressure outside, and the eardrum can vibrate freely again.
6. Change: hand cupped behind the ear or not. Keep the same: the same timer, the same quiet room, the same listener, and the same starting point. Measure: the greatest distance (in meters) at which the listener can still hear the ticking, walking slowly away, three trials each way. Control: the trials with no hand cupped.
7. The fluid in the semicircular canals keeps swirling for a moment after your head stops. It keeps bending the tiny hairs, so your brain gets a message that you are still turning even though you are not.
8. A sound from one side reaches the nearer ear a tiny bit sooner and a little louder than the farther ear, because the head is in the way. The brain compares the two ears and uses the difference to judge the direction. With one ear covered, that comparison is lost, so finding the sound is harder.

7.3 Taste and Smell

OBJECTIVES

- Name the five basic tastes, describe taste buds and smell receptors, and explain why the old “tongue map” is wrong.
- Explain that flavor is taste and smell working together, and test it with a fair experiment that has a control.
- Record taste-test results in a data table, change them to percents, and read a bar graph.

Warm-up. Look at your tongue in a mirror with a flashlight. Do you see the tiny bumps all over it? Now put one drop of water with a little sugar dissolved in it on the tip of your tongue, then one on the side, then one near the back (as far as is comfortable). Can you taste the sweetness in all three places? Write down what you notice.

Video. Coming soon. How taste buds and the sense of smell work together to make flavor, and the five basic tastes, for children; search SciShow Kids, Homeschool Pop (Alternate), Science Max, Moody Science classics, the Smithsonian, and kitchen-science demonstrations of the jelly-bean and pinched-nose taste test.

KEY TERMS

taste bud
A tiny cluster of taste cells, mostly on the tongue, that senses chemicals dissolved in saliva and sends signals to the brain.

papillae
The small bumps on the tongue that you can see; many of them hold taste buds. (One bump is a papilla.)

basic tastes
The five kinds of taste the tongue senses: sweet, salty, sour, bitter and umami (savory).

olfactory receptors
Smell-sensing cells in a small patch high inside the nose that catch odor molecules floating in the air.

flavor
The whole impression a food gives, made by taste and smell together, along with its texture and temperature.

CORE IDEAS

The story. In 1908 a chemistry professor at Tokyo Imperial University named Kikunae Ikeda was enjoying a simple dish cooked in broth made from *kombu*, a kind of seaweed long used in Japanese cooking. The broth had a rich, savory taste. It was not sweet, not salty, not sour

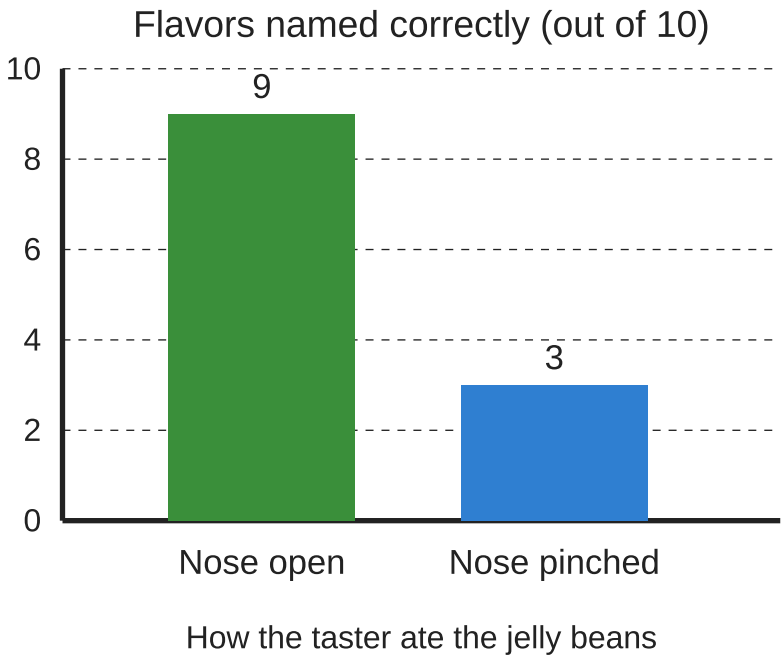
and not bitter. What was it? Ikeda did what a good chemist does. He boiled down a great quantity of kombu, separated its substances one by one, and at last crystallized the one that carried the taste: glutamate. He named the taste *umami*, a Japanese word meaning something like “delicious, savory taste.” You have tasted umami in tomatoes, cheese, mushrooms and meat broth. For many years scientists in Europe and America paid little attention, but later research found taste cells built especially to sense it, and today umami is counted as the fifth **basic taste**.

How they figured it out. Many old textbooks showed a “tongue map”: sweet on the tip, salty and sour on the sides, bitter at the back. Where did it come from? In 1901 a German scientist, David Hänig, carefully dripped weak solutions on different parts of people’s tongues and found that some places were *slightly* more sensitive to certain tastes than others. In 1942 an American, Edwin Boring, redrew Hänig’s numbers as a graph, and later writers turned the graph into a map with neat zones, as if each part of the tongue tasted only one thing. When scientists tested it again, the map failed: every part of the tongue that has taste buds can sense all five tastes. The lesson for young scientists is a good one. Go back to the evidence and test it yourself.

The big idea. Your tongue is covered with small bumps called **papillae**, and many of them hold **taste buds**. You have several thousand taste buds, each a cluster of dozens of taste cells. When food dissolves in saliva, its chemicals touch the taste cells, and they send signals along nerves to the brain. Taste cells wear out and are replaced about every week or two, which is why a burned tongue heals and tastes again. Smell works on molecules in the air. High inside your nose is a patch about the size of a postage stamp holding millions of **olfactory receptors** of about 400 kinds. Together they let you tell apart thousands of different odors. When you chew, odor molecules from the food also rise from the back of your mouth into your nose. Your brain blends taste and smell into one experience: **flavor**. That is why food seems bland when you have a stuffy nose.

Try it and see. You can prove that smell makes much of flavor with a bag of mixed jelly beans. Pinch your nose shut, chew a bean you did not see, and try to name the flavor. You will probably taste only “sweet” and perhaps “sour.” Let go of your nose, and suddenly it is cherry or lemon. In this lesson’s project you will run that test as a real experiment, with a control and a data table.

God’s handiwork. Taste and smell are guards as well as delights. Bitterness warns of many poisons, and a sour, rotten smell warns of spoiled food. The gas company adds a strong, unpleasant smell to natural gas, which has no smell of its own, so that people will notice a leak. The smell of smoke can wake a sleeping family. Yet God did not make eating a mere chore: He filled the world with strawberries, fresh bread and cinnamon. The psalmist uses taste to invite us to know God Himself: “O taste and see that the LORD is good” (Psalm 34:8).



Results of one jelly bean test: far fewer flavors were named correctly with the nose pinched shut.

PICTURE STUDY



Basket of Fruit, Michelangelo Merisi da Caravaggio, about 1599 · Oil on canvas · Pinacoteca Ambrosiana, Milan, Italy

The Italian painter Caravaggio painted this basket of fruit at eye level, as if it were sitting on a shelf right in front of you. It is one of the most famous still-life paintings ever made, and it hangs in a library and art gallery in Milan that was founded by Cardinal Federico Borromeo, who owned the painting.

Caravaggio did not make the fruit perfect. Some leaves are fresh and green; others are dry and curling. Look closely at the apple. The painter wanted us to see fruit as it really is, the way a scientist does: ripe, beautiful and already beginning to spoil.

Look closely

- Name every kind of fruit you can find in the basket.
- Find the apple. What small mark on it tells you something has been at work inside?
- Compare the leaves. Which look fresh, and which look dry and old?
- Which fruit do you think would smell the strongest if you could lean in close?

Talk about it

1. If you could only smell this basket, not see it, how might you tell ripe fruit from spoiled fruit?
2. Why might the painter have included a spotted apple and withered leaves instead of making everything perfect?
3. Which of your five senses does this painting make you think of besides sight?

> **Safety first.** Check with a parent about any food allergies before the taste tests. Use only clean, fresh food from the kitchen, and use a clean spoon or toothpick for each taster. In science, never taste or sniff directly an unknown substance; when a scientist must smell something, she gently waves the air above it toward her nose.

EXPERIMENT: THE JELLY BEAN TEST: DOES SMELL MAKE FLAVOR?

Is flavor mostly in your tongue or in your nose? In this experiment a blindfolded taster will try to name jelly bean flavors with the nose open and with the nose pinched shut. You will record the results, change them to percents and draw a bar graph.

You will need

- A bag of jelly beans with many flavors (or small pieces of fruit such as apple, pear, banana, orange and strawberry)
- A blindfold or scarf
- A small plate and a list of the flavors in the bag
- A cup of water for rinsing the mouth between tastes
- Lab notebook, pencil and colored pencils

Steps

1. **Question.** Can a person name a flavor as well with the nose pinched shut as with the nose open?
2. **Prediction.** Write how many out of 10 you think the taster will name correctly each way.

3. Make a table with three columns: Trial, Nose open (right or wrong), Nose pinched (right or wrong).
4. **Nose open (the control).** Blindfold the taster. The helper hands over one jelly bean at a time without saying the flavor. The taster chews and names it. Record right or wrong. Rinse with water. Do 10 beans.
5. **Nose pinched.** Do 10 more beans the same way, but the taster pinches the nose shut before the bean goes in and keeps it pinched until after answering.
6. **What we change:** nose open or pinched. **What we keep the same:** the same taster, the same kind of jelly beans, a blindfold every time, a rinse between beans. **What we measure:** how many flavors out of 10 are named correctly.
7. Change each score to a percent: number right ÷ 10 × 100.
8. Draw a bar graph with two bars, one for each way. Label the axes.
9. Bonus: let the taster pinch the nose, chew a bean, guess, and then let go while still chewing. Write what happens.
10. Write a conclusion of two or three sentences that answers the question and uses your numbers.

Tips

- The blindfold keeps the color of the bean from giving the answer away. That is part of keeping the test fair.
- If you have several tasters, add up all their results to get a bigger, more trustworthy sample.
- Expect the taster to still notice “sweet” or “sour” with the nose pinched: the tongue tastes those, but the nose recognizes cherry, lime or cinnamon.

Check your work

- I can name the five basic tastes.
- I used a control (nose open) and changed only one thing.
- I changed my results to percents and showed them on a labeled bar graph.

NATURE NOTEBOOK

1. Draw your tongue as you saw it in the mirror, with its papillae. Write a sentence correcting the old “tongue map.”
2. Make a chart with five columns: sweet, salty, sour, bitter, umami. Under each, draw or list three foods from your kitchen that have that taste.
3. Go on a smell walk around your house or yard. Draw and name five things you smelled and describe each smell in your own words (sharp, sweet, earthy, and so on).

> **From history.** How can the nose tell apart thousands of smells? In 1991 two American scientists, Linda Buck and Richard Axel, discovered the large family of genes that build the smell receptors in the nose. They showed that each receptor cell carries one kind of

receptor and that the brain recognizes a smell from the pattern of receptors it sets off, much as many letters spell many words. They received the Nobel Prize in 2004.

WORKED EXAMPLES

Example 1. In the jelly bean test, Grace named 9 of 10 flavors correctly with her nose open and 3 of 10 with her nose pinched. Change each score to a percent. How many percentage points lower was her score with her nose pinched?

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

1. Nose open: 9 ÷ 10 = 0.9, and 0.9 × 100 = 90%.
2. Nose pinched: 3 ÷ 10 = 0.3, and 0.3 × 100 = 30%.
3. Difference: 90% − 30% = 60 percentage points.
4. Conclusion: Grace could name far fewer flavors without her sense of smell, so smell supplies much of what we call flavor.

Answer: 90% with the nose open, 30% with the nose pinched: 60 percentage points lower.

Example 2. Peter makes a row of sugar-water cups to find the weakest sweetness he can taste. Cup A has 10 g of sugar in every 100 mL of water. He makes each next cup half as strong as the one before by mixing equal amounts of the last cup and plain water: cups B, C, D and E. He tastes sweetness in A, B, C and D, but not in E. How much sugar is in each 100 mL of cup D? How many times weaker is D than A?

1. Cup A: 10 g per 100 mL.
2. Cup B: 10 ÷ 2 = 5 g per 100 mL.
3. Cup C: 5 ÷ 2 = 2.5 g per 100 mL.
4. Cup D: 2.5 ÷ 2 = 1.25 g per 100 mL.
5. Cup E: 1.25 ÷ 2 = 0.625 g per 100 mL (Peter could not taste this one).
6. Times weaker: 10 ÷ 1.25 = 8, since it was halved three times (2 × 2 × 2 = 8).

Answer: Cup D has 1.25 g of sugar in each 100 mL; it is 8 times weaker than cup A.

PRACTICE

1. EASY List the five basic tastes and give one food for each.
2. EASY Where in the body are the olfactory receptors, and what do they sense?
3. MEDIUM Why does food taste bland when you have a bad cold?
4. MEDIUM Four students did the jelly bean test with 5 beans each way. Anna: open 5, pinched 2. Ben: open 4, pinched 1. Clara: open 5, pinched 2. David: open 4, pinched 1. (a) Find the total correct each way out of 20. (b) Change each total to a percent.

5. MEDIUM A worksheet shows a tongue with “sweet” only on the tip and “bitter” only at the back. What is wrong with it?
6. HARD Design a fair test to find out whether a blindfolded person with a pinched nose can tell a piece of apple from a piece of pear. Name the variable you change, what you keep the same, what you measure and your control.
7. HARD Natural gas has no smell of its own. Why do gas companies add a strong, unpleasant smell to it?
8. CHALLENGE Taste cells are replaced about every week or two. Explain why this is a good design, and tell what this means for a person who burns her tongue on hot soup.

COMMON MISTAKES

- Believing the tongue map, with each taste in its own zone. All parts of the tongue with taste buds sense all five tastes.
- Thinking flavor comes only from the tongue. Smell supplies much of flavor; the tongue alone senses only the five basic tastes.
- Thinking “spicy hot” is a taste. The burn of a chili pepper is sensed by pain and heat nerves in the mouth, not by taste buds.

> **Make it a game · Mystery Smell Jars.** A parent puts a small amount of something with a strong smell into each of six covered cups: for example cinnamon, coffee, orange peel, vanilla, an onion slice and peppermint. Poke a few holes in each cover. Blindfolded players take turns sniffing (waving the air toward the nose) and guessing. One point for each correct answer, and a bonus point for saying whether the food’s main taste would be sweet, salty, sour, bitter or umami.

> **Scripture.** “O taste and see that the LORD is good: blessed is the man that trusteth in him.” (Psalm 34:8, KJV)

David knew that tasting is a way of knowing something for yourself, not just hearing about it. God invites us to know His goodness that personally.

Practice answers

1. Sweet (honey), salty (pretzels), sour (lemon), bitter (unsweetened cocoa or coffee), umami (meat broth, tomatoes or cheese). Other correct foods are fine.
2. In a small patch high inside the nose. They sense odor molecules carried in the air.
3. A stuffy nose keeps odor molecules from reaching the olfactory receptors. The tongue can still sense sweet, salty, sour, bitter and umami, but the smell part of flavor is missing.
4. (a) Open: 5 + 4 + 5 + 4 = 18 out of 20. Pinched: 2 + 1 + 2 + 1 = 6 out of 20. (b) Open: 18 ÷ 20 = 90%. Pinched: 6 ÷ 20 = 30%.
5. It is the old tongue map, which grew from a misreading of Hänig’s 1901 measurements. Every part of the tongue that has taste buds can sense all five basic tastes; the differences between areas are very small.
6. Change: nose pinched or nose open. Keep the same: pieces of equal size, both peeled, the same temperature, a blindfold every time, a water rinse between pieces, and the same order

of trials decided by a coin flip. Measure: number of correct answers out of 10 each way. Control: the trials with the nose open.

7. So that people will smell a leak and get out and call for help before the gas can cause a fire or explosion. Our sense of smell works as a warning system.
8. Taste cells are worn by hot, cold, sharp and acidic foods every day, so replacing them keeps the sense of taste working all through life. After a burn, the damaged cells are replaced with new ones, so within a week or two the person can usually taste normally again.

7.4 Touch Map

OBJECTIVES

- Explain that the skin holds different kinds of receptors for light touch, pressure, heat, cold and pain, and that some places have far more touch receptors than others.
- Measure the two-point threshold on several parts of the body, as Ernst Weber did, and make a touch map with a data table and a bar graph.
- Tell how Louis Braille's raised-dot alphabet and Helen Keller's story depend on the sensitive fingertips God gave us.

Warm-up. Close your eyes. Have someone place a coin, a button, a paper clip and a bottle cap one at a time in your palm, and try to name each one without moving your fingers. Then try again, this time feeling each object with your fingertips. Which way was easier? Why do you think so?

Video. Coming soon. The sense of touch, touch receptors in the skin and the two-point discrimination test, plus how Braille works, for children; search SciShow Kids, Homeschool Pop (Alternate), Science Max, Moody Science classics, the Smithsonian, the Perkins School for the Blind, and the American Printing House for the Blind.

KEY TERMS

skin
The body's largest organ. It covers and protects the body and holds millions of nerve endings that sense the world.

touch receptor
A nerve ending in the skin that senses touch, pressure or vibration and sends a signal to the brain. Other receptors sense heat, cold and pain.

two-point threshold
The smallest distance between two points touching the skin at which a person can still feel two points instead of one.

sensitivity
How well a part of the body can sense small things. More receptors packed close together means higher sensitivity and a smaller two-point threshold.

Braille
A system of reading and writing with raised dots that blind people read with their fingertips, invented by Louis Braille.

CORE IDEAS

The story. In 1834 Ernst Heinrich Weber, a professor of anatomy at the University of Leipzig in Germany, published a short book in Latin called *De Tactu* ("On Touch"). Weber had asked

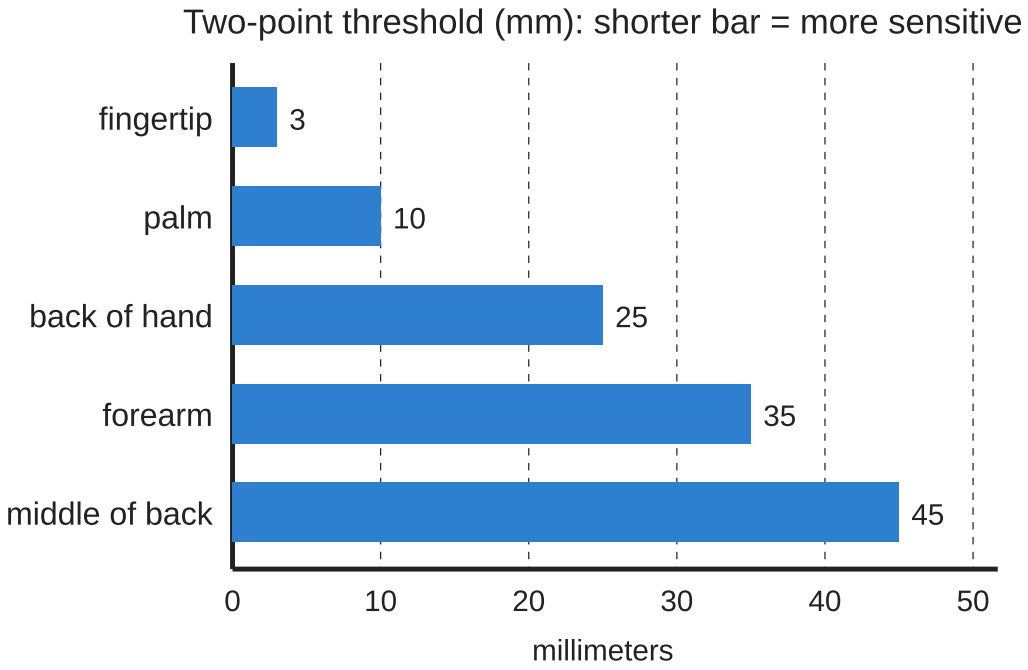
a simple question: is every part of the skin equally good at feeling? To find out, he used a drawing compass, the kind with two points whose distance apart can be set exactly. With a person's eyes closed, he touched the skin with both points at once and asked whether the person felt one point or two. Then he moved the points closer together until the person could no longer tell. That smallest distance is now called the **two-point threshold**.

How they figured it out. Weber tested place after place and found enormous differences. On the tip of the tongue, two points only about 1 mm apart could be told apart. On the fingertips it was about 2 mm, on the lips a few millimeters, on the palm about 1 cm, and on the middle of the back several centimeters, more than 25 times as far apart as on a fingertip. Two pencils pressed on your back with a whole thumb's width between them may feel like one. Careful testers also touch with only one point now and then, to make sure people are not simply guessing "two" each time. Scientists and doctors still use Weber's method, and you will use it in this lesson's project.

The big idea. Your **skin** is packed with nerve endings. Some sense light touch, some deep pressure, some vibration, some heat, some cold and some pain. They are not spread evenly. Fingertips, lips and the tongue are crowded with **touch receptors**, so they have high **sensitivity** and a small two-point threshold. The back and upper arm have few, spaced far apart. If two points touch the area served by just one receptor, the brain gets only one message and you feel one point. In the brain itself there is a strip that receives touch messages from every part of the body, and the fingertips, lips and tongue have far bigger shares of it than the back does. A map of how sensitive each part of your body is, then, looks very different from a map of how big each part is.

In the world today. Louis Braille was born in 1809 in the French village of Coupvray. At three years old he was hurt by a tool in his father's harness workshop, and before long he was blind in both eyes. At the Royal Institute for Blind Youth in Paris he learned of a code of raised dots a French army officer had made for sending messages at night. It was too big and clumsy, so young Louis improved it. By about age 15 he had worked out a system in which every letter fits in a small **cell** of up to six dots, two columns of three. The dots are only about 2.5 mm apart, just right for the fingertip's tiny two-point threshold. Braille is still used all over the world, in books, on elevator buttons and on medicine boxes.

God's handiwork. Touch is the first sense to be at work in a baby and one of the most needed. Pain is unpleasant, but it is a gift: it tells you to pull your hand from a hot stove. Fingertips sensitive enough to read dots 2.5 mm apart let a blind child read the Bible for herself. When the apostle John wanted to show that Jesus was real and truly raised, he wrote of what "our hands have handled" (1 John 1:1).



One student's touch map as a bar graph. A shorter bar means a more sensitive place.

PICTURE STUDY



Helen Keller with Anne Sullivan, Unknown photographer, 1888 · Photograph · New England Historic Genealogical Society, Boston, Massachusetts; widely reproduced

Helen Keller became blind and deaf from an illness before she was two years old. In 1887 a young teacher, Anne Sullivan, came to her home in Tuscumbia, Alabama. Anne spelled words into Helen's palm with her fingers. One day at the water pump, as cool water ran over one of Helen's hands, Anne spelled w-a-t-e-r into the other, and Helen suddenly understood that everything has a name. She learned many words that same day.

This photograph was taken about a year later, during a summer on Cape Cod in Massachusetts. Helen went on to read Braille in English, French, German, Latin and Greek, to graduate from Radcliffe College, and to write books, all through the sense of touch.

Look closely

- Find Helen and Anne. Who do you think is the teacher, and who is the student?
- Look at their hands. Why would hands matter so much to these two?
- Look at their faces and how close together they sit. What do you think they felt about each other?
- What clues in the clothing and the photograph tell you this picture is old?

Talk about it

1. Helen could not see or hear. Which senses did she use to learn about the world?
2. Why would Anne spell words into Helen’s palm and fingers rather than her arm or back?
3. What does Helen’s story teach about patience and about never giving up on a person?

> **Safety first.** Use two blunt points, such as the ends of a paper clip bent into a U or two dull pencils. Never use pins, needles or sharp compass points. Press just hard enough to be felt, never hard enough to hurt or mark the skin, and stay away from the eyes and face. Test only on hands, arms, the back of the neck and the back (over a thin shirt is fine).

EXPERIMENT: MY TOUCH MAP

Like Ernst Weber, you will measure the two-point threshold on five places on the body. You will record the results in a table, make a bar graph, and color a body outline to make your own touch map.

You will need

- A large paper clip bent into a U shape (or two dull pencils held together with a rubber band)
- A metric ruler with millimeter marks
- A blindfold, or a partner who keeps eyes closed
- A simple outline drawing of a person (front and back)
- Colored pencils
- Lab notebook and pencil

Steps

1. **Question.** Which parts of the body are most sensitive to touch, and how big are the differences?

2. **Prediction.** Number these five places from most sensitive to least: fingertip, palm, back of hand, forearm, middle of the back.
3. Make a table with columns: Body part, Trial 1, Trial 2, Trial 3, Average (mm).
4. Start with the paper-clip points about 50 mm apart, measured with the ruler. Touch the first body part gently with both points at the same moment. Ask, “One or two?”
5. Squeeze the points closer, a few millimeters at a time, and test again. The two-point threshold is the smallest distance at which your partner still says “two.” Record it.
6. Mix in some touches with *only one point*, so you know your partner is not guessing. If your partner says “two” when only one point touched, do that step over.
7. Do three trials on each body part and find the average.
8. **What we change:** the place on the body. **What we keep the same:** the same tool, the same gentle pressure, the same partner, eyes closed every time. **What we measure:** the two-point threshold in millimeters.
9. Draw a bar graph of your averages. Then color your body outline: red for the most sensitive places, orange for the middle, yellow for the least.
10. Write a conclusion: Which place was most sensitive? Least? How many times bigger was the largest threshold than the smallest?

Tips

- Touch both points down at exactly the same moment; if one lands first, it will feel like two touches.
- Results differ from person to person and from trial to trial. That is why you do three trials and average.
- Switch roles and test your partner, then compare your two touch maps.

Check your work

- I can explain what the two-point threshold is and why it differs from place to place.
- I used one-point “check” touches to keep the test honest.
- I averaged three trials for each place and made a bar graph and a colored touch map.

NATURE NOTEBOOK

1. Draw your hand at actual size by tracing it. On each fingertip and on the palm, write your measured two-point threshold.
2. Write your first name in Braille. Draw each six-dot cell as two columns of three circles and fill in the raised dots. (Use a Braille alphabet chart from a library book or from the American Printing House for the Blind.)
3. Go outdoors with your eyes closed and a parent guiding you. Feel five things (bark, a leaf, a stone, grass, moss) with your fingertips. Draw each and write two words for how it felt.

> **From history.** In the 1930s and 1940s a surgeon named Wilder Penfield, working in Montreal, Canada, operated on patients with a kind of seizure. Because the brain itself

feels no pain, the patients could stay awake while he gently touched different spots on the surface of the brain with a tiny electric probe. A patient might report a tingling feeling in the thumb or in the lip. Penfield carefully recorded every answer and drew a map of the strip of brain that receives touch messages. His drawings showed the hands, lips and tongue taking up much more of that strip than the back or legs, just as Weber's compass tests would lead you to expect.

WORKED EXAMPLES

Example 1. Lydia measured the two-point threshold on her palm three times: 9 mm, 11 mm and 10 mm. What is her average? The dots in a Braille cell are about 2.5 mm apart. Could Lydia read Braille with her palm? Explain.

1. Add the three trials: 9 + 11 + 10 = 30 mm.
2. Divide by the number of trials: 30 ÷ 3 = 10 mm.
3. Compare: 10 mm is 4 times as large as 2.5 mm (10 ÷ 2.5 = 4).
4. Two dots 2.5 mm apart on her palm would feel like one touch, so she could not tell the dot patterns apart there.

Answer: The average is 10 mm (1 cm, about 0.4 inch). She could not read Braille with her palm, because her palm cannot tell apart points closer than about 10 mm. That is why Braille is read with the fingertips.

Example 2. Use the bar graph of one student's touch map. How many times larger is the two-point threshold on the middle of the back than on the fingertip? Give the back's threshold in centimeters and in inches.

(Use the map or drawing "Read the fingertip and back bars." shown earlier in this lesson.)

1. Read the graph: fingertip = 3 mm; middle of the back = 45 mm.
2. Divide: 45 ÷ 3 = 15.
3. Change to centimeters: 45 mm ÷ 10 = 4.5 cm.
4. Change to inches: 4.5 cm ÷ 2.54 ≈ 1.8 inches.

Answer: The back's threshold is 15 times larger: 4.5 cm, or about 1.8 inches.

PRACTICE

1. EASY What is the two-point threshold?
2. EASY Name three parts of the body that are very sensitive to touch.
3. MEDIUM Use the touch-map bar graph: fingertip 3 mm, palm 10 mm, back of hand 25 mm, forearm 35 mm, middle of back 45 mm. (a) Which place is least sensitive? (b) How many millimeters larger is the forearm threshold than the palm threshold?

4. MEDIUM Why is Braille read with the fingertips and not with the palm or the back of the hand?
5. MEDIUM Besides light touch, name three other things that receptors in the skin can sense.
6. HARD Design a fair test of whether a chilled fingertip is less sensitive than a warm one. Name the variable you change, what you keep the same, what you measure and your control.
7. HARD In the touch-map test, why should the tester sometimes touch with only one point?
8. CHALLENGE A Braille cell has 6 dot places, and each place can be raised or flat. How many different patterns can be made? How many of them have at least one raised dot? (Hint: 1 dot place gives 2 patterns; each new place doubles the number.)

COMMON MISTAKES

- Thinking the whole body feels touch equally well. Receptors are crowded in the fingertips, lips and tongue and spread far apart on the back.
- Thinking touch is just one sense. The skin has different receptors for light touch, pressure, vibration, heat, cold and pain.
- Thinking pain is only bad. Pain is a warning that protects the body, and people who cannot feel pain are often badly hurt without knowing it.

> **Make it a game · Feely Bag Challenge.** A parent hides ten small objects in a pillowcase: for example a walnut, a feather, a key, a marble, a sponge, a pine cone, a spool, a leaf, a shell and a smooth stone. Reach in and identify each object by touch alone, using only your fingertips. Score one point for each object named correctly and a bonus point for naming one thing you felt that helped (rough, smooth, cold, soft, pointed). Then try again using only the back of your hand and compare scores.

> **Scripture.** “That which was from the beginning, which we have heard, which we have seen with our eyes, which we have looked upon, and our hands have handled, of the Word of life;” (1 John 1:1, KJV)

John names the senses of hearing, sight and touch as his witnesses. The apostles did not follow a made-up story; they knew Jesus with their own senses.

Practice answers

1. The smallest distance between two points touching the skin at which a person can still feel two separate points.
2. The fingertips, the lips and the tip of the tongue.
3. (a) The middle of the back (45 mm). (b) 35 − 10 = 25 mm larger.
4. The fingertips have many touch receptors packed close together, so they can tell apart dots only about 2.5 mm apart. The palm and the back of the hand have larger thresholds, so the dots would blur into one touch.
5. Any three of: pressure, vibration, heat (warmth), cold and pain.

6. Change: the temperature of the fingertip (held in ice water for 1 minute, or not chilled). Keep the same: the same finger, the same person, the same paper-clip tool, the same gentle pressure, eyes closed, three trials each. Measure: the two-point threshold in millimeters. Control: the warm, unchilled fingertip.
7. To check that the person is not just guessing or always saying “two.” If the person says “two” when only one point touched, the answer cannot be trusted. This makes the results more honest and reliable.
8. 2 × 2 × 2 × 2 × 2 × 2 = 64 patterns. One of them has no raised dots (a blank), so 63 patterns have at least one raised dot, plenty for all the letters, numbers and punctuation marks.

Unit 7 review

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

1. (5 pts) Put these parts of the eye in the order light passes through them, and tell the job of each: retina, cornea, lens, pupil.
2. (5 pts) What did Christoph Scheiner see when he looked at the back of an animal’s eye, and why did it look that way?
3. (5 pts) A student measures the distance at which a dot disappears into her blind spot: 26 cm, 30 cm and 28 cm. Find the average. Why does each eye have a blind spot?
4. (5 pts) Trace a sound from the air to the brain, naming at least five parts of the ear in order.
5. (5 pts) You see lightning and hear thunder 12 seconds later. Sound travels about 343 meters per second. About how far away was the lightning?
6. (5 pts) What do the semicircular canals do, and why do you feel dizzy after spinning?
7. (5 pts) Name the five basic tastes. Who named the fifth one, and where did he find it?
8. (5 pts) In a jelly bean test, a taster named 8 of 10 flavors with the nose open and 2 of 10 with the nose pinched. (a) Change each to a percent. (b) What was the control? (c) What does this show about flavor?
9. (5 pts) What is the two-point threshold? Why is it much smaller on a fingertip than on the back?
10. (5 pts) Design a fair test to find whether the fingertip or the forearm is more sensitive. Name the variable you change, two things you keep the same, and what you measure. Then tell why Braille is read with the fingertips.

Unit project: my book of the senses

Make a small illustrated book with one chapter for each lesson: the eye, the ear, taste and smell, and touch. Each chapter needs a large labeled diagram drawn by you, the story of the scientist from that lesson in your own words, and your experiment: question, prediction, what you changed, what you kept the same, your data table and a bar graph. Finish with your colored touch map and a closing page that copies Proverbs 20:12 and tells, in a short paragraph, which sense you are most thankful for and why.

- **Accuracy**: Diagrams of the eye and ear are correctly drawn and labeled, and explanations of how each sense works are correct.
- **Experiments**: Each experiment names the variable changed, the things kept the same and the control, and the data tables and averages or percents are complete and correctly worked.
- **Graphs and maps**: Bar graphs have titles, labeled axes and correct bar heights; the touch map is colored to match the measured data.
- **Care**: The book is neat, dated and easy to read, with the scientists’ stories told clearly in the student’s own words.

Answer key

1. Cornea (the clear front window that bends light), pupil (the opening that lets light in), lens (focuses light by changing shape), retina (the back layer whose rods and cones sense light and send signals to the optic nerve).
2. He saw a small, sharp picture of the scene in front of the eye, upside down. The cornea and lens bend the light rays so that they cross inside the eye, which turns the image upside down on the retina.
3. (26 + 30 + 28) ÷ 3 = 84 ÷ 3 = 28 cm. The blind spot is where the optic nerve leaves the retina; there are no rods or cones there.
4. Ear flap, ear canal, eardrum, the three tiny bones (hammer, anvil, stirrup), cochlea (hair cells), auditory nerve, brain.
5. 343 × 12 = 4,116 m, about 4 km (about 2.6 miles).
6. They sense turning and help you keep your balance. After you stop spinning, the fluid inside them keeps moving for a moment, so the brain still gets a message that you are turning.
7. Sweet, salty, sour, bitter and umami. Kikunae Ikeda, a chemist in Tokyo, named umami in 1908 after finding glutamate in broth made from kombu seaweed.
8. (a) 80% and 20%. (b) The trials with the nose open. (c) Smell supplies much of flavor; without it the taster could mostly sense only the basic tastes such as sweet and sour.
9. It is the smallest distance between two points on the skin at which a person can still feel two points. Fingertips have many touch receptors packed close together, while the back has few, spread far apart.
10. Change: the body part (fingertip or forearm). Keep the same (any two): the same tool, the same gentle pressure, the same partner, eyes closed, three trials each with some one-point check touches. Measure: the two-point threshold in millimeters. Braille dots are only about 2.5 mm apart, and only sensitive places like the fingertips can tell points that close apart.

UNIT 8

Health and Medicine

All year you have studied the body God made: cells, bones, muscles, heart, lungs, stomach, brain and senses. In this last unit you will learn how people discovered ways to protect that body from its tiny enemies. For most of history, no one knew why wounds rotted, why food spoiled or why sickness passed from one person to the next. Then, in about a hundred years, a handful of careful, patient people changed medicine forever by observing, testing and counting.

You will stand with Edward Jenner in an English country village in 1796 as he tests a milkmaid's saying about cowpox, and look through Louis Pasteur's microscope at the living yeast in a vat of beet juice. You will watch Joseph Lister clean a boy's broken leg with carbolic acid in Glasgow, and follow Ignaz Semmelweis as he discovers that washing hands saves mothers' lives in Vienna. In every lesson you will run a real experiment with a control: a grid model of spreading sickness, yeast and balloons, rotting apples and moldy bread.

Through it all we remember that the body's defenses are God's design, and that the knowledge these people found was given to be used in loving our neighbors. The unit ends with something you can use every day: washing your hands well and giving simple first aid, like the Good Samaritan who "bound up his wounds" (Luke 10:34).

BEFORE YOU BEGIN

- Knows that blood carries white blood cells that help fight germs (Unit 3)
- Knows that the skin covers and protects the body (Unit 7)
- Can multiply and subtract whole numbers and read a simple bar graph
- Can measure length in centimeters with a ruler

MASTERY CHECKLIST

- I can tell how Jenner used cowpox to protect James Phipps from smallpox, and explain how the body remembers a germ.
- I can explain how Pasteur's swan-neck flasks showed that microbes come from other microbes, and what pasteurization does.
- I can tell how Lister used carbolic acid to stop infections, and explain the difference between antiseptic and aseptic surgery.
- I can read a bar graph of Lister's or Semmelweis's results and tell what the numbers show.
- I can plan a fair experiment with a control, naming what I change, what I keep the same and what I measure.
- I can wash my hands correctly and give simple first aid for a small cut, a burn and a nosebleed.

OPTIONAL BOOKS AND RESOURCES

- **Dr Jenner's House, Museum and Garden** (https://jennermuseum.com/): Jenner's home in Berkeley, Gloucestershire, now a museum. Its website has pictures of the house, the garden and the little hut where Jenner vaccinated the poor of the village for free (Lesson 8.1).
- **Institut Pasteur** (https://www.pasteur.fr/en): The research institute in Paris that opened in Pasteur's honor in 1888. The English site has a short history of Pasteur's life and work, including his apartment and laboratory, now a museum (Lesson 8.2). A parent may want to choose the pages.
- **American Red Cross** (https://www.redcross.org/): Free first-aid tips and information about first-aid classes, some open to older children with a parent (Lesson 8.4).

8.1 Jenner's Smallpox Vaccine (1796) ★

OBJECTIVES

- Tell the story of Edward Jenner, Sarah Nelmes and James Phipps, and explain how Jenner tested the milkmaids' saying about cowpox.
- Explain in simple words how white blood cells "remember" a germ, and why a mild cowpox infection protected people from smallpox.
- Use a grid model to show how a sickness spreads from person to person and how protected people slow or stop the spread.

Warm-up. Think of a song you learned when you were small. You probably still know every word without trying, because once you learn something well, your brain remembers it. Now write one sentence guessing: could the body have a way of "remembering" a sickness it has fought before? Keep your guess to check at the end of the lesson.

Video. Coming soon. Edward Jenner, cowpox and the first smallpox vaccine in 1796, and how white blood cells remember germs; search history-of-medicine channels, Dr Jenner's House museum, Homeschool Pop, SciShow Kids, and simple animated explanations of the immune system for children.

KEY TERMS

smallpox
A dangerous disease that spread from person to person and caused fever and blisters all over the body. About 3 out of every 10 people who caught it died, and many who lived were left with scars.

cowpox
A mild disease of cows that milkmaids could catch on their hands. It is caused by a germ much like the smallpox germ.

vaccine
Something given to a person to teach the body to fight a disease before the person ever meets it. The word comes from the Latin *vacca*, "cow," because the first one came from cowpox.

immune system
The parts of the body, especially white blood cells, that find and fight germs that get inside.

immunity
Protection from a disease because the body already knows how to fight it.

CORE IDEAS

The story. On May 14, 1796, in the village of Berkeley in Gloucestershire, England, a country doctor named Edward Jenner did something no one had tried in quite this way. A young milkmaid named Sarah Nelmes had sores on her hand from cowpox, which she had caught while milking a cow named Blossom. Jenner took a little of the matter from one of her sores and scratched it into the arm of James Phipps, the eight-year-old son of his gardener. James felt a little unwell for a few days, then got better. On July 1, Jenner did the brave and serious part of the test. He scratched matter from a real smallpox sore into the boy's arm. James did not get smallpox.

How they figured it out. Smallpox was one of the most feared diseases in the world. In Jenner's time, people sometimes protected themselves by having a little matter from a mild smallpox case put into a scratch on purpose. Most got only a light case, but some became very sick or spread smallpox to others. Meanwhile, country people in Gloucestershire had a saying: milkmaids who had caught cowpox never caught smallpox. Many doctors laughed at the idea. Jenner did not. His old teacher in London, the surgeon John Hunter, had taught him not just to think about a question but to try the experiment. For years Jenner collected cases of people who had had cowpox, and then he tested the saying on James Phipps. In 1798 he published a small book of his cases. He named the cowpox matter *variolae vaccinae*, Latin words meaning smallpox of the cow, from the Latin *vacca*, cow. That is where our word **vaccine** comes from.

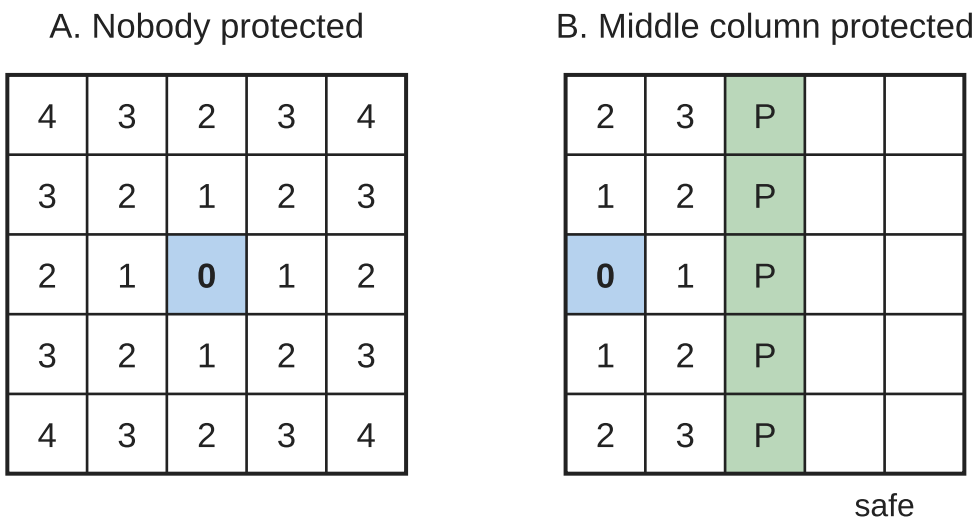
The big idea. Jenner did not know what caused smallpox. No one had yet proved that germs cause disease (you will meet Louis Pasteur in the next lesson). Today we know the answer. Smallpox and cowpox are caused by two germs so much alike that the body treats them almost as the same enemy. When a germ gets inside you, your **immune system** goes to work. Some white blood cells learn the exact shape of the invader and make tiny "tags" called antibodies that stick to it. After the fight is won, some of these cells stay behind as memory cells. If the same kind of germ ever comes again, the memory cells recognize it and the body fights back so fast that you may never feel sick. That protection is called **immunity**. James Phipps's body learned to fight the mild cowpox germ, and that lesson protected him from the deadly smallpox germ.

Try it and see. Smallpox spread from one person to the people near them, and from them to the people near them. In this lesson's project you will model that spread on a grid of squares, one square for each person. You will see that a sickness passes easily through a crowd where no one is protected, but stops at a line of protected people. You will also see something surprising: protected people help keep safe some of the people beyond them.

In the world today. Jenner sent cowpox matter to doctors all over the world, and in America, President Thomas Jefferson had his own family and neighbors vaccinated at Monticello. Jefferson later wrote to thank Jenner, saying that his discovery had removed one of the worst sufferings from the list of human troubles. Jenner did not try to get rich from his discovery; he wanted it shared. Nearly two hundred years later, after a long effort by doctors in many countries, the last natural case of smallpox was found in 1977, and in 1980 the

disease was declared gone from the whole earth. It is the only human disease ever wiped out completely.

God's handiwork. Long before anyone knew what a germ was, God had already built into our bodies an army that learns, fights and remembers. Jenner did not create immunity. He discovered a way to put the body's own design to work. Good science often looks like this: careful people noticing what God has already made and learning to use it to help their neighbors.



The grid model. Each square is a person. Each round, sickness spreads up, down, left or right to a person who is not protected. The number shows the round when that person gets sick.

PICTURE STUDY



Dr Jenner Performing His First Vaccination, 1796, Ernest Board, early 1900s · Oil on canvas · Wellcome Collection, London

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

Ernest Board was an English painter who made a series of pictures of famous moments in the history of medicine for Henry Wellcome, a businessman who collected anything to do with healing. Board was not in the room in 1796, of course. He painted this scene more than a hundred years later, studying old clothes, furniture and the story itself to imagine how it must have looked when Jenner first vaccinated James Phipps.

Look closely at how the painter shows that this is a quiet, careful moment in an ordinary country house, not a grand hospital. Many of the most important experiments in science happened in small rooms like this one.

Look closely

- Find James Phipps's arm. What is the doctor doing with his hands?
- Look at the faces of the people watching. Do they look worried, curious or calm?
- Find clues that this is a home and not a hospital.
- Where does the light fall brightest? What does the painter want you to notice first?

Talk about it

1. Why do you think James's family agreed to the test? What would you have asked Dr. Jenner if you had been there?
2. Jenner tested his idea on one boy first and waited to see the result. Why is it wise to test a new idea carefully before using it on many people?

3. Board painted this scene long after it happened. How could a painter make a history painting as true as possible?

EXPERIMENT: THE GRID MODEL: HOW DOES PROTECTION SLOW A SPREADING SICKNESS?

Scientists often use a **model**, a simple version of something real, to understand how it works. You will model a village on a grid where each square is a person, start one “sick” square, and follow a simple spreading rule. Then you will change how many people are protected and see what happens.

Question: Does the number of protected people change how many people get sick?
Prediction: Write your guess before you begin.

You will need

- Graph paper or a hand-drawn 5-by-5 grid of squares about 2 cm (about 3/4 inch) on a side; draw several copies
- 50 dried beans or small buttons of one color (sick) and 25 of another color (protected), or two colored pencils
- Pencil, ruler and lab notebook
- A die (optional, for the challenge version)

Steps

1. Draw a 5-by-5 grid. Each of the 25 squares is one person in the village.
2. **Spreading rule:** each round, every sick person makes sick each neighbor directly above, below, left or right (not corners) who is not protected. Protected people never get sick and never pass it on.
3. **Run A (the control):** no one is protected. Put one sick bean in the very middle square and write 0 in it. Play round 1, round 2 and so on, writing the round number in each square as it gets sick, until no new squares get sick. Count the sick squares.
4. **Run B:** on a fresh grid, mark the whole middle column (5 squares) as protected. Start the sick bean in the middle square of the left-hand column. Play the rounds and count.
5. **Run C:** on a fresh grid, start the sick bean in the middle and mark as protected only the 4 squares touching it (above, below, left, right). Play and count.
6. **Run D (your design):** choose any 5 squares to protect and start the sickness anywhere. Predict the number of sick squares, then play and count.
7. Record a table with the columns: Run, Number protected, Where the sickness started, Number sick at the end, Rounds until it stopped.
8. Write two sentences: What did you change? What happened to the number of sick people?

Tips

- **What we change:** how many people are protected and where they stand. **What we keep the same:** the grid size and the spreading rule. **What we measure:** the number of sick squares at the end.
- A model is simpler than real life. Real people move around and meet others far away, so real sickness does not travel in neat lines. But a model can still show a true pattern.
- Challenge version: before each spread, roll a die. On a 1 or 2 the germ does not pass that round. How does chance change your results?

Check your work

- I can explain the spreading rule and play it correctly.
- I can name the control run and tell why it is needed.
- I can explain how protected people can help keep others safe.

NATURE NOTEBOOK

1. Draw James Phipps's arm with the small scratch, and beside it draw Sarah Nelmes's hand with cowpox sores. Label each and write the date May 14, 1796.
2. Make a two-row timeline: May 14, 1796 (cowpox given) and July 1, 1796 (smallpox test). Write what happened on each day and how many days apart they are.
3. Draw a white blood cell as a little guard with a notebook, "writing down" the shape of a germ. Write one sentence about memory cells.

> **From history.** Jenner was not the very first person to try cowpox. In 1774, more than twenty years earlier, a Dorset farmer named Benjamin Jesty heard the same milkmaid saying and scratched cowpox into the arms of his wife and two sons during a smallpox outbreak. They stayed well. But Jesty did not test, record and publish his work. Jenner's careful cases, his test on James Phipps and his book of 1798 are why the world learned to trust vaccination. Many years later, Jenner gave James Phipps a cottage in Berkeley to live in, rent free.

WORKED EXAMPLES

Example 1. Jenner gave James Phipps cowpox on May 14, 1796, and tested him with smallpox on July 1, 1796. How many days apart were the two events? About how many weeks is that?

1. May has 31 days. From May 14 to May 31 is $31 - 14 = 17$ days.
2. All of June adds 30 days: $17 + 30 = 47$ days, which brings us to June 30.
3. One more day reaches July 1: $47 + 1 = 48$ days.
4. Weeks: $48 \div 7$ is 6 with 6 left over, so a little less than 7 weeks.

Answer: 48 days, almost 7 weeks. Jenner waited long enough for the cowpox to come and go completely before the real test.

Example 2. Look at grid B in the figure. The middle column of 5 people is protected, and the sickness starts in the middle of the left-hand column. How many people get sick? How many people who are *not* protected stay well?

(Use the map or drawing "In grid B, the protected column stops the spread." shown earlier in this lesson.)

1. The sickness can spread only up, down, left or right. The protected column blocks every path to the right side.
2. So only the two left-hand columns can get sick: 2 columns × 5 people = 10 people. The numbers in the figure show the last ones fall sick in round 3.
3. The two right-hand columns are not protected, but the sickness can never reach them: 2 × 5 = 10 people stay well.
4. Check: 10 sick + 5 protected + 10 safe = 25 people, the whole grid.

Answer: 10 people get sick, and 10 unprotected people stay well because the protected people stand between them and the sickness.

PRACTICE

1. EASY Who was the milkmaid, and who was the boy, in Jenner's famous test? What disease did the milkmaid have?
2. EASY The word *vaccine* comes from a Latin word. What is the word and what does it mean? Why was it a good choice?
3. EASY Jenner's test was in 1796 and his book came out in 1798. How many years did he wait before publishing? Why might a careful scientist wait instead of announcing a result right away?
4. MEDIUM A family ran the grid model three times on a 5-by-5 grid. Use the table to answer.
   Run A: 0 protected, 25 sick.
   Run B: 5 protected (middle column), 10 sick.
   Run C: 4 protected (all around the starting square), 1 sick.
   (a) Which run had the fewest sick? (b) In Run B, how many people were neither sick nor protected? (c) Run C had fewer protected people than Run B but fewer sick. Why?
5. MEDIUM In your own words, explain why catching cowpox protected James Phipps from smallpox.
6. MEDIUM In Jenner's time, about 3 out of every 10 people who caught smallpox died. If 200 people in a town caught smallpox, about how many would die, and about how many would live?
7. HARD Mateo wants to use the grid model to test whether protecting more people means fewer people get sick. Plan his experiment: What will he change? What must he keep the same? What will he measure? What is his control run?
8. CHALLENGE On a 5-by-5 grid with no one protected and the sickness starting in the middle square, how many new people get sick in round 1, round 2, round 3 and round 4? Show that your total is 25.

COMMON MISTAKES

- Thinking Jenner knew about germs. He did not; germ theory came decades later. He worked from careful observation and testing.
- Thinking a vaccine works like a medicine that cures you once you are sick. A vaccine prepares the body *ahead of time* so it can fight off a disease quickly.
- Thinking white blood cells fight every germ the same way. Each kind of germ has its own shape, and the body's memory cells recognize particular germs.

Make it a game · Guard Cell Memory. Make ten pairs of "germ cards" by drawing ten simple shapes (star, zigzag, spiral and so on), two of each. Shuffle and lay them face down. You are a white blood cell: flip two cards. If they match, you have "recognized" the germ and keep the pair. If not, turn them back and remember where they were for next time. Play against a parent. Afterward, talk about how memory helped you win, just as memory cells help the body win.

Scripture. "Look not every man on his own things, but every man also on the things of others." (Philippians 2:4, KJV)

Jenner could have tried to keep his discovery for himself. Instead he sent cowpox matter and instructions to doctors around the world so that others could be protected. Good science serves our neighbors.

Practice answers

1. The milkmaid was Sarah Nelmes, who had cowpox. The boy was James Phipps, the eight-year-old son of Jenner's gardener.
2. *Vacca*, meaning cow. The first vaccine was made from cowpox, a disease of cows.
3. 2 years. He wanted to test more people and gather more cases so that others could trust the result, not rely on one boy alone.
4. (a) Run C, with only 1 sick. (b) 25 − 10 − 5 = 10 people. (c) In Run C the protected people surrounded the sickness right where it started, so it could not spread at all. Where the protected people stand matters, not just how many there are.
5. The cowpox germ is very much like the smallpox germ. When James caught mild cowpox, his white blood cells learned to recognize and fight that kind of germ, and memory cells stayed ready. When smallpox came, his body recognized it and fought it off quickly before it could make him sick.
6. 200 ÷ 10 = 20 groups of 10; 20 × 3 = 60 would die and 200 − 60 = 140 would live.
7. Change: the number of protected squares (for example 0, 3, 6, 9). Keep the same: the grid size, the spreading rule, the starting square, and a fair way of placing protected squares (for example, choosing them by dice each time). Measure: the number of sick squares when the spread stops. Control: a run with 0 protected squares, to compare against.
8. Round 1: 4 new. Round 2: 8 new. Round 3: 8 new. Round 4: 4 new (the corners). Total: 1 (start) + 4 + 8 + 8 + 4 = 25.

8.2 Pasteur's Germs

OBJECTIVES

- Tell how Louis Pasteur discovered that living microbes cause fermentation and spoiling, and how his swan-neck flasks showed that microbes come from other microbes.
- Explain germ theory, the idea that many diseases are caused by tiny living things, and describe how pasteurization protects food.
- Run a yeast-and-balloon experiment with a control, record measurements in a table, and explain the result.

Warm-up. Look at a slice of bread, a spoonful of yogurt and a pinch of dry yeast from the kitchen. All three were made with the help of living things far too small to see. Which ones do you think are still alive? Write your guesses, then check them as you read the lesson.

Video. Coming soon. Louis Pasteur, the swan-neck flask experiment, germ theory and pasteurization explained for children; search the Pasteur Institute, history-of-science channels, Homeschool Pop, SciShow Kids, Science Max, and microscope footage of yeast and bacteria.

KEY TERMS

microbe
A living thing too small to see without a microscope. Bacteria and yeasts are microbes. A microbe that causes disease is often called a **germ**.

bacteria
Very tiny one-celled living things. Some are helpful, such as those that make yogurt; some cause disease or make food spoil.

yeast
A tiny one-celled fungus. It feeds on sugar and gives off carbon dioxide gas, which makes bread rise.

fermentation
The change microbes make when they feed on sugar without much air, turning it into things like alcohol, acid or gas.

spontaneous generation
The old idea that living things such as microbes or maggots could spring up by themselves from nonliving things like broth or meat. Pasteur showed it was wrong.

pasteurization
Heating a food or drink, such as milk, just enough to kill most harmful microbes without boiling it.

CORE IDEAS

The story. In 1856, in the French city of Lille, a factory owner named Monsieur Bigo had a problem. His business made alcohol from beet juice in great vats, and some of the vats kept turning sour and spoiling. He asked a young chemistry professor named Louis Pasteur for help. Pasteur took drops from the good vats and the bad vats and put them under his microscope. In the good vats he saw round yeast cells, plump and budding. In the sour vats he saw something else: crowds of tiny rod-shaped microbes. Pasteur realized that the yeast was alive and was doing the work of fermentation, and that the rods were different living things making the juice go sour.

How they figured it out. Many scientists of the time believed in **spontaneous generation**: that microbes simply appear by themselves in broth, milk or meat. Pasteur thought they came from other microbes floating on specks of dust in the air. To test it, he boiled meat broth in glass flasks to kill everything in it. Then he heated the necks of the flasks and bent them into a long S-shape like a swan's neck. Air could still reach the broth, but dust and microbes got caught in the low bend of the neck. The broth stayed clear for weeks and months. When he broke off the neck, or tipped the flask so broth touched the dust in the bend, the broth soon turned cloudy with microbes. The only thing he changed was whether microbes could reach the broth. Life came from life, not from broth.

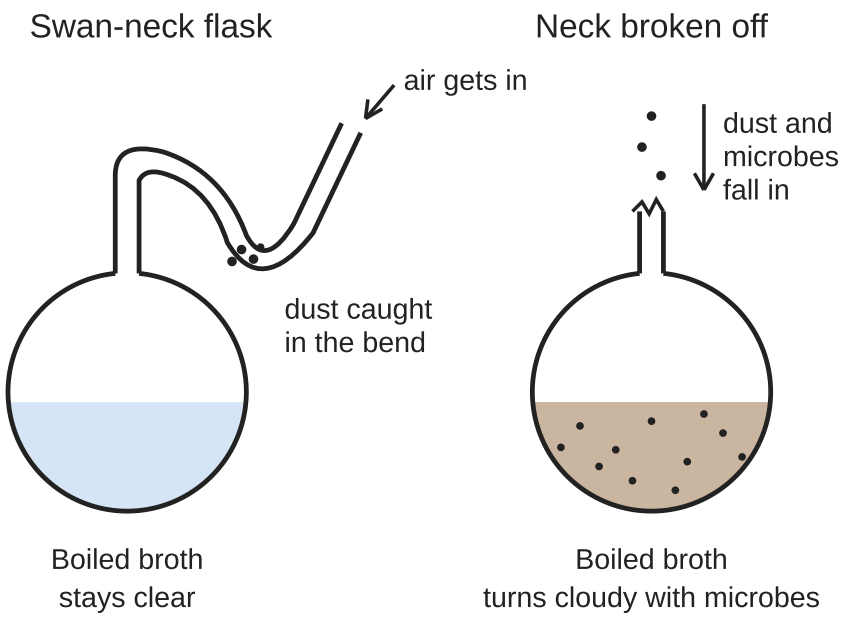
The big idea. Pasteur's work led to **germ theory**: many diseases, and most spoiling of food, are caused by microbes. This changed medicine. If tiny living things cause sickness, then we can keep them out, kill them, or train the body to fight them. Pasteur himself went on to make vaccines against diseases of chickens and sheep. In 1885 a nine-year-old boy named Joseph Meister was badly bitten by a dog with rabies, a disease that was almost always deadly. Pasteur's team gave him a series of injections of a weakened form of the rabies germ, and the boy lived. Pasteur also proposed that all such treatments be called **vaccines**, in honor of Jenner's cowpox.

Try it and see. You can watch microbes work without a microscope. In this lesson's project you will feed yeast different amounts of sugar in bottles of warm water, each with a balloon stretched over the top. As the living yeast feeds, it gives off carbon dioxide gas, which fills the balloon. One bottle gets no sugar at all. That bottle is your **control**: it shows what happens when you leave out the one thing you are testing.

In the world today. Pasteur found that warming wine to a moderate heat, well below boiling, killed the microbes that spoiled it but did not ruin the taste. We still use his method, called **pasteurization**. Most milk sold in stores is heated to about 72 °C (161 °F) for at least 15 seconds and then cooled quickly. That kills most of the harmful bacteria that once made milk a common cause of sickness. Refrigerators help too, because cold slows microbes down. Not all microbes are enemies. Yeast raises our bread, and helpful bacteria make yogurt and cheese and live in our own intestines, helping us digest food.

God's handiwork. Pasteur once told his students that in the field of observation, chance favors only the prepared mind. He looked for a long time at drops of juice that other people

would have poured away. In those drops was a whole hidden world of living things, each one made “after his kind,” each one growing only from others like it. The God who made the stars also made the yeast cell, and His order holds even where our eyes cannot see.



Pasteur’s swan-neck test. Both flasks were boiled and both let air in. Only the flask that let dust and microbes fall into the broth turned cloudy.

PICTURE STUDY



Louis Pasteur, Albert Edelfelt, 1885 · Oil on canvas · Musée d’Orsay, Paris

Albert Edelfelt was a painter from Finland who worked in Paris. In 1885, the same year young Joseph Meister was saved from rabies, Edelfelt painted Pasteur in his laboratory. Pasteur is not posing in fine clothes in a grand room. He is at work, looking hard at a glass jar. In it hangs a piece of dried spinal cord from a rabbit, part of his careful work toward the rabies vaccine.

The painting became famous and was copied in many prints. Pasteur liked it so much that he hung it in his own dining room. People wanted to see the scientist the way he spent his days: observing.

Look closely

- Find the jar in Pasteur's hands. Where are his eyes looking?
- Look at the table. What tools and papers can you find? What do they tell you about his work?
- Notice the colors. Is this a bright, cheerful room or a quiet working room?
- Look at Pasteur's face. What words would you use to describe how he is thinking?

Talk about it

1. Why do you think Edelfelt chose to paint Pasteur working instead of standing in a fancy pose?
2. Pasteur kept careful notebooks of every experiment. Why are notes just as important as the experiment itself?
3. If someone painted you doing science, what would you be holding and looking at?

> **Safety first.** Use warm tap water, not hot or boiling water; ask an adult to check the temperature. Do not drink the yeast mixture. If anyone in the family is allergic to latex, use non-latex balloons. Pour the mixture down the drain and rinse the bottles when you finish.

EXPERIMENT: LIVING YEAST AND THE BALLOON TEST

Pasteur showed that fermentation is the work of living yeast. You will test it yourself by giving yeast different amounts of sugar and measuring how much gas it makes.

Question: Does the amount of sugar change how much gas the yeast makes? **Prediction:** Write which bottle you think will blow its balloon up most, and why.

You will need

- 3 clean, empty plastic bottles of the same size, about 500 mL (about 16 fl oz) each
- 3 balloons of the same kind, stretched a few times so they inflate easily
- 3 packets of dry yeast (about 7 g, or 2 1/4 teaspoons, each)
- Sugar and a tablespoon (15 mL)
- Warm tap water, about 40 °C (about 105 °F), and a measuring cup

- Funnel, string, ruler, masking tape, marker, lab notebook and a clock

Steps

1. Label the bottles A (no sugar), B (1 tablespoon sugar) and C (2 tablespoons sugar).
2. Using the funnel, put one packet of yeast into each bottle.
3. Add the sugar: none in A, 1 tablespoon in B, 2 tablespoons in C.
4. Pour 250 mL (about 1 cup) of warm water into each bottle. Swirl gently to mix.
5. Quickly stretch a balloon over the mouth of each bottle. Set the three bottles side by side in the same warm spot.
6. Every 10 minutes for 40 minutes, wrap the string around the widest part of each balloon, then measure the string against the ruler. Record the circumference in centimeters (write 0 if the balloon is still flat).
7. Make a table with a row for each bottle and a column for 0, 10, 20, 30 and 40 minutes.
8. Draw a bar graph of the 40-minute measurements. Write two sentences: Was your prediction right? What does bottle A tell you?

Tips

- **What we change:** the amount of sugar. **What we keep the same:** bottle size, yeast, water amount, water temperature, balloon type and place. **What we measure:** balloon circumference. **Control:** bottle A, with no sugar.
- Look closely at the water. You may see foam and tiny bubbles rising. Those bubbles are carbon dioxide gas made by the living yeast.
- If the room is cold, the yeast works slowly. Keep all three bottles in the same place so the test stays fair.

Check your work

- I can name what I changed, what I kept the same, what I measured and my control.
- I can record my measurements in a table and a bar graph.
- I can explain why the gas shows that yeast is alive.

NATURE NOTEBOOK

1. Draw Pasteur’s swan-neck flask and a broken-neck flask side by side. Label the broth, the bend in the neck and the dust, and write which broth stays clear.
2. Draw what Pasteur saw under the microscope: round, budding yeast cells in one circle and tiny rods in another. Label them “good vat” and “sour vat.”
3. List five foods in your kitchen made with the help of microbes (for example bread, yogurt, cheese, vinegar, pickles). Next to each, write whether it was pasteurized, baked or kept cold to stay safe.

> **From history.** Before his work on germs, Pasteur helped save France’s silk industry. In the 1860s a disease was killing the silkworms, and he spent several summers in the south of France studying them with his microscope. He found the sick worms and showed

farmers how to choose only healthy moths to lay eggs. Joseph Meister, the boy saved from rabies in 1885, later worked for many years as a caretaker at the Pasteur Institute in Paris, the research center that opened in Pasteur's honor in 1888.

WORKED EXAMPLES

Example 1. In warm broth with plenty of food, some kinds of bacteria can split in two about every 20 minutes. If one bacterium lands in a bowl of soup left on the counter, how many could there be after 2 hours, if every one keeps splitting?

1. 2 hours = 120 minutes. 120 ÷ 20 = 6, so the bacteria double 6 times.
2. Start with 1. Double it 6 times: 1 → 2 → 4 → 8 → 16 → 32 → 64.
3. Check with multiplication: 2 × 2 × 2 × 2 × 2 × 2 = 64.

Answer: About 64 bacteria from just one. After 4 hours (12 doublings) it would be 4,096. This is why leftovers should go into the refrigerator, where cold slows the splitting.

Example 2. A student ran the yeast balloon test. Here is the sample data (balloon circumference in cm).
Time 0, 10, 20, 30, 40 minutes.
A (no sugar): 0, 0, 0, 1, 1.
B (1 tbsp sugar): 0, 4, 9, 14, 18.
C (2 tbsp sugar): 0, 5, 11, 17, 22.
(a) How much did balloon B grow from 10 to 40 minutes? (b) At 40 minutes, how much bigger around was C than B? (c) What does bottle A show?

1. (a) Subtract: 18 − 4 = 14 cm.
2. (b) Subtract: 22 − 18 = 4 cm.
3. (c) Bottle A had yeast and warm water but no sugar, and its balloon barely grew. So the gas came from yeast feeding on the sugar.

Answer: (a) 14 cm. (b) 4 cm. (c) Without sugar the yeast made almost no gas, so sugar is the food the yeast needs. More sugar gave more gas in this test.

PRACTICE

1. EASY What did Pasteur see under his microscope in the good beet-juice vats? What did he see in the sour ones?
2. EASY What is pasteurization? About what temperature is most milk heated to, and for how long?
3. EASY Name one helpful microbe and one harmful one, and tell what each does.
4. MEDIUM Pasteur's swan-neck flask was open to the air, yet the broth stayed clear. Explain why.

5. MEDIUM Use the yeast table from Worked Example 2. (a) Which bottle grew fastest between 0 and 10 minutes? (b) What was the balloon circumference of bottle B at 20 minutes? (c) Water boils at 100 °C. How many degrees below boiling is the 72 °C used to pasteurize milk?
6. HARD Grace wants to test whether water temperature changes how fast yeast makes gas. Plan her experiment: What will she change? What will she keep the same? What will she measure? What could be her control?
7. HARD If bacteria split every 20 minutes, how many could come from one bacterium in 1 hour 40 minutes?
8. CHALLENGE Some people in Pasteur's day said broth needs fresh air for life to appear in it. Explain why the swan-neck flask answered that objection better than a flask sealed shut with a stopper.

COMMON MISTAKES

- Thinking all microbes are harmful. Many are helpful, like the yeast in bread and the bacteria in yogurt and in our intestines.
- Thinking pasteurized milk has been boiled. It is heated to about 72 °C (161 °F), well below boiling, and only for a short time.
- Thinking the clear broth proved microbes need no air. It proved that microbes come from other microbes, not from the broth itself.

> **Make it a game · Microbe or Not?.** A parent names a thing: yeast, a grain of salt, a speck of dust, the bacteria in yogurt, sugar, mold on bread, a drop of water, a rabies germ. You answer "living microbe" or "not alive" and, for each microbe, "helper" or "harmful." Score a point for each correct answer and a bonus point if you can tell how we keep the harmful ones away (cooking, cold, washing, pasteurizing). Play to ten.

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

God hid a whole world of tiny living things in a drop of juice. It was an honor for Pasteur, and it is an honor for you, to search out what God has made.

Practice answers

1. In the good vats he saw round yeast cells. In the sour vats he saw tiny rod-shaped microbes.
2. Heating a food or drink just enough to kill most harmful microbes without boiling it. Milk is usually heated to about 72 °C (161 °F) for at least 15 seconds.
3. Example: yeast is helpful because it makes bread rise. Bacteria that spoil milk or soup are harmful because they can make us sick. (Other good answers: yogurt bacteria, gut bacteria; disease germs such as rabies.)
4. Air could pass through the long bent neck, but dust and microbes in the air settled in the low bend and could not reach the broth. Since the boiled broth had no microbes and none could get in, nothing grew.
5. (a) Bottle C (0 to 5 cm). (b) 9 cm. (c) $100 - 72 = 28$ °C below boiling.

6. Change: the water temperature (for example cool, warm and hot-tap water, measured with a thermometer). Keep the same: bottle size, amount of yeast, amount of sugar, amount of water, balloon type, place and timing. Measure: balloon circumference every 10 minutes. Control: the bottle at ordinary warm temperature (about 40 °C), or a bottle with no yeast to show that gas comes from the yeast.
7. 1 hour 40 minutes = 100 minutes; 100 ÷ 20 = 5 doublings. 1 → 2 → 4 → 8 → 16 → 32. About 32 bacteria.
8. A stoppered flask keeps out both air and microbes, so people could say nothing grew only because there was no air. The swan-neck flask let air in but kept microbes out. Since the broth still stayed clear, air alone does not make life appear; microbes must come from other microbes. Changing only one thing made the test fair.

8.3 Lister's Clean Surgery

OBJECTIVES

- Tell how Joseph Lister used Pasteur's germ discovery and carbolic acid to save James Greenlees and many other patients.
- Explain the difference between antiseptic (killing germs in a wound) and aseptic (keeping germs out from the start) methods, and name ways surgeons keep germs out today.
- Read Lister's hospital numbers in a table and bar graph, and run an apple experiment that tests how broken skin and an antiseptic affect rotting.

Warm-up. Look closely at an apple. Its skin is smooth and whole. Now think about a bruised or cut apple left on the counter for a few days. Where does it start to go brown and soft first? Write one sentence guessing why the skin matters, and keep it for later.

Video. Coming soon. Joseph Lister, carbolic acid and antiseptic surgery in the 1860s, and how surgeons keep germs out today; search history-of-medicine channels, museum channels such as the Science Museum (London), Homeschool Pop, SciShow Kids, and children's explanations of skin as a germ barrier.

KEY TERMS

infection
When harmful germs get into the body and grow, causing redness, swelling, pus, fever or worse.

compound fracture
A broken bone that pokes through the skin, leaving an open wound. Today it is often called an open fracture.

antiseptic
A substance that kills or slows germs on skin or in a wound without badly harming the body. Rubbing alcohol and iodine are antiseptics.

carbolic acid
A strong-smelling chemical, also called phenol, that Lister used as the first surgical antiseptic. It kills germs but can also burn skin.

sterilize
To kill every living microbe on something, for example by heating surgical tools in steam under pressure.

aseptic
Germ-free. Aseptic surgery keeps germs out from the start with sterilized tools, clean gowns, masks and gloves.

CORE IDEAS

The story. On August 12, 1865, an eleven-year-old boy named James Greenlees was carried into the Royal Infirmary in Glasgow, Scotland. A cart had run over his leg. The bone of his shin was broken and had torn through the skin. In those days a **compound fracture** like this was terribly dangerous. The broken bone could mend, but the open wound almost always became infected, swelling and filling with pus. Often the only hope was to cut off the leg, and many patients died anyway. The surgeon, Joseph Lister, decided to try something new. He cleaned the wound with carbolic acid, covered it with cloth soaked in carbolic acid, and kept it covered. The wound healed without infection. Six weeks later, James walked out of the hospital on his own two legs.

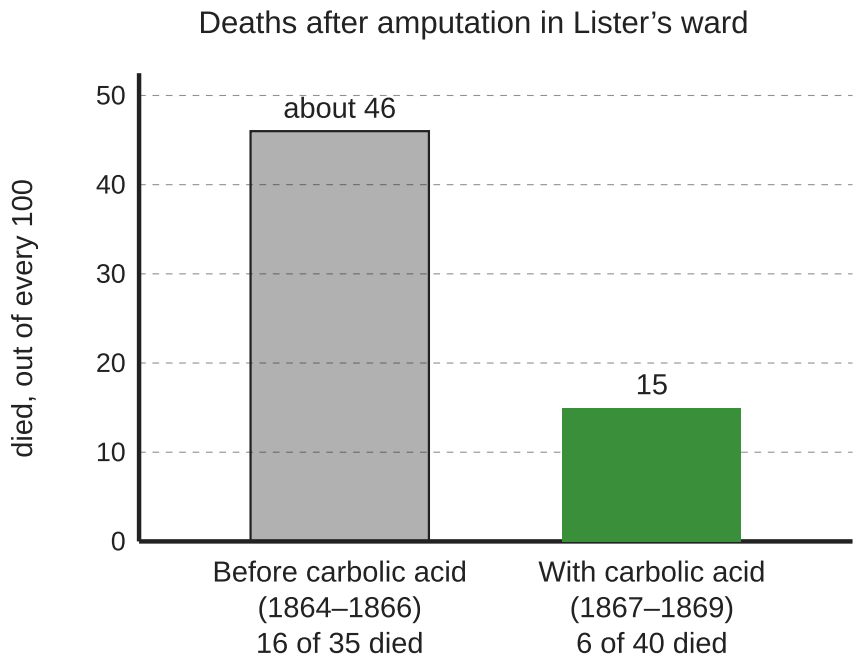
How they figured it out. Surgeons of that time often operated in old coats stiff with blood, washed their tools only now and then, and went from one patient to the next. They thought wound infection came from "bad air" or from the wound itself. Lister was not satisfied. His father had improved the microscope, and Lister had used one since he was young. In 1865 a chemistry professor in Glasgow, Thomas Anderson, told him about Louis Pasteur's papers showing that rotting is caused by living microbes carried in the air. Lister reasoned: if microbes make broth spoil, perhaps they also make wounds rot. He could not boil a wound, as Pasteur boiled broth, but he could kill the microbes with a chemical. He had read that the town of Carlisle used **carbolic acid** on its sewage to stop the bad smell. He chose it as his weapon.

The big idea. Your skin is a wall that keeps germs out. A cut, a scrape or a surgeon's knife opens a door in that wall. Lister's method, the **antiseptic** method, was to kill the germs at the door: on the wound, the dressings, the tools and the surgeon's hands. He counted his results carefully. Of 35 patients in his ward who had a limb cut off in the years just before he began, 16 died. Of 40 such patients after he began using carbolic acid, only 6 died. Later surgeons went a step further with the **aseptic** method: instead of killing germs in the wound, keep them out from the start. Tools are **sterilized** in hot steam, and the surgeons scrub their hands and wear clean gowns, masks and gloves.

Try it and see. An apple's skin works much like your skin. In this lesson's project you will rub the germs from a rotting apple onto fresh apples, some with whole skin and some with a small cut, and treat one cut with rubbing alcohol, a modern antiseptic. After a week you will measure the brown rotten spots with a ruler. The apple with whole skin and no germs is your **control**, showing what an apple does when nothing is done to it.

In the world today. Every time a nurse wipes your skin before a shot, or a doctor cleans a scrape before putting on a bandage, they are following Lister. Operating rooms today are among the cleanest places on earth. Everything that touches the patient has been sterilized, and surgeons scrub their hands and arms for several minutes before putting on sterile gloves. Lister became one of the most honored doctors in the world, and Queen Victoria made him a lord. A mouthwash invented in America in 1879 was even named Listerine after him.

God’s handiwork. Lister grew up in a devout Quaker family, and he was known for his gentleness with patients, rich and poor alike. He did not invent germs or skin or healing. God made skin as a covering and gave the body the power to knit a broken bone back together. Lister’s great gift was to clear the way so that the healing God built into the body could do its work.



Lister’s own count of patients who died after having a limb removed in his Glasgow ward, before and after he began his antiseptic method. Percents are rounded.

PICTURE STUDY

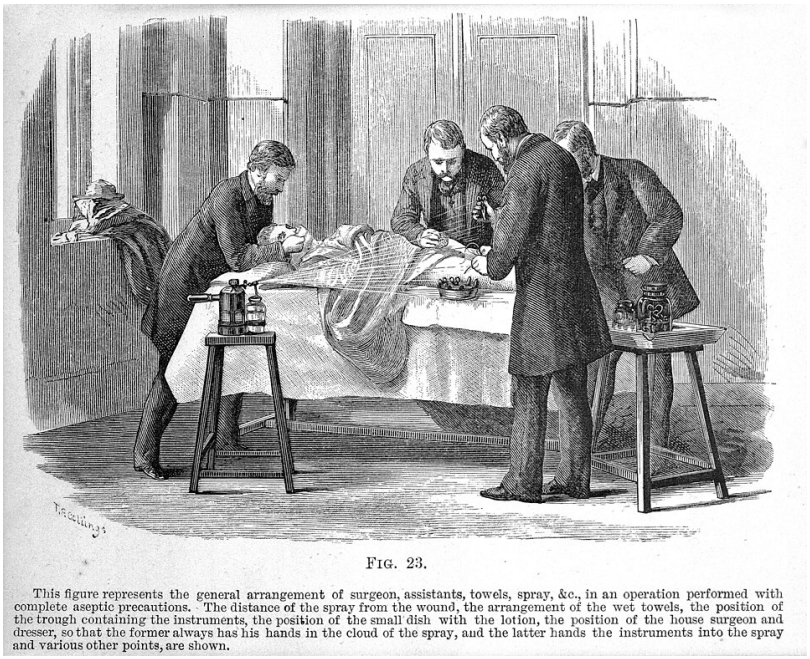


FIG. 23.

This figure represents the general arrangement of surgeon, assistants, towels, spray, &c., in an operation performed with complete aseptic precautions. The distance of the spray from the wound, the arrangement of the wet towels, the position of the trough containing the instruments, the position of the small dish with the lotion, the position of the house surgeon and dresser, so that the former always has his hands in the cloud of the spray, and the latter hands the instruments into the spray and various other points, are shown.

An Operation Using Lister's Carbolic Spray, Unknown engraver, for William Watson Cheyne, 1882 · Engraving (book illustration) · Printed in William Watson Cheyne's book *Antiseptic Surgery* (London, 1882)

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

William Watson Cheyne was one of Lister's students and assistants, and he wrote a book to teach other surgeons the antiseptic method. This engraving from his book shows an operation done Lister's way in the years after 1870. Lister had invented a spray machine that filled the air over the wound with a mist of carbolic acid, because he thought germs floating in the air were the greatest danger.

Look carefully and you will notice what is *not* there yet. The surgeons wear ordinary coats, with no gowns, masks or gloves. Later Lister learned that germs on hands and tools mattered far more than germs in the air, and by about 1890 he gave up the spray. A good scientist changes his method when the evidence shows a better way.

Look closely

- Find the spray machine. Where is it pointing?
- Count the people around the table. What job do you think each one has?
- Look at what the surgeons are wearing. What would be different in an operating room today?
- Find any bowls, cloths or tools. Why would they need to be clean?

Talk about it

1. Why did Lister think spraying the air would help? What did he later learn?
2. Why is it a good thing, not a bad thing, when a scientist changes his method because of new evidence?

3. If you drew an operating room today, what three things would you add to this picture?

> **Safety first.** An adult should make all the cuts with the knife and handle the rubbing alcohol. Rubbing alcohol catches fire easily, so keep it away from flames and stoves, and never drink it. Do not eat the test apples. Keep each apple sealed in its own bag, do not open the bags to sniff, and throw the sealed bags away at the end. Wash your hands with soap and water after handling the apples.

EXPERIMENT: THE APPLE WOUND EXPERIMENT

Lister's idea had two parts: germs get in through broken skin, and an antiseptic can stop them. You will test both parts with apples.

Question: Does a break in the skin let rot in, and can an antiseptic slow it down?
Prediction: Write which apple you think will have the biggest rotten spot after a week.

You will need

- 4 fresh apples of the same kind and size, with no bruises
- 1 rotting apple (or a spoonful of garden soil) as the germ source
- Clean paring knife (for an adult), cotton balls, rubbing alcohol
- 4 zip-top plastic bags, masking tape and a marker
- Ruler marked in centimeters, lab notebook and pencil

Steps

1. Label the bags A, B, C and D.
2. Apple A (control): do nothing to it. Put it in bag A.
3. Apple B: rub the rotting apple on one spot of its whole, unbroken skin. Put it in bag B.
4. Apple C: an adult makes a small cut about 2 cm (about 3/4 inch) long in the skin. Rub the rotting apple on the cut. Put it in bag C.
5. Apple D: an adult makes the same size cut. Rub the rotting apple on the cut, then right away dab the cut with a cotton ball soaked in rubbing alcohol. Put it in bag D.
6. Seal all four bags and keep them side by side in the same place at room temperature.
7. Every day for 7 days, look without opening the bags. On day 7, measure the width of any brown, soft spot in centimeters.
8. Record a table with the columns Apple, What we did, Day the first brown spot appeared, Width of spot on day 7. Then write two sentences explaining your results using the words skin, germs and antiseptic.

Tips

- **What we change:** whether the skin is broken and whether an antiseptic is used. **What we keep the same:** kind and size of apple, size of cut, germ source, bags, temperature and time. **What we measure:** the width of the rotten spot. **Control:** apple A.

- Real experiments do not always come out the way we expect. If your results surprise you, write them down honestly and think about why. Doing the test twice, with two apples in each group, makes your results more trustworthy.
- A cut apple also turns brown quickly in the air because of a reaction with oxygen. That thin brown color on the surface is not rot. Rot is soft, spreading and deeper.

Check your work

- I can name the control and explain why it is needed.
- I can measure and record the rotten spots in a table.
- I can explain what my results show about skin as a wall and about antiseptics.

NATURE NOTEBOOK

1. Draw a cross-section of skin as a brick wall, with germs trying to get in. Then draw a "door" made by a cut, and an antiseptic guard standing at the door.
2. Draw your four apples on day 7 at actual size. Measure and label the width of each rotten spot in centimeters.
3. Make a two-column chart titled "Operating Room: 1860 and Today." List at least four differences.

> **From history.** Rubber surgical gloves began with a kindness. Around 1890 at Johns Hopkins Hospital in Baltimore, the surgeon William Halsted noticed that the strong antiseptics were giving his chief operating nurse, Caroline Hampton, painful rashes on her hands. He asked the Goodyear Rubber Company to make thin rubber gloves for her. Soon other members of the team wore them too, and doctors later found that the gloves helped keep germs out of wounds. Halsted and Caroline Hampton were married in 1890.

WORKED EXAMPLES

Example 1. Lister counted patients in his ward who had a limb cut off. Before carbolic acid: 35 patients, 16 died. With carbolic acid: 40 patients, 6 died. About how many out of every 100 died in each group?

(Use the map or drawing "Lister's amputation results, as a bar graph." shown earlier in this lesson.)

1. Before: $16 \div 35 = 0.457\ldots$, which is about 46 out of every 100. (Check: half of 35 is 17.5, so 16 is a little less than half.)
2. With carbolic acid: $6 \div 40 = 0.15$, which is 15 out of every 100. (Check: $40 \times 2.5 = 100$ and $6 \times 2.5 = 15$.)
3. Compare: $46 - 15 = 31$. About 31 more patients out of every 100 lived with Lister's method. 46 is about 3 times 15.

Answer: About 46 out of 100 before, and 15 out of 100 with carbolic acid. Deaths fell to about one third of what they had been.

Example 2. Here is sample data from the apple experiment, the width of the rotten spot on day 7.
A (control, nothing done): 0 cm.
B (germs on whole skin): 0 cm.
C (cut + germs): 4.5 cm.
D (cut + germs + alcohol): 1.0 cm.
(a) How much wider was the spot on C than on D? (b) What do apples B and C together show? (c) What does D show? (d) About how wide is C’s spot in inches (1 inch is about 2.5 cm)?

1. (a) 4.5 − 1.0 = 3.5 cm wider.
2. (b) B and C both got the same germs. The only difference is the cut. B did not rot and C did, so the germs got in through the broken skin.
3. (c) D got the same cut and germs as C, plus the antiseptic. Its spot was much smaller, so the antiseptic slowed the germs.
4. (d) 4.5 ÷ 2.5 = 1.8, so about 1.8 inches (a little less than 2 inches).

Answer: (a) 3.5 cm. (b) Whole skin kept the germs out; the cut let them in. (c) The antiseptic killed or slowed many of the germs. (d) About 1.8 inches.

PRACTICE

1. EASY Who was James Greenlees, and what kind of injury did he have?
2. EASY What chemical did Lister use, and where did he get the idea to use it?
3. EASY What is the difference between the antiseptic method and the aseptic method?
4. MEDIUM Use the bar graph and Lister’s numbers (before: 16 of 35 died; after: 6 of 40 died). (a) How many patients lived in each group? (b) Which group had more patients? (c) Why is it fairer to compare “out of 100” than to compare 16 and 6?
5. MEDIUM Whose discovery gave Lister his idea, and how did he hear about it?
6. HARD Ben wants to test whether vinegar works as well as rubbing alcohol on cut apples. Plan his experiment: What will he change? What will he keep the same? What will he measure? What should his control be?
7. HARD Explain why a compound fracture was so much more dangerous than a broken bone that stayed inside the skin, before Lister’s time.
8. CHALLENGE Suppose a large hospital did 200 amputations a year. Using Lister’s rates (about 46 in 100 died before, 15 in 100 died with carbolic acid), about how many more patients a year would live with his method?

COMMON MISTAKES

- Thinking germs in the air are the main danger in surgery. Lister himself first thought so, but germs on hands, tools and dressings matter much more.

- Thinking a stronger antiseptic is always better. Strong chemicals like carbolic acid also hurt skin and living tissue, so doctors look for ones that kill germs but are gentle to the body.
- Thinking the brown color on a freshly cut apple is rot. That quick browning comes from a reaction with oxygen in the air; rot is soft, spreading and caused by microbes.

Make it a game · Germ Wall Defense. One player is the Skin and stands in a doorway. The other players are Germs and try to sneak a beanbag or rolled sock past. If the Skin tags a Germ, that Germ is out. Then a parent calls “Cut!” and the Skin must step aside from part of the doorway, letting Germs through more easily, until a parent calls “Antiseptic!” and a second player joins to guard the gap. Afterward, talk about how this is like a cut and a clean bandage.

Scripture. “The heart of the prudent getteth knowledge; and the ear of the wise seeketh knowledge.” (Proverbs 18:15, KJV)

Lister was a busy, respected surgeon, but he still listened when he heard about a chemist in France working on spoiled broth. A wise person keeps learning, even from unexpected places, and puts that knowledge to work helping others.

Practice answers

1. An eleven-year-old boy whose leg was run over by a cart in Glasgow in 1865. He had a compound (open) fracture: the broken shin bone came through the skin. Lister treated him with carbolic acid and he walked home six weeks later.
2. Carbolic acid (phenol). He had read that the town of Carlisle used it on sewage to stop the bad smell of rotting.
3. Antiseptic: kill the germs that are already on the wound, tools and hands with a chemical. Aseptic: keep germs out from the start by sterilizing tools and using clean gowns, masks and gloves.
4. (a) Before: 35 − 16 = 19 lived. After: 40 − 6 = 34 lived. (b) The after group, 40 patients. (c) The groups were different sizes, so comparing out of 100 (about 46 and 15) puts them on the same scale.
5. Louis Pasteur’s discovery that living microbes in the air cause rotting. Thomas Anderson, a chemistry professor in Glasgow, told Lister about Pasteur’s papers in 1865.
6. Change: what is dabbed on the cut (rubbing alcohol, vinegar, or nothing). Keep the same: kind and size of apple, size of cut, the germ source, bags, temperature and number of days. Measure: the width of the rotten spot in centimeters on the last day. Control: a cut apple with germs and nothing dabbed on it (and it is helpful to keep an untouched apple too).
7. When the skin stays whole, it keeps germs out while the bone heals. In a compound fracture the skin is torn open, so germs from the air, dirt, hands and tools can get into the wound and grow. Infection could spread through the leg and body, so many patients lost the limb or died.
8. Before: 46 × 2 = 92 deaths. With carbolic acid: 15 × 2 = 30 deaths. 92 − 30 = 62 more patients a year would live.

8.4 Washing and First Aid

OBJECTIVES

- Tell how Ignaz Semmelweis discovered that washing hands saved mothers' lives in Vienna in 1847, and read his results on a bar graph.
- Explain how soap and water remove germs, and wash hands correctly for at least 20 seconds at the right times.
- Give simple first aid for a small cut, a minor burn and a nosebleed, and know when to get an adult or call 911.

Warm-up. Rub a little cooking oil on your hands, then sprinkle on a pinch of cinnamon. These specks are your pretend "germs." Rinse with cold water only for 5 seconds and look. Then wash with soap and warm water, scrubbing for 20 seconds. Where did the cinnamon hide longest? Write down the places.

Video. Coming soon. Ignaz Semmelweis and handwashing, how soap removes germs, and basic first aid for children (small cuts, burns, nosebleeds, calling 911); search the American Red Cross, children's hospital education channels, KidsHealth, SciShow Kids, Homeschool Pop and Science Max.

KEY TERMS

hygiene
Habits that keep us clean and healthy, such as washing hands, bathing and keeping food and kitchens clean.

soap
A cleaner made of tiny particles with one end that clings to water and one end that clings to oil and dirt, so it lifts grime and germs off the skin to be rinsed away.

first aid
The first help given to someone who is hurt or suddenly sick, before a doctor or nurse arrives or before they go to get medical care.

direct pressure
Pressing firmly on a bleeding wound with a clean cloth or gauze to help the blood clot and stop the bleeding.

childbed fever
A dangerous infection that some mothers caught soon after giving birth, often carried to them on the unwashed hands of doctors in the 1800s.

CORE IDEAS

The story. In 1847 a young Hungarian doctor named Ignaz Semmelweis worked at the great General Hospital in Vienna, Austria. The hospital had two wards where mothers came to

have their babies. In the First Clinic, run by doctors and medical students, many mothers caught a fever soon after giving birth and died. In the Second Clinic, run by midwives, far fewer died. Mothers knew it, and some begged not to be sent to the First Clinic. Semmelweis was troubled and determined to find out why.

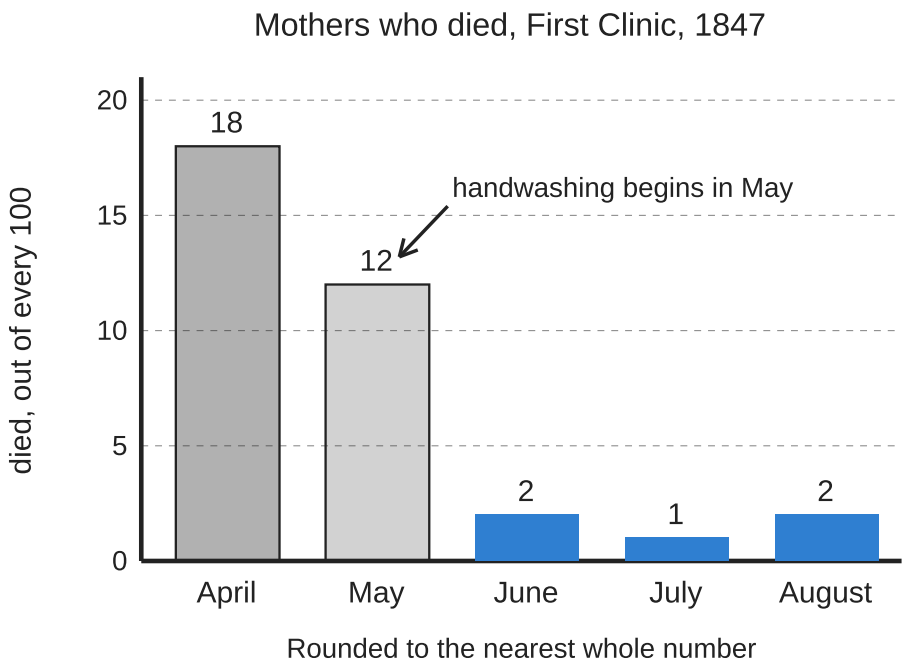
How they figured it out. That spring, a doctor friend of Semmelweis was cut by a student's knife while studying the body of a person who had died. The friend soon fell sick and died of an illness just like the mothers' fever. Semmelweis put the clues together. The doctors and students often came straight from studying bodies to care for the mothers, and the midwives did not. Something invisible must be traveling on the doctors' hands. In May 1847 he ordered everyone to wash their hands in a chlorine solution before touching a mother. In April, about 18 of every 100 mothers in the First Clinic had died. By that summer, it was about 1 or 2 in 100. Sadly, many doctors would not believe him, and his work was not widely accepted until after Pasteur and Lister showed that germs were real.

The big idea. Your hands touch everything, and germs ride along on them to your eyes, nose, mouth and food. Washing with soap and water is one of the best ways to stay well. Soap is made of tiny particles shaped like little tadpoles: one end clings to water and the other clings to oil and dirt. The oily ends grab the grime where germs hide, and the rinse water carries it all down the drain. Wet your hands, lather with soap, scrub the backs, between your fingers and under your nails for at least 20 seconds (about two rounds of "Happy Birthday"), rinse, and dry with a clean towel. Wash before eating or cooking, after using the toilet, after blowing your nose or coughing, after touching animals or trash, and before and after caring for a wound.

Try it and see. In this lesson's project you will touch slices of bread with unwashed hands, rinsed hands and soap-washed hands, seal each in a bag, and watch mold grow over the next one to two weeks. One slice is never touched by hands at all. That slice is your **control**. The mold spots will show you, in a way you cannot forget, what was riding on your hands.

In the world today. When the skin is broken, simple **first aid** keeps germs out and helps the body heal. For a small cut or scrape: wash your own hands, press on it with a clean cloth until the bleeding stops (**direct pressure**), rinse the wound under clean running water, and cover it with a clean bandage. Tell an adult, and watch over the next few days for spreading redness, swelling, warmth or pus, which are signs of infection. For a small burn, hold it under cool running water for at least 10 minutes; never use ice or butter. For a nosebleed, sit up, lean forward and pinch the soft part of the nose for about 10 minutes. For bleeding that will not stop, a bad burn, trouble breathing, or a person who will not wake up, get an adult at once or call 911.

God's handiwork. Long before anyone knew about germs, the law God gave Israel told people to wash their clothes and bathe in running water after touching sickness or the dead. And Jesus told of a Samaritan who stopped on the road, "bound up his wounds," and cared for a hurt stranger. Washing and first aid are small acts, but they are a way of loving our neighbor with our own two hands.



Deaths in Semmelweis's First Clinic in 1847, rounded to the nearest whole number out of every 100 mothers. Handwashing with a chlorine solution began in May.

PICTURE STUDY



The Doctor, Luke Fildes, 1891 · Oil on canvas · Tate Britain, London

Luke Fildes was an English painter. In 1877 his own young son, Philip, became very ill and died at home. Fildes never forgot how the family's doctor cared for the boy through the long hours. Years later, when the businessman Henry Tate asked him to paint a picture for the new national gallery Tate was giving to Britain, Fildes chose this subject: a doctor watching over a sick child in a poor fisherman's cottage through the night.

The painting was shown in London in 1891 and became one of the best-loved pictures in England. Copies hung in doctors' offices for many years as a picture of what a good doctor should be.

Look closely

- Find the doctor's face and hands. What is he doing? Is he busy or is he watching and waiting?
- Find the lamp and the window. Where does each light come from, and what time of day do you think it is?
- Find the mother and father. How do the painter's shadows show how they feel?
- Look at the room. What clues tell you this family is not rich?

Talk about it

1. Fildes did not paint a medicine or a famous discovery. What did he think was most important about a good doctor?
2. The morning light is coming in. What do you hope will happen to the child?
3. Who in your life has cared for you when you were sick or hurt? How could you thank them?

> **Safety first.** Keep each bread bag sealed for the whole experiment. Do not open the bags or sniff the mold, and throw them away still sealed. Anyone with mold allergies or asthma should only look from a distance. Use pretend wounds when practicing first aid. In a real emergency, get an adult right away or call 911.

EXPERIMENT: THE BREAD SLICE HANDWASHING TEST

Semmelweis could not see what was on the doctors' hands, but he could count the results. You will do the same with mold, a microbe that grows big enough to see.

Question: Does the way we wash our hands change how much mold grows on bread we touch? **Prediction:** Rank the slices from most mold to least before you begin.

You will need

- 4 slices of the same bread (homemade or bakery bread molds faster than store bread with preservatives)
- 4 zip-top plastic bags, masking tape, marker
- A clean fork or tongs
- A spray bottle or spoon with a little water
- Soap, a sink and a clean towel
- Lab notebook, pencil and a ruler

Steps

1. Label the bags A (no hands), B (unwashed hands), C (rinsed with water only) and D (washed with soap for 20 seconds).
2. Slice A: use the clean fork or tongs to put it straight into its bag. No hands touch it.
3. Slice B: after a morning of ordinary play, without washing, rub your fingers and palm all over the slice. Put it in bag B.
4. Slice C: rinse your hands in water for 5 seconds with no soap and shake them dry. Rub the slice the same way. Put it in bag C.
5. Slice D: wash your hands with soap for 20 seconds, rinse and dry with a clean towel. Rub the slice the same way. Put it in bag D.
6. Add the same few drops of water to each slice, seal the bags, and keep them side by side in a dark, room-temperature place such as a cupboard.
7. Every two days for up to two weeks, look through the bags (without opening them). Count the mold spots on each slice and record the numbers in a table.
8. When you are finished, make a bar graph of the last day's counts and write a paragraph telling what Semmelweis would say about your results.

Tips

- **What we change:** how the hands were washed. **What we keep the same:** bread, size of slice, how long and how hard you rub, water drops, bags, place and time. **What we measure:** the number of mold spots. **Control:** slice A, touched by no hands.
- Mold may appear as fuzzy green, blue, white or black spots. If the spots join together, estimate how much of the slice is covered instead, such as one quarter or one half.
- Results can surprise you. If slice A molds too, remember that mold spores float in the air. That is why the control matters: it shows how much mold grows from the air alone.

Check your work

- I can explain what I changed, what I kept the same and what I measured.
- I can tell why slice A is the control.
- I can wash my hands the right way for at least 20 seconds and say when to wash.

NATURE NOTEBOOK

1. Trace your hand. Shade the places you think germs hide most (between fingers, under nails, the thumbs, the backs). Label the five steps of handwashing around it.
2. Draw your four bread slices on the last day of the experiment and label the number of mold spots on each.
3. Make a small first-aid card for your family's kitchen: three short steps each for a cut, a burn and a nosebleed, plus your home address for calling 911.

> **From history.** The red cross that marks first-aid kits began with a Swiss businessman, Henry Dunant. In 1859 he came upon the battlefield of Solferino in Italy, where thousands of wounded soldiers lay without care. In the nearby town of Castiglione he helped organize the local women to wash wounds, give water and bandage the hurt, caring for

soldiers from both armies alike. His work led to the founding of the Red Cross in Geneva in 1863. In America, Clara Barton, who had nursed wounded soldiers during the Civil War, founded the American Red Cross in 1881. Its volunteers still teach first aid to families today.

WORKED EXAMPLES

Example 1. Use the Semmelweis bar graph. About 18 of every 100 mothers died in April 1847, before handwashing, and about 1 of every 100 died in July. In a month when 300 mothers came to the First Clinic, about how many would die at the April rate? At the July rate? How many lives would washing save?

(Use the map or drawing "Semmelweis's results, 1847." shown earlier in this lesson.)

1. 300 mothers is 3 groups of 100.
2. April rate: 18 × 3 = 54 mothers would die.
3. July rate: 1 × 3 = 3 mothers would die.
4. Lives saved: 54 − 3 = 51.

Answer: About 54 at the April rate and about 3 at the July rate, so about 51 mothers saved in one month, just by washing hands.

Example 2. Here is sample data from the bread experiment, mold spots counted on day 10.
A (no hands, control): 1.
B (unwashed hands): 15.
C (water only): 9.
D (soap, 20 seconds): 2.
(a) How many more spots did B have than D? (b) Did rinsing with water alone help? How much? (c) Why does slice A have any mold at all?

1. (a) 15 − 2 = 13 more spots on the unwashed-hands slice.
2. (b) Water only: 15 − 9 = 6 fewer spots than unwashed, so it helped some. But soap did better: 9 − 2 = 7 fewer than water only.
3. (c) Mold spores float in the air and were already on the bread. The control shows how much grows without hands, so we compare the others to it. Slice D (2) was almost as clean as the control (1).

Answer: (a) 13 more. (b) Yes, a little: 6 fewer spots than unwashed. Soap and scrubbing removed much more. (c) Spores from the air; the control shows that small starting amount.

PRACTICE

1. EASY Name four times when you should always wash your hands.
2. EASY List the steps of good handwashing in order. How long should you scrub?
3. EASY Your little brother scrapes his knee and it is bleeding a little. Put these first-aid steps in the right order: cover with a clean bandage; rinse under clean running water; wash your own hands; press with a clean cloth until the bleeding stops.
4. MEDIUM Use the Semmelweis bar graph. (a) About how many mothers out of 100 died in May? (b) By how much did the number out of 100 drop from April to June? (c) Why is May's bar between April's and June's?
5. MEDIUM Explain how soap and water get germs off your hands better than water alone.
6. HARD Hannah wants to test whether hand sanitizer works as well as soap and water, using bread slices. Plan her experiment: What will she change? What will she keep the same? What will she measure? What is her control?
7. MEDIUM Your sister touches a hot pan and gets a small red burn on one finger. What should she do? Name two things she should *not* do.
8. CHALLENGE Think like Semmelweis. Why did the Second Clinic, run by midwives, have far fewer deaths than the First Clinic, even before anyone washed with chlorine? What does this comparison show about using two groups in science?

COMMON MISTAKES

- Thinking hands that look clean are clean. Germs are far too small to see, so wash at the right times even if your hands look fine.
- Thinking a quick rinse is enough. Water alone leaves much of the oil and germs behind; it takes soap and at least 20 seconds of scrubbing.
- Thinking ice or butter is good for a burn. Ice can damage the skin and butter holds in heat and germs; cool running water is right.

> **Make it a game · First Aid Freeze.** A parent calls out a pretend emergency: "Scraped knee!", "Burned finger!", "Nosebleed!", "Dirty hands before dinner!" or "Grandpa will not wake up!" Everyone freezes, then the first player to act out the right first steps (pressure and rinse, cool water, lean forward and pinch, wash for 20 seconds, get an adult and call 911) scores a point. A wrong step such as ice on a burn or tipping the head back for a nosebleed loses a point. Play to ten.

> **Scripture.** "And went to him, and bound up his wounds, pouring in oil and wine, and set him on his own beast, and brought him to an inn, and took care of him." (Luke 10:34, KJV)

The Good Samaritan gave first aid to a stranger. He cleaned and bound the man's wounds, carried him to safety and made sure someone would keep caring for him. Learning first aid is a way to be ready to love your neighbor.

Practice answers

1. Any four: before eating, before cooking or handling food, after using the toilet, after blowing your nose, coughing or sneezing, after touching animals, after touching trash, before and after caring for a cut.
2. Wet your hands with clean running water, add soap and lather, scrub all over (backs, between fingers, under nails) for at least 20 seconds, rinse well, and dry with a clean towel or air dry.
3. 1. Wash your own hands. 2. Press with a clean cloth until the bleeding stops. 3. Rinse under clean running water. 4. Cover with a clean bandage. (And tell an adult.)
4. (a) About 12. (b) $18 - 2 = 16$ fewer out of every 100. (c) Handwashing began partway through May, so part of the month was before washing and part after.
5. Germs cling to the oil and dirt on our skin, and water alone does not mix with oil. Soap particles have one end that grabs oil and dirt and another end that clings to water, so scrubbing with soap loosens the grime and germs and the rinse water carries them away.
6. Change: how the hands are cleaned (unwashed, sanitizer, soap and water). Keep the same: kind and size of bread, the way and time each slice is rubbed, water drops, bags, place and number of days. Measure: the number of mold spots (or how much of each slice is covered) on the same day. Control: a slice touched by no hands (put in with clean tongs).
7. Hold the burn under cool running water for at least 10 minutes and tell an adult; cover it loosely with a clean bandage if needed. Do not put ice on it and do not put butter or grease on it (also: do not pop any blister).
8. The midwives did not study the bodies of people who had died, so they did not carry that deadly matter on their hands to the mothers. The doctors and students did. Comparing two groups that were alike except for one thing helped Semmelweis find the cause, just as a control does in an experiment.

Unit 8 review

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

1. (5 pts) What did Edward Jenner do on May 14, 1796? Name the milkmaid and the boy.
2. (5 pts) Explain how a mild case of cowpox could protect a person from smallpox. Use the words *white blood cells* and *memory*.
3. (5 pts) On a 5-by-5 grid model, the middle column of 5 squares is protected and the sickness starts in the middle of the left-hand column. Sickness spreads only up, down, left and right. How many squares get sick? How many unprotected squares stay well?
4. (5 pts) Describe Pasteur’s swan-neck flask experiment. What did it show?
5. (5 pts) Bacteria in warm soup can split in two about every 20 minutes. Starting from one, how many could there be after 1 hour 20 minutes? How does a refrigerator help?
6. (5 pts) Before carbolic acid, 16 of 35 of Lister’s amputation patients died. With carbolic acid, 6 of 40 died. About how many out of every 100 died in each group? What does this show?
7. (5 pts) What is the difference between antiseptic and aseptic surgery? Give one example of each.
8. (5 pts) In April 1847 about 18 of every 100 mothers in the First Clinic died; after handwashing began, about 2 of every 100 died in June. In a month with 200 mothers, about how many lives would handwashing save?
9. (5 pts) In the bread experiment, one slice is put in its bag with clean tongs and is never touched by hands. Why is this slice needed? Name two things that must be kept the same for every slice.
10. (5 pts) Tell the right first aid for (a) a small bleeding cut and (b) a small burn. When should you call 911?

Unit project: my health and medicine discovery museum

Turn a table or a large trifold board into a small museum of the great discoveries in this unit. Make one station each for Jenner, Pasteur, Lister and Semmelweis, with a date, a drawing of the key moment, a one-paragraph story and one bar graph or table of real numbers (Lister’s amputations, Semmelweis’s clinic, or your own experiment results). Add the lab reports from at least two of your experiments (grid model, yeast balloons, apple wounds or bread slices), each naming what you changed, what you kept the same, what you measured and your control.

Finish with a fifth station: a family first-aid kit you assemble in a box (adhesive bandages, gauze, clean cloths, tape, a small bottle of hand soap or sanitizer) with a handmade instruction card for washing hands, cuts, burns and nosebleeds, and your home address for calling 911. Give a tour of your museum to your family.

- **Accuracy**: Names, places, dates and numbers for Jenner, Pasteur, Lister and Semmelweis are correct, and each discovery is explained in the student’s own words.

- **Experiments**: At least two lab reports are complete, with a question, prediction, control, data table or graph, and an honest conclusion.
- **First aid**: The kit is complete and the instruction card gives correct, clear steps for handwashing, cuts, burns, nosebleeds and calling 911.
- **Care and presentation**: Stations are neat, labeled and easy to follow, and the tour is given clearly and with thanks to God for the gifts of health and healing.

Answer key

1. He took matter from the cowpox sores on the hand of the milkmaid Sarah Nelmes and scratched it into the arm of James Phipps, his gardener's eight-year-old son. Later he tested James with smallpox, and James did not catch it.
2. The cowpox germ is very much like the smallpox germ. White blood cells learn to recognize and fight the cowpox germ, and memory cells stay ready afterward. When the smallpox germ comes, the body recognizes it and fights it off quickly before the person gets sick.
3. 10 squares get sick (the two left columns). 10 unprotected squares stay well (the two right columns), because the protected column blocks the spread. Check: 10 + 5 + 10 = 25.
4. Pasteur boiled broth in flasks with long S-shaped necks. Air could get in, but dust and microbes were trapped in the bend, and the broth stayed clear. When the neck was broken off, the broth turned cloudy. It showed that microbes come from other microbes carried on dust in the air, not from the broth itself (it disproved spontaneous generation).
5. 80 minutes ÷ 20 = 4 doublings: 1 → 2 → 4 → 8 → 16. About 16 bacteria. Cold slows the bacteria down so they split much more slowly.
6. Before: about 46 out of 100 (16 ÷ 35 ≈ 0.46). After: 15 out of 100 (6 ÷ 40 = 0.15). Killing germs in and around the wound saved many lives; deaths fell to about one third.
7. Antiseptic surgery kills germs already on the wound, tools and hands, for example Lister's carbolic acid or wiping skin with alcohol. Aseptic surgery keeps germs out from the start, for example sterilizing tools in steam and wearing sterile gloves, gowns and masks.
8. April rate: 18 × 2 = 36 deaths. June rate: 2 × 2 = 4 deaths. 36 − 4 = 32 lives saved.
9. It is the control. It shows how much mold grows from the air alone, so we can tell how much extra mold came from hands. Keep the same (any two): kind and size of bread, how long and how hard each slice is rubbed, water drops, bags, place, and number of days.
10. (a) Wash your hands, press with a clean cloth until the bleeding stops, rinse with clean running water, cover with a clean bandage and tell an adult. (b) Hold under cool running water for at least 10 minutes; no ice or butter. Call 911 (or get an adult at once) for bleeding that will not stop, a bad burn, trouble breathing, or a person who will not wake up.

Bonus: Nature Lab

All year you have studied the body God made: cells, bones, muscles, heart, lungs, stomach, brain and senses. In this bonus unit you take that body outdoors and use it as a scientist's instrument. Your eyes, ears, nose and fingertips gather observations; your step and arm span become rulers; your pulse becomes a measurement of what a walk does to your heart. And you will compare your own body with the bodies of other creatures "after their kind."

You will keep a nature journal the way Anna Botsford Comstock taught, survey one small patch of ground the way Gilbert White studied his village of Selborne, visit a zoo, farm or museum like the one Charles Willson Peale built in Philadelphia, and start a labeled specimen collection like Ole Worm's cabinet in Copenhagen. These lessons are lighter and playful, done mostly outdoors, and they can be scattered through the year whenever the weather is fine.

BEFORE YOU BEGIN

- Can take a pulse at the wrist and multiply a 15-second count by 4
- Can measure in centimeters and meters and read a simple bar graph
- Knows the main bones of the arm and the five senses from earlier units
- Can find an average of three or four numbers

MASTERY CHECKLIST

- I can keep a nature journal page with the date, place, weather, a labeled sketch and observations from my senses.
- I can use quadrats and an average to estimate how many plants live in a yard.
- I can compare an animal's skeleton, teeth, breathing and heart rate with my own.
- I can collect, clean and label specimens safely and lawfully.
- I can name the variable, the control and what I measure in a simple experiment.

OPTIONAL BOOKS AND RESOURCES

- **Smithsonian National Museum of Natural History** (https://naturalhistory.si.edu/): Free. Online exhibits, including the Hall of Bones, are good for comparing skeletons before or after a museum visit (Lesson 9.3).
- **All About Birds, from the Cornell Lab of Ornithology** (https://www.allaboutbirds.org/): Free. Bird identification guides with pictures and recorded songs for naming the birds you see and hear on a nature journal walk (Lesson 9.1).

9.1 Nature Journal Walk

OBJECTIVES

- Keep a nature journal page with the date, place, weather, a labeled sketch and notes from at least three senses.
- Measure my own step length and pulse and use them to record a walk the way a field scientist does.
- Explain how my senses, muscles, heart and lungs work together on a nature walk.

Warm-up. Sit by an open window or on the back step. Close your eyes for 2 minutes and list every sound you hear. Then open your eyes and list five things you see that you never noticed before. Which sense gave you the longer list? Keep both lists for your first journal page.

Video. Coming soon. Nature journaling for kids and how to keep a field notebook (search John Muir Laws nature journal lessons, Cornell Lab of Ornithology, Homeschool Pop (Alternate), SciShow Kids, and quiet nature footage of woods and meadows).

KEY TERMS

nature journal
A notebook where a naturalist records the date, place, weather, sketches and careful notes about living things seen outdoors.

observation
Something you notice with your senses, such as seeing, hearing, smelling or touching, written down exactly as it is.

step length
The distance covered by one ordinary walking step, measured heel to heel. It lets you measure distance with your own body.

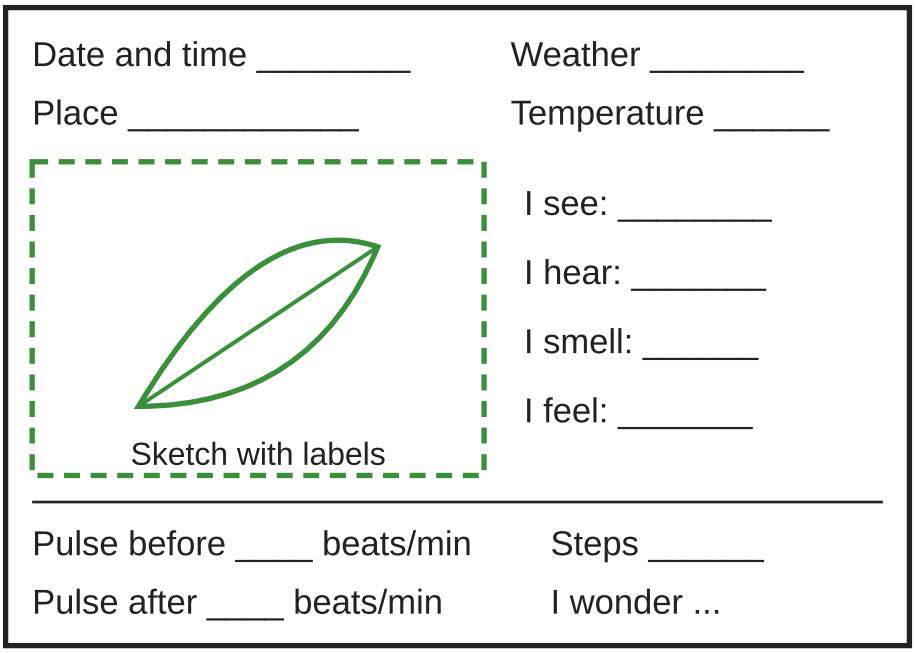
pulse
The beat you feel in an artery each time the heart pumps. Pulse rate is counted in beats per minute.

CORE IDEAS

The story. In 1911 a teacher and artist named Anna Botsford Comstock published a thick book called *Handbook of Nature Study*. She had spent years at Cornell University in Ithaca, New York, making careful wood engravings of insects for her husband’s science books and teaching teachers how to take children outdoors. Her idea was simple: a child does not need a laboratory to begin science. A child needs a notebook, a pencil, a patient eye and a real leaf, bird or beetle to look at. Families and schools used her book for generations, and it is still used by homeschoolers today.

The big idea. A good nature journal page always begins with the facts that let someone check your work later: **date, time, place and weather**. Then come your **observations**, the things you actually noticed with your senses, kept separate from your guesses. This is where everything you learned this year comes outdoors with you. Your eyes focus light on the retina, your ears catch a bird call, your nose and tongue tell you about wet soil and mint, and the touch receptors in your fingertips feel the rough bark. Your leg muscles pull in pairs to carry you, your lungs breathe faster, and your heart pumps harder to bring oxygen to those muscles. You can even use your body as a measuring tool. If you know your **step length**, you can count steps and work out how far you walked, and if you take your **pulse** before and after, you can record what the walk did to your heart.

Try it and see. On your walk, stop at three places and write one thing you see, one you hear and one you smell or feel at each. Draw one living thing large on the page and add labels with lines pointing to the parts. Do not worry about making it beautiful. Comstock taught that the drawing is a way of looking, because you cannot draw a leaf without noticing how its veins branch. **God's handiwork.** The same God who made the hare, the oak and the cricket made the eyes that see them and the mind that wonders about them. Job said, "ask now the beasts, and they shall teach thee." A nature journal is a way of asking.



One way to set up a nature journal page. The facts at the top let anyone check your observations later.

PICTURE STUDY



Young Hare, Albrecht Dürer, 1502 · Watercolor and gouache (opaque watercolor) on paper · Albertina, Vienna, Austria

Albrecht Dürer was a painter and engraver from Nuremberg, Germany. In 1502 he painted this hare with a fine brush, building up the fur hair by hair in many shades of brown, gray and cream. He signed it with his monogram, a large A with a small D inside, and wrote the year below it. More than five hundred years later it is still one of the most famous animal pictures ever made, and it is a lesson for every nature journaler: look long, and draw what is really there.

Look closely

- Find the whiskers and the long ears. How many directions does the fur grow on the hare’s back and sides?
- Look closely at the hare’s eye. Some people see the reflection of a window in it. What does that tell you about where Dürer was working?
- Find Dürer’s monogram and the date 1502 near the bottom of the picture.
- Look at the hare’s back feet and front paws. How is it holding its body?

Talk about it

1. Why do you think Dürer left the background plain instead of painting a field behind the hare?
2. Which would teach you more about a hare: a quick photograph or an hour spent drawing one? Why?
3. What animal near your home would you like to draw this carefully?

> **Safety first.** Walk with an adult and stay on paths. Do not touch or taste unknown plants, berries or mushrooms, and learn to spot poison ivy (“leaves of three, let it be”). Watch from a distance if you see a wild animal. Never look straight at the sun. Stay well back from deep or fast water. Check for ticks when you come home and wash your hands.

EXPERIMENT: MY STEP AND PULSE NATURE WALK

You will turn an ordinary walk into a small experiment. Question: **How much does a brisk walk raise my pulse compared with a slow walk on the same path?** Along the way you will fill a journal page with real observations and use your own step length to find how far you went.

You will need

- Nature journal or sketchbook and a pencil
- Tape measure or meter stick
- Watch, phone timer or clock with a second hand
- Small magnifying glass (optional)
- Colored pencils for later

Steps

1. Find your step length. On a sidewalk, mark a starting line, walk 10 ordinary steps and mark where your front heel lands. Measure the distance and divide by 10. Write it in your journal in centimeters and inches.
2. Write your prediction: “I think a brisk walk will raise my pulse by about ____ beats per minute more than a slow walk.”
3. Sit quietly for 2 minutes. Find the pulse on the thumb side of your wrist with two fingers (not your thumb). Count the beats for 15 seconds and multiply by 4. Record it.
4. Walk a short route slowly for 5 minutes, counting your steps. Stop and take your pulse right away. Record it.
5. Rest until your pulse returns close to your resting number. Then walk the same route briskly for 5 minutes. Take your pulse again and record it.
6. What you changed: walking speed. What you kept the same: the walker, the route, the length of time and the way you counted. What you measured: pulse in beats per minute.
7. On the way back, stop at three places and write one thing you see, hear and smell or feel at each. Sketch one living thing with labels.
8. At home, multiply your step count by your step length to find the distance you walked. Finish your page with one sentence about your pulse results and one “I wonder” question.

Tips

- Count your pulse as soon as you stop, because the heart begins slowing down within a minute.
- If you lose count of steps, count only the left foot and double it.
- Write the facts at the top of the page before you start drawing, so you never forget them.

Check your work

- My page has the date, time, place and weather.
- I recorded my resting pulse and my pulse after a slow walk and a brisk walk.
- I can tell what I changed, what I kept the same and what I measured.
- I found the distance I walked using my step length.

NATURE NOTEBOOK

1. Draw one leaf as large as your page. Label the blade, the stem (petiole) and the veins, and write how it feels to your fingers.
2. Make a “Sense Map” of your walk: a simple map of the route with small symbols for a sound, a smell, something rough and something smooth.
3. Copy this sentence and finish it in your own words: “My heart beat faster on the brisk walk because ...”

> **From history.** Field journals have carried science for centuries. On the Lewis and Clark expedition across the American West (1804–1806), Meriwether Lewis and William Clark filled notebooks with careful descriptions and sketches of plants and animals that were new to them. In April 1805 they even shipped a live prairie dog and several magpies from their winter camp at Fort Mandan back east to President Thomas Jefferson. The prairie dog and one magpie arrived alive.

WORKED EXAMPLES

Example 1. Before a walk, Lydia counts 18 pulse beats in 15 seconds. After a brisk 5-minute walk she counts 29 beats in 15 seconds. What were her pulse rates in beats per minute, and how much did her pulse go up?

1. There are four 15-second periods in 1 minute, so multiply each count by 4.
2. Resting: $18 \times 4 = 72$ beats per minute.
3. After the brisk walk: $29 \times 4 = 116$ beats per minute.
4. Increase: $116 - 72 = 44$ beats per minute.

Answer: Resting 72 beats per minute; after the walk 116 beats per minute; her pulse rose by 44 beats per minute.

PRACTICE

1. EASY Name four facts that belong at the top of every nature journal page.
2. MEDIUM Caleb walks 10 steps and measures 5.5 meters. What is his step length? On his nature walk he takes 200 steps. About how far did he walk?
3. MEDIUM Read this table from one student's journal. Pulse at rest: 76 beats per minute. After a slow walk: 92. After a brisk walk: 120. After resting 5 minutes: 84. (a) When was the pulse highest? (b) How much higher was it than at rest? (c) What happened after resting, and why?
4. HARD Design an experiment to test this question: "Does walking up a hill raise my pulse more than walking on flat ground?" Name the variable you change, the things you keep the same, what you measure and your control.
5. CHALLENGE In two or three sentences, explain why your heart beats faster and you breathe harder on a brisk walk.

COMMON MISTAKES

- Writing guesses as if they were observations. "The bird was angry" is a guess; "the bird chirped loudly and flew at the cat" is an observation.
- Taking a pulse with the thumb. The thumb has its own pulse, so use your first two fingers.
- Thinking a nature journal must have beautiful art. A rough, labeled sketch with the date and place is real science; a pretty picture with no facts is not.

> **Make it a game · Sense Detective.** On your walk, a parent calls out a sense: see, hear, smell or touch. You have 30 seconds to find something new for that sense and describe it in one exact sentence, with a number or a color if you can ("three white petals," not "a pretty flower"). An exact observation scores 2 points; a vague one scores 1. First to 15 points chooses the snack.

> **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)

Creation is a book that teaches anyone who will look carefully. A nature journal is how a young scientist "asks" the beasts and the earth and writes down what they teach.

Practice answers

1. The date, the time, the place and the weather (a temperature is a good extra).
2. Step length = 5.5 m ÷ 10 = 0.55 m (55 cm, about 22 inches). Distance = 200 × 0.55 m = 110 m (about 360 feet).
3. (a) After the brisk walk. (b) 120 − 76 = 44 beats per minute higher. (c) It dropped to 84, back toward the resting rate, because the muscles needed less oxygen once they stopped working hard, so the heart slowed down.

4. Change: the ground (uphill or flat). Keep the same: the same walker, the same walking time (for example 3 minutes), the same speed as nearly as possible, resting first both times and the same way of counting the pulse (15 seconds × 4). Measure: pulse in beats per minute right after each walk. Control: the walk on flat ground, which is the comparison for the hill walk. Repeating each walk two or three times makes the result more trustworthy.
5. Working leg muscles need more oxygen and food to release energy. The lungs breathe faster and deeper to take in more oxygen, and the heart beats faster to pump oxygen-rich blood to the muscles more quickly and carry away carbon dioxide.

9.2 Backyard Survey

OBJECTIVES

- Mark out a 1-meter quadrat and count the plants and small animals living inside it.
- Use the average of several quadrats to estimate how many of one kind of plant live in a whole yard.
- Use my own body (hand span, step and arm span) as a measuring tool and compare a sunny and a shady habitat.

Warm-up. Stretch your arms straight out to the sides and have someone measure from fingertip to fingertip. Then measure your height. Are the two numbers close? Write both down. You have just found a built-in ruler you will carry into the backyard.

Video. Coming soon. Quadrat sampling and backyard wildlife surveys for kids (search Cornell Lab of Ornithology, Smithsonian, National Wildlife Federation, SciShow Kids, Homeschool Pop (Alternate), and close-up nature footage of soil animals, ants and earthworms).

KEY TERMS

survey
A careful count of the living things in a place, done the same way each time so the results can be compared.

quadrat
A square frame or string square, often 1 meter on each side, used to count living things in a small sample of ground.

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

estimate
A careful, reasoned guess about a large number, made from a smaller sample that was actually counted.

average
The total of several counts divided by the number of counts. It gives one fair number for a typical sample.

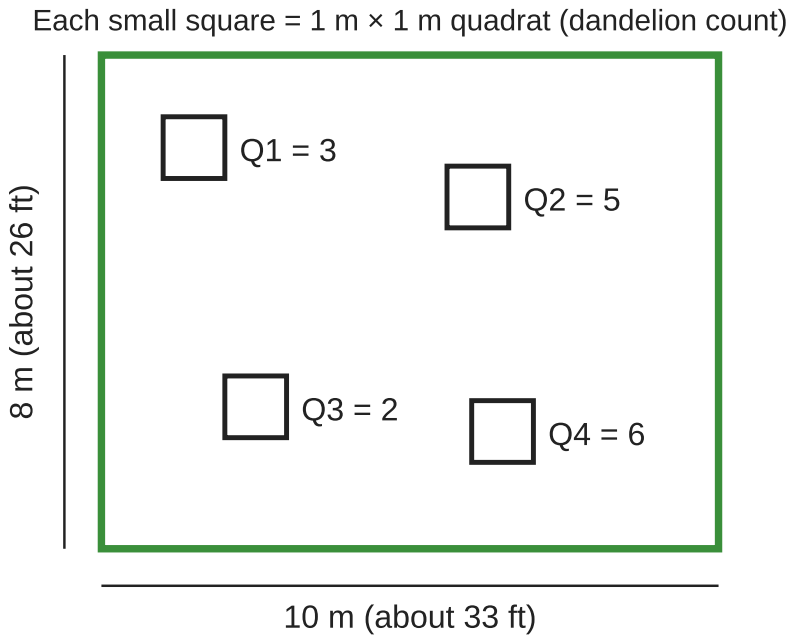
CORE IDEAS

The story. Gilbert White was a country minister in the village of Selborne in Hampshire, England. For most of his life he watched the same lanes, fields, hedges and garden, writing down when the swallows arrived each spring, where the crickets lived and how the earthworms loosened the soil. He even kept notes on his old tortoise, Timothy, recording

when it dug in for the winter and woke in the spring. In 1789 his letters were published as *The Natural History of Selborne*, and it became one of the most loved nature books in the English language. White proved that you do not have to travel far to discover something. A naturalist who looks carefully at one small place, again and again, can learn more than a traveler who glances at a hundred.

The big idea. A yard is far too big to count every blade of grass, so scientists use a **survey** with **quadrats**. You mark a square 1 meter (about 3 feet 3 inches) on each side, count what lives inside it, and then do the same in several other squares. The **average** of your squares lets you **estimate** the whole yard: multiply the average count per square meter by the number of square meters in the yard. Your own body helps here. For most people the arm span from fingertip to fingertip is close to their height, a child's hand span is often 15 to 18 centimeters (6 to 7 inches), and you already know your step length from Lesson 9.1. Measure your own once, and you can lay out a quadrat or pace off a lawn without a tape measure.

Try it and see. Compare two **habitats** in the same yard, such as a sunny lawn and a shady spot under a tree or bush. Count the plants, the ants, the beetles and, if your parent lets you lift a stone or dig one trowel of soil, the earthworms. Earthworms breathe through their moist skin, so you may find more of them where the soil stays damp and cool. Put every stone back the way you found it and every creature back where it lives. Solomon told the lazy man, "Go to the ant ... consider her ways, and be wise." A survey is a way of considering.



Four 1-meter quadrats spread across a 10 m by 8 m lawn. Spreading them out gives a fairer sample than putting them all in one corner.

PICTURE STUDY



The Large Piece of Turf, Albrecht Dürer, 1503 · Watercolor and gouache on paper · Albertina, Vienna, Austria

A year after he painted his hare, Albrecht Dürer knelt down and painted a single clump of weeds as if it were a portrait of a king. Botanists who have studied the picture can name many of the plants, including meadow grasses, dandelions and the broad leaves of plantain. Dürer painted them at the height a rabbit or a beetle would see them, from very low down. It is, in a way, the first great quadrat survey in art.

Look closely

- Find the dandelions. Can you find one in flower and one that is only leaves?
- Look at the bottom of the picture. What do you see at the roots of the plants?
- Count how many different kinds of leaves you can find. Look at their shapes: long and thin, broad and flat, or toothed.
- Where is the eye of the viewer? Are you looking down on the plants or across at them?

Talk about it

1. Why might Dürer have chosen such an ordinary clump of plants to paint so carefully?
2. If you painted one square of your own yard this closely, what plants do you think you would find?

> **Safety first.** Wear garden gloves when you dig or lift stones, and lift a stone toward you so anything under it moves away from you. Watch for bees, wasps, fire ants and spiders, and do not handle snakes. Learn to recognize poison ivy and stay away from it. Do not put soil or plants in your mouth. Put every stone and creature back where you found it, and wash your hands with soap afterward.

EXPERIMENT: SUN AND SHADE: A FOUR-SQUARE BACKYARD SURVEY

Question: **Do more small animals live in a shady patch of the yard than in a sunny patch?** You will survey two quadrats in the sun and two in the shade and compare your counts like a real field biologist.

You will need

- About 5 meters (16 feet) of string and 4 sticks or tent pegs for each quadrat
- Meter stick or tape measure (or your own hand span and arm span)
- Magnifying glass
- Garden gloves and a small trowel
- Nature journal, pencil and a tally chart
- Thermometer (optional)

Steps

1. Write your prediction: “I think the shady quadrats will have more / fewer / the same number of animals because …”
2. Choose two spots in full sun and two in shade. Push in four sticks to make a square 1 meter on each side and run the string around them.
3. Make a tally chart with rows for grass, other plants (such as clover or dandelion), ants, beetles, spiders, earthworms and other creatures.
4. Kneel and search each quadrat for exactly 5 minutes. Count and tally what you find. If allowed, dig one trowel of soil in the center and count the earthworms, then put the soil back.
5. If you have a thermometer, lay it on the ground in each quadrat for 2 minutes and record the temperature.
6. What you changed: sun or shade. What you kept the same: the size of the quadrat, the search time, the time of day and the person counting. What you measured: the number of each kind of living thing.
7. Add up the sunny counts and the shady counts. Draw a bar graph comparing them.
8. Write two sentences: Was your prediction right? What about the habitat might explain the difference?

Tips

- Survey both habitats on the same day at about the same time, or the weather may change your results.
- Ants are easy to count twice. Count the ones crossing one string side in a minute, or just record “many” if there is a nest.
- Spiders have eight legs and two body parts; insects have six legs and three body parts. Count them in separate rows.

Check your work

- I made at least four 1-meter quadrats, two in sun and two in shade.
- I counted each quadrat for the same length of time.
- I made a bar graph and wrote whether my prediction was right.
- I put the habitat back the way I found it.

NATURE NOTEBOOK

1. Draw a top-view map of your yard. Mark sun, shade, trees, paths and the places where you put your quadrats.
2. Draw the most interesting creature you found as large as your hand, with labels for legs, body parts and antennae. Write whether it is an insect, a spider or something else.
3. Trace your hand with fingers spread. Measure and label your hand span in centimeters and inches. Write two things in the yard you measured with it.

> **From history.** Ordinary families still help scientists with backyard surveys. In 1900 the ornithologist Frank Chapman of the American Museum of Natural History suggested that instead of a Christmas hunting contest, people should go out on Christmas Day and count birds. A small group of volunteers took part that first year. The Christmas Bird Count has been held every winter since, and its long record of counts helps scientists see which birds are becoming more common or less common.

WORKED EXAMPLES

Example 1. Noah surveys a lawn that is 10 meters long and 8 meters wide. In four 1-meter quadrats he counts 3, 5, 2 and 6 dandelions. Estimate the number of dandelions in the whole lawn.

(Use the map or drawing “Noah’s four quadrats and their dandelion counts.” shown earlier in this lesson.)

1. Add the counts: 3 + 5 + 2 + 6 = 16 dandelions.
2. Find the average per quadrat: 16 ÷ 4 = 4 dandelions per square meter.
3. Find the area of the lawn: 10 m × 8 m = 80 square meters.
4. Estimate: 4 dandelions per square meter × 80 square meters = 320 dandelions.

Answer: About 320 dandelions. It is an estimate, not an exact count, because only 4 of the 80 square meters were counted.

PRACTICE

1. EASY What is a quadrat, and why do scientists use one instead of counting every plant in a field?
2. MEDIUM Grace is 142 cm tall. About how long is her arm span? Give your answer in centimeters and inches.

3. MEDIUM Read the table. Sunny quadrats: ants 14, earthworms 1, beetles 2. Shady quadrats: ants 6, earthworms 5, beetles 3. (a) Which animal was more common in the sun? (b) Which animal showed the biggest difference in favor of the shade? (c) Give one reason earthworms might prefer the shade.
4. HARD Design an experiment to answer: “Do more earthworms live under a layer of fallen leaves than under bare soil?” Name the variable you change, two things you keep the same, what you measure and the control.
5. CHALLENGE Three quadrats in a meadow hold 6, 9 and 6 clover plants. The meadow is 50 square meters. Estimate the clover plants in the meadow, and explain why the real number might be different.

COMMON MISTAKES

- Thinking one quadrat tells about the whole yard. Living things are patchy, so you need several quadrats spread out and an average.
- Calling every small crawling creature a bug or an insect. Insects have six legs and three body parts; spiders have eight legs and two body parts; earthworms and snails are not insects at all.
- Thinking an estimate is just a wild guess. A good estimate comes from real counts and simple math, and it can be checked.

Make it a game · Quadrat Bingo. Before the survey, each player draws a 3 by 3 bingo card with things that might be in a quadrat: ant, clover, beetle, earthworm, spider, dandelion, moss, a seed, a feather. Search your quadrat. Mark a square only when you can show it to the other player and name it correctly (spider or insect?). Three in a row wins. Bonus point for anything nobody put on a card.

Scripture. “Go to the ant, thou sluggard; consider her ways, and be wise:” (Proverbs 6:6, KJV)

Solomon sends the lazy man to a backyard survey. Watching ants carry food and build their nest teaches diligence, and careful watching is the beginning of wisdom.

Practice answers

1. A quadrat is a square, often 1 meter on each side, marked on the ground for counting living things. Scientists use it because a whole field has too many plants to count; counting a few sample squares lets them estimate the total.
2. For most people arm span is close to height, so about 142 cm (about 56 inches).
3. (a) Ants (14 in sun, 6 in shade). (b) Earthworms (5 in shade, 1 in sun, a difference of 4). (c) Shady soil stays cooler and damper, and earthworms breathe through moist skin, so they dry out in hot, sunny soil.
4. Change: leaf-covered ground or bare ground. Keep the same: the size of the patch (for example, one trowel of soil 15 cm deep), the same yard and the same day and time, the same weather and the same person counting. Measure: the number of earthworms in each sample.

Control: the bare soil, which is compared with the leaf-covered soil. Taking several samples of each makes the result more reliable.

5. Average = (6 + 9 + 6) ÷ 3 = 21 ÷ 3 = 7 per square meter. Estimate = 7 × 50 = 350 clover plants. The real number may differ because only 3 of 50 square meters were counted, and clover may grow thickly in some places and hardly at all in others. More quadrats spread across the meadow would make a better estimate.

9.3 Zoo, Farm or Museum Visit

OBJECTIVES

- Compare the bodies of other animals with my own body: skeleton, teeth, breathing, heart rate and body covering.
- Read a bar graph of animal heart rates and describe the pattern between body size and heart rate.
- Read a museum sign carefully, separating what I can see from how the sign explains it.

Warm-up. Lay your arm on the table. Feel the one long bone between your shoulder and elbow and the two bones between your elbow and wrist (twist your hand and feel one bone roll over the other). Now look at a picture of a bat, a horse or a whale. Where do you think the same three bones are hiding?

Video. Coming soon. Comparing animal skeletons and animal heart rates for kids (search Smithsonian National Museum of Natural History, zoo keeper talks from accredited zoos, farm animal care videos from state agricultural extension services, SciShow Kids, and Homeschool Pop (Alternate)).

KEY TERMS

vertebrate
An animal with a backbone, such as a fish, frog, snake, bird or mammal. People are vertebrates too.

comparative anatomy
The study of how the bodies of different animals are alike and different, part by part.

herbivore
An animal that eats plants. Herbivores usually have broad, flat teeth for grinding.

carnivore
An animal that eats meat. Carnivores usually have sharp, pointed teeth for tearing.

heart rate
The number of times the heart beats in one minute.

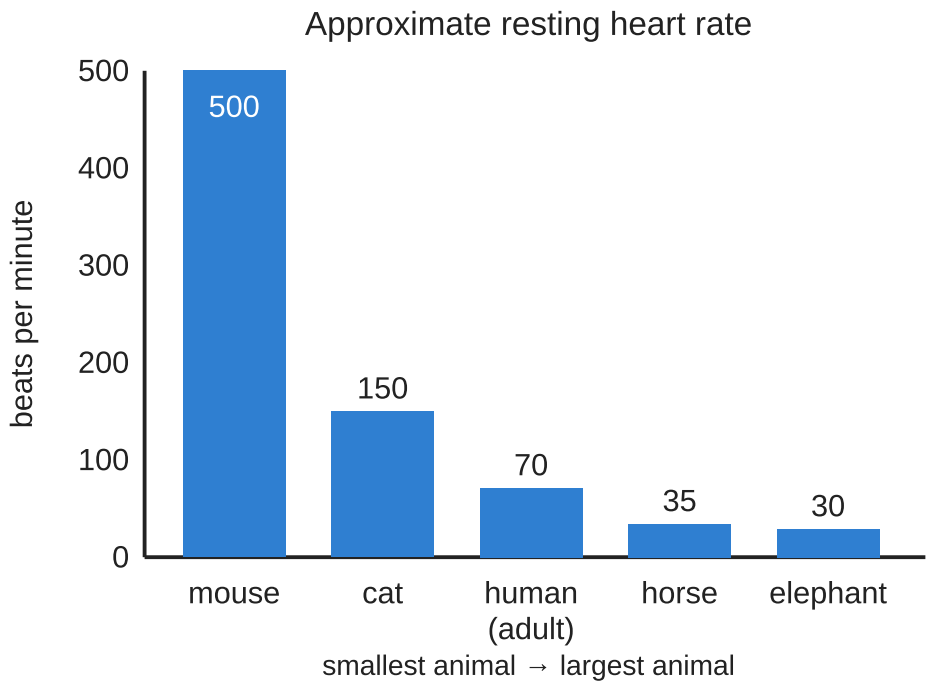
CORE IDEAS

The story. Charles Willson Peale was a painter in Philadelphia who loved natural history as much as art. In 1786 he opened a museum in his own house, filled with stuffed birds, minerals, insects and portraits, and he arranged the animals in order by the naming system of the Swedish naturalist Linnaeus so visitors could learn as they walked. In 1801 he heard that huge bones had been found on a farm near Newburgh, New York. Peale went there, had a giant wheel built that men walked inside to pump water out of the pit, and dug up the bones of a mastodon, a great elephant-like animal. By Christmas Eve of that same year he

had put the skeleton together and opened it to visitors in Philadelphia, and crowds came to stand beneath it. When he was 81 he painted himself lifting a curtain to invite you in.

The big idea. A zoo, farm or museum is a room full of bodies to compare with your own, which is called **comparative anatomy**. Look at skeletons and you will see the same pattern again and again: one upper arm bone (the humerus), two forearm bones (the radius and ulna), then wrist and finger bones, whether in your arm, a bat's wing, a whale's flipper or a horse's front leg. Look at teeth: a cow or horse (a **herbivore**) has broad, flat grinding teeth, while a lion or wolf (a **carnivore**) has long, pointed ones. A cow has one stomach with four compartments that let it chew its cud and digest grass. Watch an animal's side rise and fall to count its breaths. You will also find a pattern in **heart rate**: small animals have fast hearts and big animals have slow ones. A resting mouse's heart beats about 500 times a minute, while an elephant's beats only about 30.

Try it and see. At a museum you will read signs. Copy one sign word for word. Underline what you can see for yourself (the bones, their size, the teeth) and circle what the sign says those things mean. Signs beside a mastodon or mammoth often use the museum word "Ice Age." Learn to read such words accurately, and keep your own observations clear. **God's handiwork.** When God brought the animals to Adam "to see what he would call them," He invited man to study and name His creatures. The shared plan of bones, hearts and lungs across so many kinds shows one wise Designer at work.



Approximate resting heart rates. Small animals have fast hearts; large animals have slow ones.

⏳ Thinking About Time

What the sign says. Signs near a mastodon or mammoth skeleton often say these animals lived during the "Ice Age," many thousands of years ago, and signs near dinosaur

skeletons say those creatures lived millions of years ago.

What we observe. What we can actually see is the bones themselves: their size, shape and teeth, and records of where they were dug up, such as in bogs and soft layers of mud and gravel. No date is written on a bone; the ages on the sign come from dating methods, such as measuring radioactive carbon, that rest on assumptions about the past.

How Christians read it. Many Christians read the Ice Age as a real time of great cold that came after the Flood of Noah's day, when the warm oceans and changed weather of a world recovering from the Flood brought heavy snows. In this reading, mastodons and mammoths were among the animal kinds that spread over the earth after the Flood, not very many thousands of years ago.

Try it. Copy one museum sign and split it into two columns: "What I can see" and "What the sign says it means."

Job 38:29

PICTURE STUDY



The Artist in His Museum, Charles Willson Peale, 1822 · Oil on canvas · Pennsylvania Academy of the Fine Arts, Philadelphia

Peale painted this life-size self-portrait at the age of 81. He holds back a heavy curtain to show the long room of his museum, with rows of glass cases full of birds and, above them, portraits of famous Americans. In the back a few visitors walk and look. In the front corner lie some of the mastodon bones he dug up in 1801, and beside him is a turkey waiting to be prepared for display, with the tools of a taxidermist. Peale wanted his museum to be a school for everyone, and this painting is his invitation.

Look closely

- Find the mastodon bones in the front of the picture. Which bones can you recognize?
- Look at the cases along the wall. How are the birds arranged?
- Find the visitors in the gallery. One is reacting to something she sees. What might it be?
- Find the turkey and the tools near Peale. What job is he in the middle of?

Talk about it

1. Why do you think Peale chose to show himself lifting a curtain?
2. How is Peale's museum like a museum you have visited, and how is it different?
3. If you could add one specimen to Peale's museum, what would it be and where would you put it?

> **Safety first.** At a farm or petting zoo, follow every rule the keepers give. Never stand directly behind a horse, cow or goat, keep fingers out of fences and cages, and feed animals only food the farm allows, on a flat open hand. Do not eat or drink near animal pens. Wash your hands with soap and running water right after touching animals or their fences, because animals can carry germs such as *E. coli* and *Salmonella* even when they look healthy. At a museum, touch only what a sign or guide says you may.

EXPERIMENT: MY BODY COMPARISON FIELD SHEET

Question: **How do the bodies of three animals compare with my own?** You will fill in a comparison chart on your visit and do one small measurement: counting an animal's breathing rate and comparing it with yours.

You will need

- Nature journal and pencil on a clipboard
- Watch or timer with seconds
- A comparison chart you make before the trip (see step 1)
- Camera (optional, and only where photographs are allowed)

Steps

1. Before the trip, rule a chart with four columns: Me, Animal 1, Animal 2, Animal 3. Make rows for: backbone (yes or no), number of legs, body covering (skin, hair, fur, feathers, scales), kind of teeth or beak, what it eats, how it breathes, and breaths per minute.
2. Fill in the Me column at home. Sit still for a minute, then count your breaths for 30 seconds and multiply by 2.
3. Write a prediction: "I think a bigger animal will breathe faster / slower than I do."
4. At the zoo, farm or museum, choose three animals (a skeleton counts). Fill in as many rows as you can by careful looking, and by reading signs or asking a keeper.

5. For one living animal that is resting, watch its side or chest rise and fall. Count breaths for 30 seconds and multiply by 2. Try to count two different animals of different sizes.
6. What you changed: the kind and size of animal. What you kept the same: the animal resting, the 30-second count and the way of counting. What you measured: breaths per minute.
7. Sketch one skeleton or animal and label the humerus, the radius and ulna (or the leg bones), and the teeth.
8. At home, write three sentences: one way each animal is like you, one way each is different and whether your prediction about breathing rate was right.

Tips

- A sleeping or lying-down animal is easiest to count. Animals that are running or eating will not give a resting rate.
- Keepers and farmers love good questions. Ask, “What does this animal eat?” or “How do you check that it is healthy?”
- If you visit a museum, look for a hall of skeletons and compare front legs side by side.

Check your work

- My chart compares me with three animals in at least five rows.
- I counted the breathing rate of at least one resting animal and wrote it in breaths per minute.
- I labeled the bones or teeth on one sketch.
- I washed my hands after touching any animal.

NATURE NOTEBOOK

1. Draw your own arm bones, a bird’s wing bones and a horse’s front leg bones side by side. Color the humerus the same color in all three, and the radius and ulna another color.
2. Sketch the teeth of one herbivore and one carnivore (from a skull, a model or a living animal) and label which is which.
3. Copy one museum sign. Underline what you can see and circle what the sign says it means.

> **From history.** The largest museum family in America began with a man who never saw the country. James Smithson, an English chemist who died in 1829, left his fortune to the United States to found an institution in Washington for the increase and spread of knowledge. Congress founded the Smithsonian Institution in 1846. Today its National Museum of Natural History holds millions of specimens of animals, plants, rocks and fossils, and its halls of skeletons are a wonderful place to practice comparative anatomy.

WORKED EXAMPLES

Example 1. Use the bar graph of resting heart rates (mouse about 500, cat about 150, human adult about 70, horse about 35, elephant about 30 beats per minute). (a) About how many times faster does a mouse's heart beat than an elephant's? (b) In one minute, how many more beats does a cat's heart make than a human adult's? (c) What pattern do you see?

(Use the map or drawing "Approximate resting heart rates of five mammals." shown earlier in this lesson.)

1. (a) Divide: 500 ÷ 30 ≈ 16.7, so about 17 times faster.
2. (b) Subtract: 150 − 70 = 80 more beats in one minute.
3. (c) List the animals from smallest to largest: mouse, cat, human, horse, elephant. Their heart rates go 500, 150, 70, 35, 30, getting smaller as the animal gets bigger.

Answer: (a) About 17 times faster. (b) 80 more beats. (c) The larger the animal, the slower its resting heart rate.

PRACTICE

1. EASY Name the three long bones found in the human arm that are also found in a bat's wing and a whale's flipper.
2. MEDIUM At a museum you see two skulls. Skull A has long, pointed teeth at the front and sharp, blade-like teeth at the side. Skull B has broad, flat, ridged teeth at the back. Which skull belonged to a herbivore and which to a carnivore? How do you know?
3. MEDIUM Use the heart-rate graph. (a) List the five animals from fastest heart to slowest. (b) How many beats does an elephant's heart make in 10 minutes at rest? (c) A rabbit is bigger than a mouse but smaller than a cat. Predict whether its heart rate is above or below 150.
4. HARD Design an experiment to answer: "Does my dog breathe faster after playing than when resting?" Name the variable you change, two things you keep the same, what you measure and the control.
5. CHALLENGE A child pets a healthy-looking goat at a farm and then wants to eat a sandwich. In two or three sentences, explain what the child should do first and why, using what you learned about germs in Unit 8.

COMMON MISTAKES

- Thinking whales are fish. Whales are mammals: they breathe air with lungs, are warm-blooded and feed their young with milk.
- Thinking bigger animals have faster hearts. It is the other way around: small animals like mice have very fast heart rates and large animals like elephants have slow ones.
- Saying a cow has four stomachs. A cow has one stomach divided into four compartments, which let it digest tough grass.

Make it a game · Same Bones Challenge. At a skeleton display or with pictures, one player points to a bone in an animal skeleton. The other player must point to the matching bone in his or her own body and name it (humerus, radius, ulna, skull, rib, backbone, thighbone or femur). Correct match and name: 2 points. Correct match only: 1 point. Take turns until each player has scored 10.

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)

Adam’s first work was to look closely at the animals and give them names, the first comparative anatomy. A zoo, farm or museum visit lets us do the same work.

Practice answers

1. The humerus (upper arm) and the radius and ulna (forearm).
2. Skull A is a carnivore: pointed and blade-like teeth grab and tear meat. Skull B is a herbivore: broad, flat, ridged teeth grind plants.
3. (a) Mouse, cat, human adult, horse, elephant. (b) 30 × 10 = 300 beats. (c) Because it is smaller than a cat, the pattern predicts a heart rate above 150 beats per minute (and below a mouse’s 500).
4. Change: resting or right after 5 minutes of play. Keep the same: the same dog, the same 30-second count multiplied by 2, the same place and the same person counting. Measure: breaths per minute (watch the chest or side rise). Control: the resting count, which the after-play count is compared with. Repeating on two or three days makes the result more reliable.
5. The child should wash both hands with soap and running water before eating. Animals can carry germs such as *E. coli* and *Salmonella* on their fur and in their pens even when they look healthy, and Pasteur showed that germs too small to see can cause sickness. Washing removes the germs so they are not swallowed with the food.

9.4 Specimen Collection

OBJECTIVES

- Collect, clean, label and display specimens legally and safely, with a complete label for each one.
- Compare the bones of a chicken wing with the bones of my own arm and name the humerus, radius and ulna.
- Plan and carry out a fair test showing what makes bones hard, naming the variable, the control and what I measure.

Warm-up. Empty a pocket, a junk drawer or a nature box onto the table. Sort the things into groups any way you like. Now pick one object and write four facts about it: what it is, where it came from, when you got it and who found it. Could a stranger understand your object from those four facts alone?

Video. Coming soon. How to start a nature specimen collection and the chicken bone in vinegar experiment for kids (search Smithsonian National Museum of Natural History behind-the-scenes collections, Science Max, SciShow Kids, Homeschool Pop (Alternate), and Moody Science classics).

KEY TERMS

specimen
A real natural object, such as a leaf, shell, rock, feather or bone, kept and studied as an example of its kind.

specimen label
A small card kept with a specimen that tells what it is, where and when it was found, and who collected it.

humerus
The single long bone of the upper arm, from the shoulder to the elbow. Birds have one in each wing.

radius and ulna
The two bones of the forearm, between the elbow and the wrist. The same pair is found in a bird’s wing.

collagen
A tough, bendable protein in bone. Hard minerals containing calcium are packed around it.

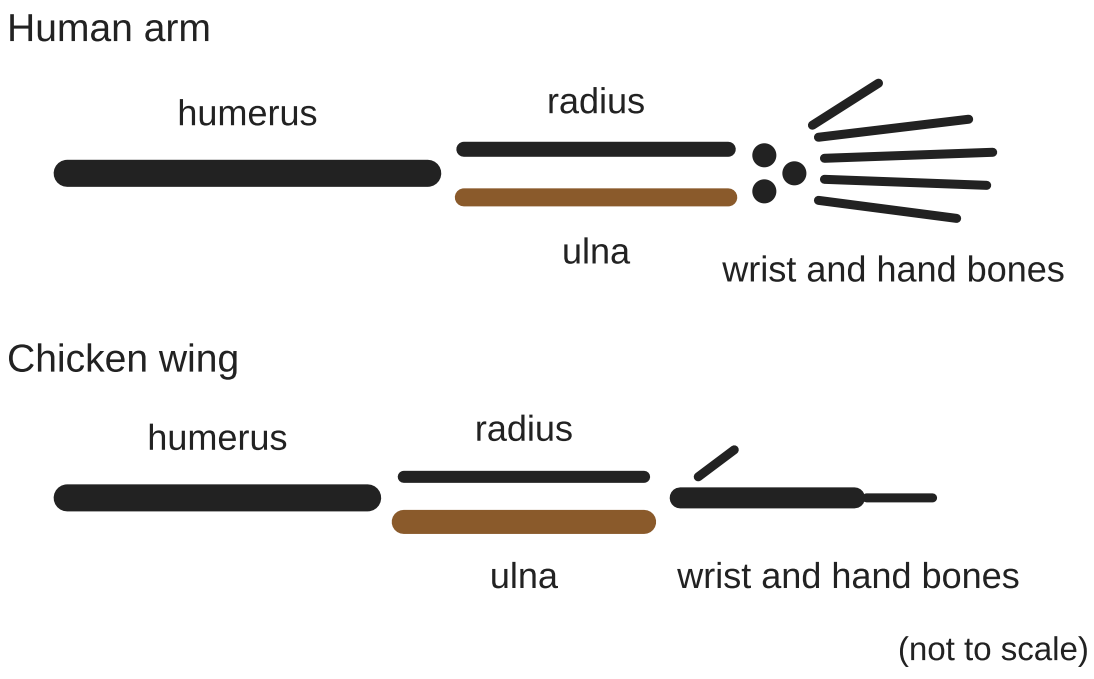
CORE IDEAS

The story. Ole Worm was a Danish doctor and professor in Copenhagen who filled his house with a famous collection: shells, rocks, fossils, stuffed animals, plants, horns and tools from

faraway lands. People in his day paid great sums for “unicorn horns,” long twisted ivory spikes that were thought to cure poison. In 1638 Worm showed his students that these horns were really the tusks of the **narwhal**, a small whale of the Arctic seas. A careful collector with real specimens in hand had corrected a story that many learned men believed. After his death a catalog of his museum was printed in 1655, with a picture of the room. Worm also studied the human skull, and the tiny extra bones sometimes found in the seams between skull bones are still called Wormian bones after him.

The big idea. A specimen without a label is only a souvenir. Every real **specimen** needs a **specimen label** with four facts: **what** it is, **where** it was found, **when** (the date) and **who** collected it. Collect lightly and lawfully: take common things such as fallen leaves, seeds, pine cones, empty shells, rocks and bones saved from the kitchen; never take more than a few, never collect in a park or preserve without permission, and leave nests, eggs and wild bird feathers alone, since it is against United States law to keep the feathers, nests or eggs of most wild birds. The best specimens for this course are in your kitchen. A chicken wing has the same plan as your arm: one **humerus**, then the **radius and ulna**, then wrist and hand bones. Living bone is hard because minerals containing calcium are packed around a bendable protein called **collagen**; the minerals make it stiff and the collagen keeps it from snapping like chalk.

Try it and see. Clean the bones from a cooked chicken wing and lay them out beside a drawing of your own arm. Then test what makes bone hard: soak one bone in vinegar and a matching bone in water for several days. Vinegar is a weak acid that slowly dissolves the calcium minerals, and the bone left behind becomes rubbery. **God’s handiwork.** Job said that God had “fenced me with bones and sinews.” The same wise plan of bone that lets a chicken flap and a child throw a ball is a fence made of living stone and rope together.



A human arm and a chicken wing share the same plan of bones (not to scale).

PICTURE STUDY



The Museum of Ole Worm (frontispiece of Museum Wormianum), G. Wingendorp (engraver), 1655 · Engraving (print from a copper plate) · Printed in the book *Museum Wormianum* (Leiden, 1655); copies are kept in many libraries

This engraving was printed at the front of the catalog of Ole Worm's museum, published in 1655, the year after he died. It shows the room where he kept his collection, packed from floor to ceiling. Rooms like this were called cabinets of curiosities, and they were the beginning of the natural history museums we visit today. Notice how much is sorted and labeled: Worm wanted every object to be found again and studied.

Look closely

- Find the rows of small boxes on the shelves. Can you see writing on them? Why would a collector label each box?
- Look up at the ceiling. What kinds of animals are hanging there?
- Find the horns and antlers on the walls. Can you spot anything that looks like a long, twisted tusk?
- Find something that is not from nature, such as a tool or a weapon. Why might it belong in this room?

Talk about it

1. How is Worm's room like a modern museum, and how is it different?
2. If you made a cabinet of curiosities on one shelf at home, what would you put in it, and how would you sort it?

> **Safety first.** Raw chicken can carry *Salmonella*, so let an adult cook the wings, and wash your hands with soap after handling raw or cooked chicken. An adult should handle

> boiling water and any knife. Do not drink the vinegar or the soaking water, and throw the soaked bones away when the test is over. Never pick up dead animals or bones you find outdoors with bare hands; wear gloves or leave them alone. Do not collect wild bird feathers, nests or eggs, and do not collect in parks or preserves without permission.

EXPERIMENT: CHICKEN WING BONES AND THE BENDY BONE TEST

You will make a labeled bone specimen card comparing a chicken wing with your own arm, and then run a fair test. Question: **What happens to a bone when the minerals are taken out of it?**

You will need

- 2 or 3 cooked chicken wings (whole wings with all three parts work best)
- Old toothbrush, dish soap, paper towels
- White vinegar and plain water
- 2 matching clean glass jars with lids, and masking tape for labels
- Ruler marked in centimeters and inches
- Stiff card or cardboard, white glue and small index cards for labels

Steps

1. After a meal, ask an adult to simmer the leftover wing pieces in water for a few minutes so the meat comes away easily. Let them cool.
2. Wearing gloves or washing your hands afterward, pull off the meat and scrub the bones clean with soap, water and a toothbrush. Dry them on paper towels for a day.
3. Lay out one wing’s bones in order. Find the humerus (in the drumette), the radius and ulna (in the flat middle part; the ulna is the thicker one) and the wrist and hand bones (in the tip).
4. Measure the humerus and ulna in centimeters. Then measure your own upper arm (shoulder bump to elbow) and forearm (elbow to wrist). Record all four numbers.
5. Glue one set of bones to a card in order, label each bone, and add a specimen label: what, where, when, who.
6. For the test, choose two matching bones (for example, two humerus bones). Write a prediction: “I think the bone in vinegar will …”
7. Put one bone in a jar of vinegar and the other in a jar of water. Label the jars. What you change: the liquid. What you keep the same: the kind and size of bone, the amount of liquid, the jars, the place and the number of days. The bone in water is your control.
8. Each day for 3 to 5 days, take each bone out with gloves or tongs, try gently to bend it, and record: hard, a little bendy or very bendy. Pour in fresh vinegar after 2 days. At the end, write what happened and why.

Tips

- Small bubbles on the bone in vinegar are a sign that the acid is reacting with the minerals.

- Thin bones change faster than thick ones, so the radius may turn bendy before the humerus.
- Write the start date on the jars so you can count the days accurately.

Check your work

- My bone card shows the humerus, radius, ulna and hand bones in order, each labeled.
- My specimen label has what, where, when and who.
- I can name the variable I changed, the control and what I measured in the bendy bone test.
- I can explain why the vinegar bone became rubbery.

NATURE NOTEBOOK

1. Draw your own arm and the chicken wing side by side at the same size on the page. Color the humerus, the radius and the ulna the same colors in both.
2. Design a specimen label for your collection with blank lines for what, where, when and who. Make six copies and fill them in for six things you collect this month.
3. Draw the vinegar bone and the water bone on the last day of your test, and write one sentence telling what the difference shows about what bones are made of.

> **From history.** One collector’s cabinet became one of the world’s great museums. Sir Hans Sloane, a London physician, gathered more than 71,000 objects over his lifetime, including plants, animals, shells, books and coins. When he died in 1753, his will offered the collection to the nation, and Parliament bought it to found the British Museum, which opened to the public in 1759. Many of his natural history specimens are now kept in London’s Natural History Museum.

WORKED EXAMPLES

Example 1. Esther measures her own arm and a chicken wing. Her upper arm (humerus) is 26 cm long and her forearm (ulna) is 22 cm. The chicken's humerus is 6.5 cm and its ulna is 5.5 cm. (a) How many times longer is Esther's humerus than the chicken's? (b) How many times longer is her ulna? (c) In both, which bone is longer, the humerus or the ulna?

(Use the map or drawing "The same plan of bones in an arm and a wing (not to scale)." shown earlier in this lesson.)

1. (a) Divide: 26 ÷ 6.5 = 4. Esther's humerus is 4 times as long.
2. (b) Divide: 22 ÷ 5.5 = 4. Her ulna is also 4 times as long.
3. (c) Compare: Esther 26 cm is more than 22 cm; chicken 6.5 cm is more than 5.5 cm. In both, the humerus is longer.

Answer: (a) 4 times. (b) 4 times. (c) In both arm and wing, the humerus is longer than the ulna. The wing is like a small version of the same plan.

PRACTICE

1. EASY What four facts belong on every specimen label?
2. MEDIUM What did Ole Worm show about the "unicorn horns" sold in his day, and how did a real specimen help him?
3. MEDIUM Three students measured chicken humerus bones: 6.2 cm, 6.6 cm and 6.4 cm. What is the average length? Give it in centimeters and about how many inches (1 inch = 2.54 cm).
4. HARD In the bendy bone test, one bone goes in vinegar and one in water. (a) What is the variable you change? (b) Which bone is the control, and why is it needed? (c) Name two things you must keep the same. (d) What do you measure?
5. CHALLENGE In two or three sentences, explain why the bone in vinegar became rubbery and what this shows about living bones.

COMMON MISTAKES

- Thinking bones are dead, dry sticks inside us. Living bones have blood vessels and cells; they grow, store calcium and repair themselves when broken.
- Thinking more specimens are always better. A few well-labeled specimens are worth more than a box of unlabeled ones, and over-collecting harms the places we study.
- Thinking any feather on the ground is fine to keep. In the United States, it is against the law to keep the feathers, nests or eggs of most wild birds; feathers from farm birds like chickens are fine.

Make it a game · Mystery Specimen Bag. A parent puts one specimen from your collection into a cloth bag without letting you see it. Reach in and describe it using only

touch: size, shape, texture, weight, hard or soft. After three clues, guess what it is and say one fact from its label. A correct guess with a label fact scores 2 points. Then switch roles. Play until every specimen has been in the bag.

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

Job describes the body as God’s careful building work: a frame of bones, tied by sinews, covered with flesh and skin. Every bone in your specimen collection is a small piece of that wise design.

Practice answers

1. What it is, where it was found, when it was found (the date) and who collected it.
2. He showed in 1638 that they were really the tusks of the narwhal, a small Arctic whale. By comparing the “horns” with real narwhal specimens instead of trusting old stories, he could show that each one was really a whale’s long tooth.
3. Total = 6.2 + 6.6 + 6.4 = 19.2 cm. Average = 19.2 ÷ 3 = 6.4 cm, which is about 2.5 inches (6.4 ÷ 2.54 ≈ 2.52).
4. (a) The liquid: vinegar or water. (b) The bone in water is the control; it shows that simply soaking a bone does not make it rubbery, so any change in the vinegar bone must come from the vinegar. (c) Any two of: the same kind and size of bone, the same amount of liquid, the same kind of jar, the same place and temperature, the same number of days. (d) How bendable each bone is each day.
5. Vinegar is a weak acid that dissolves the hard minerals containing calcium, leaving mostly the bendable protein collagen behind, so the bone becomes rubbery. This shows that bone is made of two materials working together: minerals make it hard and stiff, and collagen keeps it from being brittle and snapping.

Unit 9 review

This is a short review of the Nature Lab. Answer each question. Show your work for calculations and use complete sentences for explanations. The review is worth 50 points.

1. (8 pts) List four facts that belong at the top of a nature journal page. Then tell which of these is an observation and which is a guess: (a) “The robin pulled a worm out of the wet grass.” (b) “The robin was happy.”
2. (8 pts) Before a walk, Ben counts 19 pulse beats in 15 seconds. After a brisk walk he counts 30 beats in 15 seconds. Find both rates in beats per minute and the increase. Why did his pulse go up?
3. (10 pts) Four 1-meter quadrats on a lawn hold 4, 7, 3 and 6 clover plants. The lawn is 12 meters by 5 meters. (a) Find the average per quadrat. (b) Estimate the clover plants in the whole lawn. (c) Why is it better to use four quadrats than one?
4. (8 pts) Name the three long bones that your arm shares with a bat’s wing and a horse’s front leg. Then describe the pattern between body size and resting heart rate, using a mouse and an elephant as examples.
5. (8 pts) What four facts belong on a specimen label? Name one thing you should never collect, and why.
6. (8 pts) In the bendy bone test, one chicken bone soaks in vinegar and a matching bone soaks in water for 5 days. Name the variable you change, the control and what you measure, and explain why the vinegar bone becomes rubbery.

Unit project: my nature lab field book

Gather the work of this unit into one field book or folder: at least three dated nature journal pages (one with your step and pulse walk), your sun-and-shade quadrat survey with its tally chart and bar graph, your body comparison sheet from a zoo, farm or museum visit, and your labeled chicken wing bone card with the results of the bendy bone test. Add a cover with your name and the dates of the unit, a table of contents and a closing page that answers: “What did I learn about my own body by studying the creatures around me?”

- **Records**: Every page and specimen has the date, place and collector; observations are written separately from guesses.
- **Measurements**: Pulse rates, step length, quadrat averages, estimates and bone lengths are measured carefully, in metric with U.S. customary where useful, and calculated correctly.
- **Experiments**: Each small experiment names the question, prediction, variable, control, what was kept the same and what was measured, with an honest conclusion.
- **Care**: Sketches are labeled, pages are neat and organized, and the collection was gathered safely and lawfully.

Answer key

1. Date, time, place and weather. (a) is an observation, because it describes what was actually seen. (b) is a guess, because we cannot see a bird’s feelings.
2. Resting: 19 × 4 = 76 beats per minute. After: 30 × 4 = 120 beats per minute. Increase: 120 − 76 = 44 beats per minute. His working leg muscles needed more oxygen, so his heart pumped faster to carry more oxygen-rich blood to them.
3. (a) (4 + 7 + 3 + 6) ÷ 4 = 20 ÷ 4 = 5 per square meter. (b) Area = 12 × 5 = 60 square meters; 5 × 60 = 300 clover plants. (c) Plants grow in patches, so one square might be unusually thick or thin; several squares spread out give a fairer average.
4. The humerus, radius and ulna. Smaller animals have faster resting heart rates and larger animals have slower ones: a mouse’s heart beats about 500 times a minute, while an elephant’s beats about 30.
5. What it is, where it was found, when it was found and who collected it. Any one of: wild bird feathers, nests or eggs (against U.S. law for most wild birds); anything from a park or preserve without permission; dead animals or outdoor bones with bare hands (germs); rare plants or animals.
6. Variable: the liquid (vinegar or water). Control: the bone in water. Measure: how bendable each bone is. The vinegar, a weak acid, dissolves the hard minerals containing calcium, leaving mostly the bendable protein collagen, so the bone becomes rubbery.